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BUILDING NUCLEAR INFRASTRUCTURE

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ABSTRACT

Historically countries started their nuclear power program by first building a Research Reactor (RR) and the related infrastructure. The focus of the national strategy was on developing indigenous human resources (HR) and when possible national nuclear industry, starting at the very beginning of the RR Project.
The method followed by the Argentine Company INVAP reinforces this approach with “on-the-job-training” of customer’s personnel during the whole RR project. This ensures at the completion of the project, that the customer will have its own skilled HRs for the operation, maintenance and upgrade of its reactor in a long-term strategy, even when the organization had no nuclear experience before the project started. When required, INVAP has the capability to start training at the nuclear theoretical level, later bridging the gap between learning and practical experience. These resulting HRs would have developed at the end of the RR Project, the capacity and competence necessary for the successful planning, bidding, awarding, and construction initiation of a nuclear power plant. Another important point to remark upon is that the customer´s nuclear organization and its regulator will have acquired experience in dealing/working together in a real nuclear project.

INVAP is also one of the main stakeholders of the University RA-6 Reactor (designed and built by INVAP). The RA-6 Reactor is an excellent example of a well-utilized RR for training, education, research, and industrial development.

“On-the-job-training” experience of INVAP in the RRs built in Peru (RP-10), Argentina (RA-6 and RA-8), Algeria (NUR), Egypt (ETRR-2), and Australia (OPAL), is outlined in this paper. INVAP participation as a stakeholder at the University RA-6 Reactor is also described.

Introduction

INVAP is a company dedicated to the design and construction of complex technological systems, developing advanced technologies in different fields of industry, science and applied research, creating "high value added technological packages”.
INVAP’s main activities are focused in the Nuclear, Aerospace and Defense Areas, as well as Industrial and Medical Systems.

Since its beginnings in 1976, INVAP has grown from a small office to a surface area of over 10,000 square meters of laboratories, workshops and office space. INVAP´s heaquarters are located in San Carlos de Bariloche, Patagonia, in the foothills of the Andes, about 1700 km southwest of Buenos Aires.

INVAP staff comprises more than 1000 people. This includes a body of highly skilled professionals, specialized in the handling of complex systems; an advanced Quality Management System; innovative technical and administrative projects, control systems and a quarter of a century of experience in the management of innovation.

Mostly due to INVAP, which has made an important and successful effort in the aperture of new markets, Argentina is now known worldwide as a reliable supplier of nuclear facilities, as well as of cobalt therapy and industrial automation equipment.

INVAP is the only company in South America that has worked with NASA (the US National Aeronautics and Space Administration) in complete space projects. In this field, the company has shown its proficiency as a constructor of satellites, payloads and ground stations.

INVAP has been involved in nuclear development for over 30 years. In that time its teams have worked on more than 15 nuclear reactors and related facilities across the world.

“On-the-job-project” approach

The customer training method followed by INVAP is based on the approach: *“on-the-job-training” of customer’s personnel during the whole nuclear project.*

Customer’s trainees are considered “INVAP employees” with the same responsibilities as those of its own staff. Trainees work in different areas, and at different stages, of the whole nuclear project under close supervision of INVAP staff.
“On-the-job-training” ensures that at the completion of the project, the customer will have its own skilled human resources, for the operation, maintenance and upgrade, of its Nuclear Facility (e.g. Research Reactor) in a long-term strategy, even when the organization had no nuclear experience before the project started.

From the very beginning of the project, the customer sends its personnel to INVAP to be trained in the different required level of competences:

1. “nuclear”: professionals to receive formal education in nuclear subjects (e.g. neutron calculation, thermal-hydraulic, radiation protection, shielding, etc.);
2. “nuclearized”: professionals to receive formal education and training in a relevant (non-nuclear) area (e.g. mechanical, electrical, civil engineering,

systems) which are needed to acquire knowledge of the nuclear environment in which they have to apply their competencies; and
3. "nuclear-awareness": personnel requiring some nuclear knowledge to work in the nuclear facility (e.g. electricians, mechanics, and other crafts and support personnel).

Theoretical Courses

INVAP starts training at the nuclear theory level, to later bridge the gap between learning and practical experience. Hands-on training in a real environment since it is considered that classroom study is not enough.

The theoretical subjects are such as:

- Introduction to Nuclear Reactor Physics
- Reactor fuels
- Fundamentals of Thermal-hydraulics
- Radiation Protection
- Nuclear and Conventional instrumentation
- Reactor Control and Monitoring Systems
- Reactor Protection Systems
- Radiation Monitoring Systems
- Nuclear Reactors
- Basic Safety and Security Concepts

The Nuclear Project as a "training school"

For INVAP each Nuclear Project is a learning school by itself.

- The "on-the-job-training" approach implies the involvement of the future operation staff of the facility from the very beginning of the basic design. Followed by:
    - Detailed engineering,
    - Construction,
    - Operation & Maintenance.
- The operation staff actively participates in the safety approach of the nuclear facility, its PSAR, and other licensing required documents. Since is the operator, not the supplier, is the party responsible of the licensing, his involvement assures a smooth licensing process.
- When required, INVAP could also train and advice the customer's Regulator experts. For a Nuclear Project to be successful it is always necessary to have a well-qualified Regulatory counterpart.

Traditional Training

When required, INVAP could also offer "traditional training" (undergraduate and graduate) in:

- Nuclear Engineering (undergraduate)
- Master in Nuclear Engineering
- PhD in Nuclear Engineering

To this purpose INVAP works hand in hand with the "Instituto Balseiro"* (a worldwide recognized nuclear educational institution).

*National University of Cuyo
Argentina Atomic Energy Commission

INVAP could also offer “traditional training” in:

- Materials Science (undergraduate and graduate)
- Radioisotopes Production
- Nuclear Medicine
- Radiotherapy
- Radioprotection
- Radiochemistry

To this effect INVAP works together with:
Instituto Sabato*, and
Instituto Beninson*

*National University of San Martin
Argentina Atomic Energy Commission

Other National Nuclear Organizations

Technological oriented companies should work together with R&D institutions and Academia to enhance education and skills of its staff.
This also creates opportunities for more effective use of the available research facilities.
INVAP works in close relationship with:

- Argentina’s National Atomic Energy Commission
- Educational Institutions (e.g. Instituto Balseiro - IB)
- Argentina’s National Regulator Authority (ARN)

National Local Industry

From the very start of a Nuclear Project, the project itself should be used to:

- develop as much as possible local customer’s infrastructure in supporting the construction, regulatory approval, operation and maintenance of the nuclear facility (and eventual decommissioning).
- improve the degree of national participation (*technology transfer)*.
- design the nuclear facility for developing/using local technology industry/services (best method to transfer know-how to the local industry).

Operators Training Program

INVAP applies the following training program:

1. Personnel selection in the Customer’s country
2. First training stage (in Argentina)
    1. Academic training
    2. Practical training in nuclear installations
    3. “On-the-job-training” → active participation in the facility design and/or components manufacturing
    4. Operators’s licensing granted by Argentina Regulatory Body (e.g. Research Reactor)
3. Second training stage (host country)
    1. On the job training during:
        1. Erection
        2. Commissioning
        3. Facility start-up
    2. Gradual transfer of full responsibility

Training tool: RA-6 Research Reactor (Argentina)

INVAP has access to the training of its trainees, to the RA-6 Research Reactor

(which was designed and built by INVAP for the Argentina Atomic Energy Commission, CNEA).
The RA-6 Research Reactor is the training tool of Instituto Balseiro for its Nuclear Engineering Career. It is also utilized by Professionals of CNEA in R&D.
Thus, the RA-6 is utilized by university (IB), governmental (CNEA) and company (INVAP) all which allows to state that it is a well utilized nuclear facility.

Its main characteristics are:

- ✓ Power: 1 MW_{th}
- ✓ In operation since 1982
- ✓ Open pool type
- ✓ Fuel: MTR U_3Si_2 20% enriched*
- ✓ Moderator and coolant: H_2O
- ✓ Reflector: Graphite/H_2O
- ✓ Thermal flux (max): $1x10^{14}$ n/(cm^2sec)

*Converted from HEU in 2009

Conclusions

- ➢ INVAP approach: “on-the-job-training”
- ➢ For INVAP the whole Nuclear Project is a learning school
- ➢ INVAP ensures that the customer will have its own HRs for the operation, maintenance, and upgrade of its nuclear facility in a long-term strategy
- ➢ Under INVAP ’s training approach the HRs developed will have the capacity and competence for successfully planning, bidding, awarding the construction of new nuclear facilities e.g. a nuclear power plant.
- ➢ INVAP is an important stakeholder at:
    - ➢ Bariloche Research and Training Reactor (RA-6), and
    - ➢ Instituto Balseiro (Nuclear Engineering Career)

EHRO-N AND THE HUMAN RESOURCES OF THE NUCLEAR ENERGY SECTOR. ANALYSIS OF DEMAND AND SUPPLY IN EUROPE

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ABSTRACT

In 2010, the European Human Resources Observatory for the Nuclear energy sector (EHRO-N) analysed the demand and supply of human resources (HR) in the European nuclear field in the short, medium and long term. Before this analysis, no comprehensive picture on the demand/supply of nuclear HR was available for the whole EU-27. The availability of national data varies, indeed, from country to country. For instance, France, UK and, more recently, Finland have monitored their national demand and supply of the nuclear workforce through comprehensive national surveys. However, national data and reports on nuclear HR are missing for most EU's Member States (MSs). The same reports produced by international organizations, such as IAEA and OECD/NEA, do not always provide complete data.

The paper summarizes the result of the EHRO-N analysis. The focus is on the match (and mismatch) between the demand and supply of highly skilled workforce in the nuclear field (or "nuclear experts") at present and in the future. Data was collected by EHRO-N through an EU-wide survey. The process of data collection and analysis also benefited from the co-operation with relevant actors of the European nuclear energy sector. Such cooperation took place through the EHRO-N's Senior Advisory Group (SAG), which brings together the representatives of research organisations, industry, international organisations, etc. involved in nuclear energy across Europe. Finally, the paper puts the demand/supply of nuclear experts in the EU-27 into a broader perspective by highlighting the major lessons learnt and possible future areas of intervention.

1. Introduction

In the EU27, the total workforce employed in the nuclear sector is approximately 500,000 people. According to the competences needed for the operation of a nuclear power plant (NPP), the nuclear workforce can be divided into three categories:

- nuclear experts;
- nuclearized staff;
- nuclear-aware staff.

Nuclear experts are employees who possess a specialized formal education in nuclear subjects (nuclear engineering, radiochemistry, radiation protection, etc.). Nuclearized staff is employees who have a formal education and training in a technical area outside the nuclear domain (e.g. mechanical, electrical and civil engineering); these employees receive additional training on the nuclear aspects on which they work. Nuclear-aware staff consists of employees who are requested to possess a certain degree of nuclear awareness to be able to work (e.g. electricians, mechanics, and other crafts and support personnel). The focus of this paper is on nuclear experts only.

In the last 15 years, the OECD (2000; 2004) has reported about the need to enhance the presence of nuclear experts in Europe. The warning about the lack of nuclear experts drew the attention of the Council of the EU in 2008. In the same year, the European Nuclear Energy Forum (ENEF) welcomed a new initiative at the EU level under the name of European Human Resource Observatory for the Nuclear energy sector, or EHRO-N. The introduction of EHRO-N was prompted by the perceived need for a central information source for the nuclear energy sector in the EU. The EHRO-N initiative aims at monitoring and analyzing the current and future demand and supply of nuclear experts in the EU-27. A first report on the demand and supply of nuclear experts was issued in May 2012. It constitutes the basis of this paper.

The analysis was led by the following research: 'Is the supply of nuclear experts in the EU27 sufficient to cover the demand of the nuclear energy sector?'. Nuclear experts were defined as the working positions filled by nuclear engineers, nuclear physicists and nuclear chemists who have a nuclear higher education background (i.e. Bachelor, Master or PhD), or by that staff who has a non-nuclear technical higher education background (i.e. Bachelor, Master or PhD) with relevant competences/skills in the nuclear field (acquired, for instance, through in-house or other training).

2. Methodology and limitations

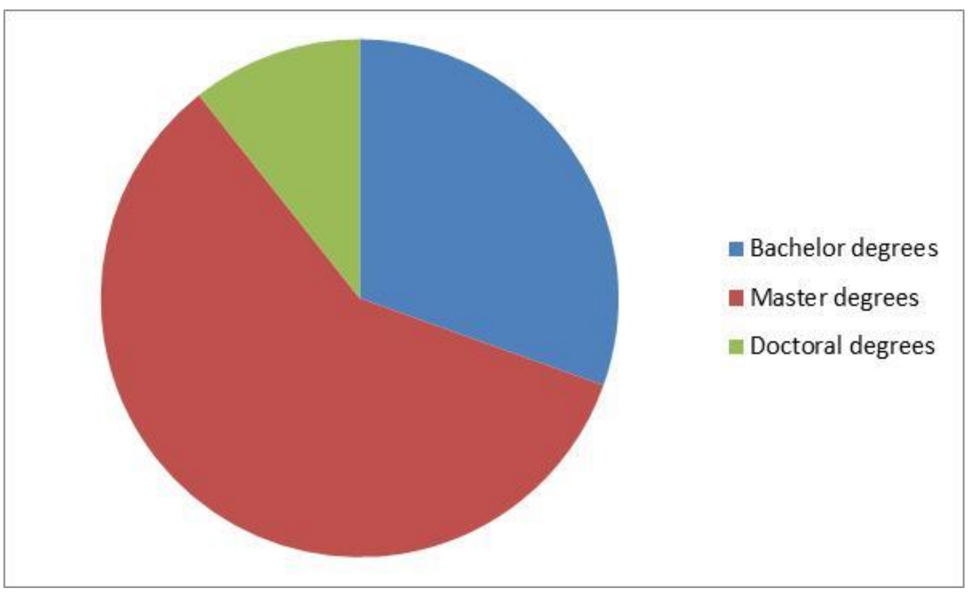
Data were collected though two surveys conducted in 2010-11. The first survey targeted higher education institutions in the EU27 which provide degrees in the nuclear domain (e.g., nuclear engineering, nuclear physics and nuclear chemistry). The list of questions asked during this survey is reported in Annex 1. The second survey targeted the nuclear industry and national authorities; the questionnaire is reported in Annex 2. Survey data were checked against other sources. Data about the supply of nuclear experts were checked against the information available from the institutions involved in nuclear education and training, and organizations and platforms such as the European Nuclear Education Network (ENEN), the Sustainable Nuclear Energy Technology Platform (SNE-TP), and the European Nuclear Society (ENS). Data on the demand of nuclear experts were checked through the EHRO-N's advisory group which includes representatives from the European nuclear industry (utilities, vendors, suppliers, consultancies, etc.) and national authorities (e.g., regulatory authorities, technical safety organizations and agencies for radioactive waste management). For the purpose of adequate triangulation, primary data were complemented by document analysis based on relevant reports issued by international organizations, such as OECD (e.g., OECD 2000; 2004; 2012) and IAEA (IAEA 2010). Some national reports on the human resources employed and needed in the nuclear sector were also consulted (e.g., for France, UK and Finland).

The survey faced several limitations, which we list here. First, although the survey aimed at constituting a census, we acknowledge that it is very likely that not all nuclear industrial organizations and education institutions have been reached by the survey. Second, the concept of 'nuclear experts' has no commonly acknowledged definition; however the use was clearly explained during data collection to the organizations contacted. Third, some organizations were not willing to disclose internal information.

3. Analysis of the results

Somewhat less than 190 higher education institutions were contacted for the supply side. The response rate was above 90%. Data showed that approximately 1800 students from the nuclear domain completed a full course of study at bachelor, master and doctoral level in 2009 (figure 1). Around 2800 students started their studies in the nuclear domain during the academic year 2009/2010.

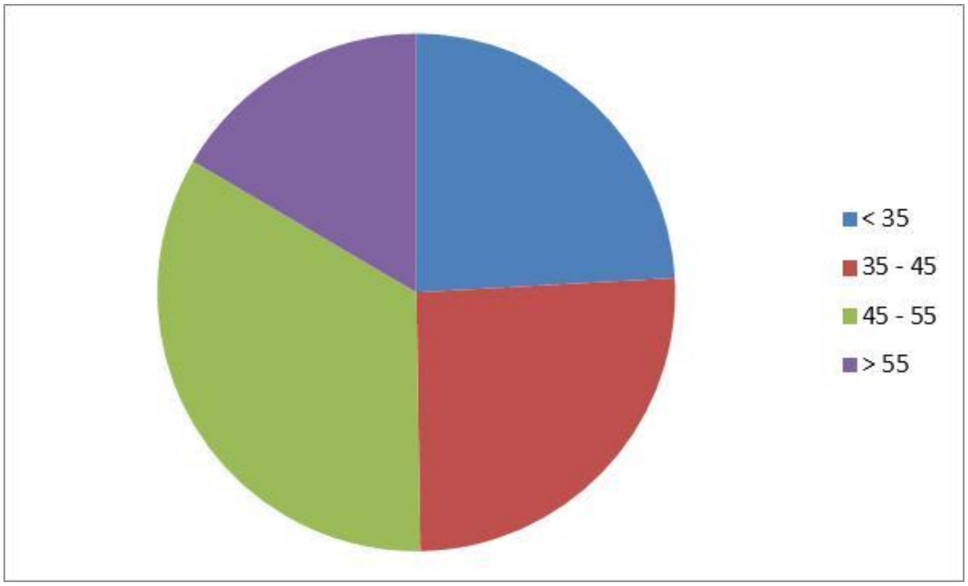
Figure 1: Degrees awarded in the nuclear domain (2009)



Source: EHRO-N (2012)

For the demand side, 358 nuclear organizations were contacted. The response rate was 67.6 per cent. The 242 organizations that responded to the questionnaire employed about 63 thousand nuclear experts in 2010. Exactly one third of the total number of these nuclear employees fell in the age group between 45 and 55 years old. The number of the nuclear experts younger than 45 years was almost equal the number of nuclear experts older than 45 years (figure 2). The important data is that sum of nuclear experts expected to be demanded by all respondents by 2020 was more than 30 thousand.

Figure 2: Nuclear experts per age group (2010)

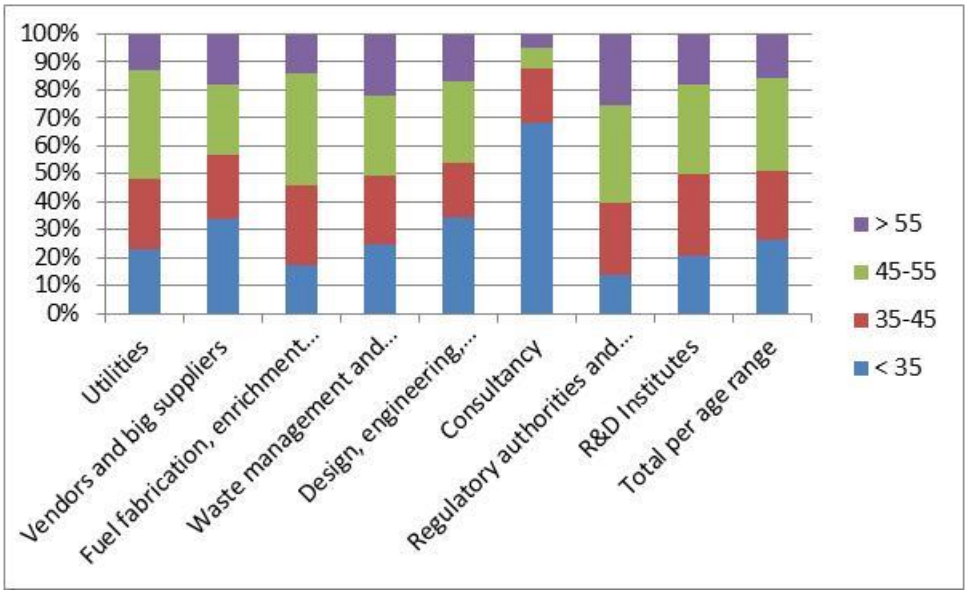


Source: EHRO-N (2012)

In 2010, the number of nuclear experts older than 55 were approximately the 16.6% of the total workforce. It follows that, by 2020, the nuclear sector will lose more than 10,000 nuclear experts. Since the survey was conducted before the Fukushima accident, most organizations were confident that they would need to recruit about 30,000 nuclear experts by 2020 in order to replace the retired ones and start new projects. Less than 2000 students were awarded a nuclear degree in 2009, which leads us to assume that in the following 10 years less than 20,000 new nuclear experts will be available in the EU. The comparison between these numbers easily suggests a significant gap between the demand of nuclear experts (about 30,000) and their supply (less than 20,000). The gap increases if a portion of the new nuclear experts leaving higher education enters a technical sector of employment outside the nuclear domain.

In conclusion, the EU seems to face an alarming problem in its nuclear energy sector. The retirement rate of the nuclear experts of the first generation is not compensated by the amount of students finishing nuclear studies and willing to start their professional career in the nuclear sector. Competition from other technical fields risks to take many talents away from the no-longer fashionable nuclear option. In particularly, in the same area of energy production, renewable energies seem to be more appealing to the younger generation. In addition, the renewable energy sector is believed to be one of the growing labour market, with the creation of a large amount of new jobs per year. On the other hand, the nuclear industry has developed mechanisms of in-house training, in order to nuclearize non-nuclear engineers according to their needs, but there are no numbers available.

Figure 3: Age distribution of nuclear experts per type of organization (2010)



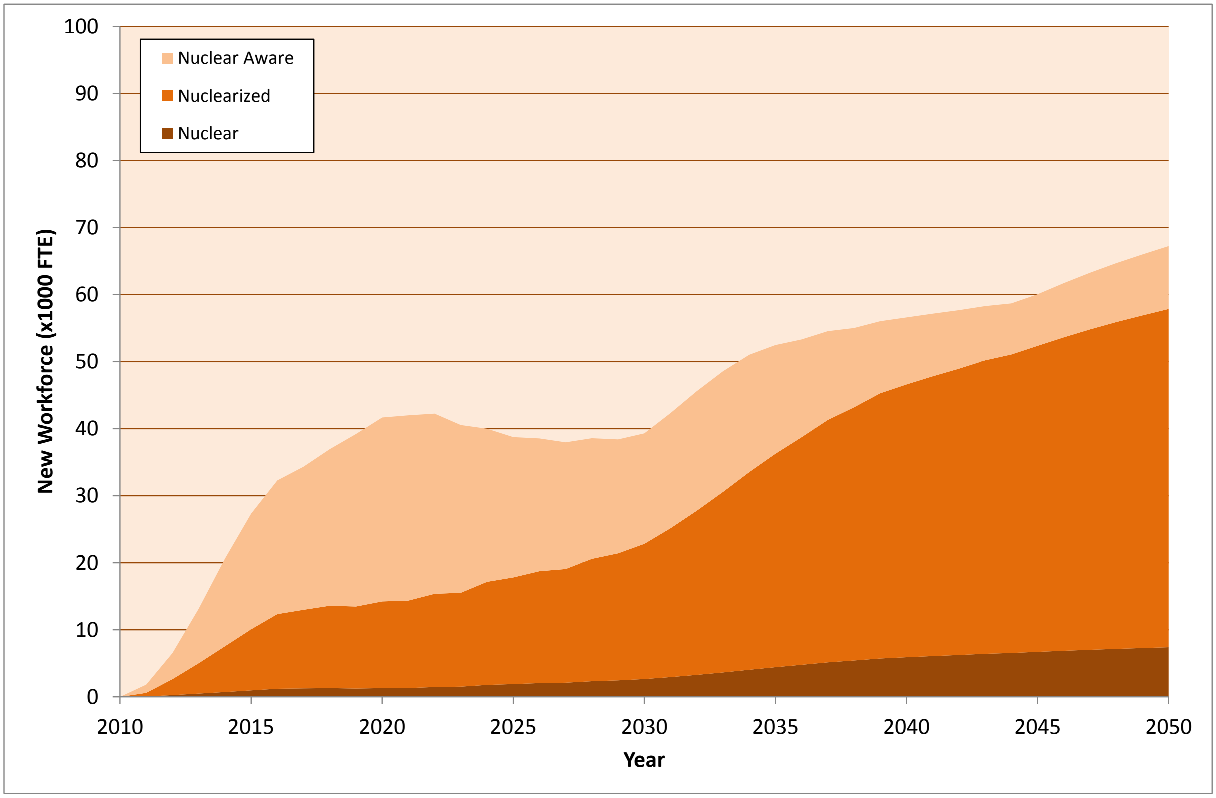
Source: EHRO-N (2012)

4. Modeling the Workforce Need based on EU Energy Scenarios

Additionally to the methodology applied in the previous chapter a study was carried out dealing with an alternative approach to derive figures for the demand side information of the nuclear workforce. In this top-down modeling approach, well accepted nuclear energy demand data is used to derive the number of nuclear power plants that are in operation and under construction as a function of time from 2010 up to 2050 assuming that the current reactor park will be replaced by generic third generation reactors of 1400 MWe or 1000 MWe. Based on workforce models for operation and construction of nuclear power plants, the model allows a prediction of these respective workforces. Using the nuclear skills pyramid, the total workforce employed at a plant is broken down in a nuclear (experts), nuclearized, and nuclear aware workforce. With retirement profiles for nuclear power plants derived from the EHRO-N survey, the replacement of the current workforce is taken into account.
Depending on the assumed nuclear energy demand scenario and the type (size) of new build reactors (for details refer to case scenarios in the reference), the analysis shows

that about 95 to 160 new reactors are required to fulfil the demand for nuclear energy. The total number of the involved in construction of nuclear power plants equals ~50000 (70000 peak) for the scenario in which 160 reactors are constructed and ~20000 (40000 peak) for the scenario in which 95 reactors are constructed.

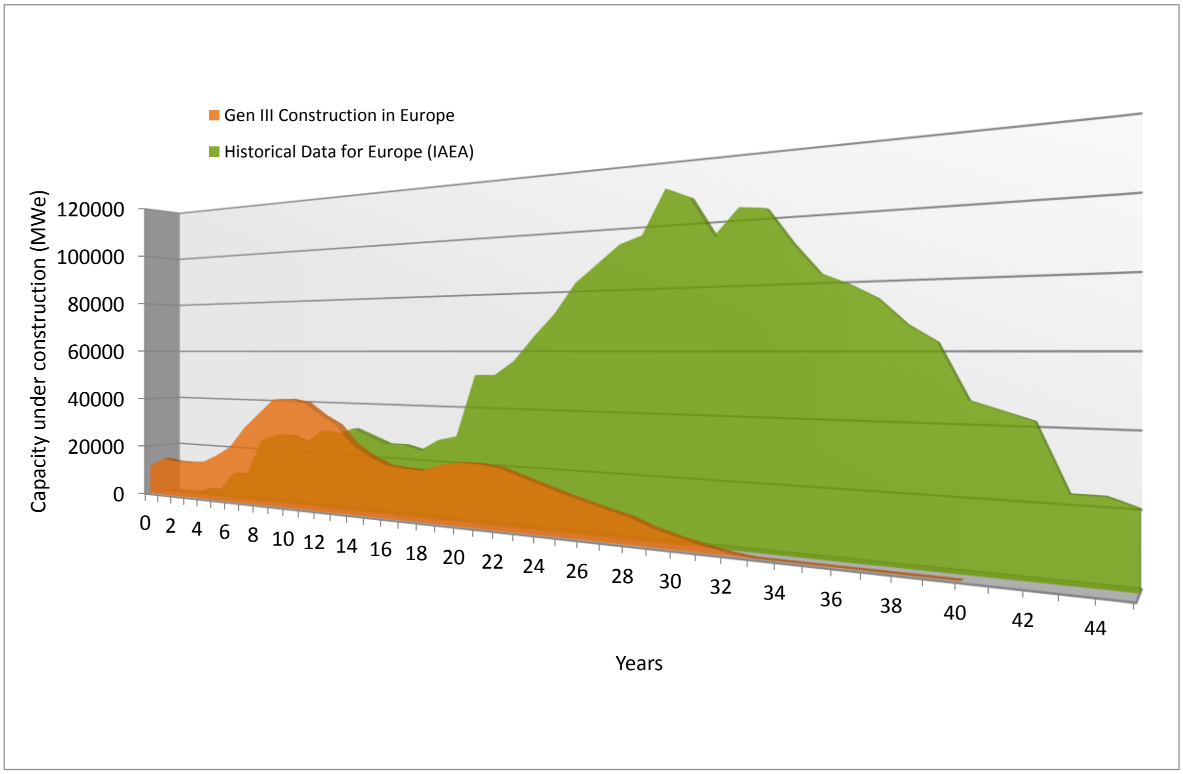
Figure 4: Case 1B example of "New workforce operations and construction" for EC Energy Roadmap 2050 (2013)



Source: EHRO-N (2013)

From figure 4 it can be deviated, that the peak of the new workforce (partly replacing the retiring workforce and additionally keeping up with the growing total workforce demand) for nuclear experts is to be expected at the end of the considered period (2050) and amounts to about 7500-10000 nuclear experts. The peak workforce for nuclearized employees is also to be expected around 2050 and amounts to about 50000-65000 nuclearized employees. On the other hand, the peak workforce for nuclear aware employees is to be expected around 2020 and amounts to about 25000-50000 nuclear aware employees. Under the assumption of a typical amount of part-time contracts in the nuclear industry of about 10%, this relates to about 45000-80000 new jobs on the short term (2020) and 70000-100000 jobs on the long term (2050).

Figure 5: Case 1B example of "New workforce operations and construction for the EC Energy Roadmap 2050" (2013)



Source: EHRO-N (2013)

When comparing to historical data for the nuclear capacity being installed at the same time in Europe (figure 5), it is clear that the expected future capacity to be installed at the same time in Europe is significantly lower (factor of 2) than in the early 1980's. However, it should be realized that the skills demand might have been more relaxed in those days. Furthermore, a steep rise in construction is to be expected within 10 to 15 years. This is due to the fact that not only additional nuclear power plants need to be built to keep up with the growing nuclear energy demand, but also to replace the current nuclear reactor park. In order to deal with this steep rise, the nuclear industry may consider buying time by extending the lifetime of the current nuclear reactor park.

5. Conclusion and policy recommendations

The analysis of the supply and demand of nuclear experts in the EU for the years to come leads to the conclusion that the need for these nuclear experts exceeds the number of young people who will be ready to enter the nuclear workforce. This conclusion must constitute an important warning for the whole European Union. Indeed, nuclear plants must be safely operated, maintained and eventually decommissioned. Specific skills are required for these purposes. More students and new talents should be attracted in order to develop an adequate flow of nuclear experts for the long term sustainability of the sector. This can be achived only with the active coopeartion of all actors involved.

First, national policy-makers must tackles this problem and anticipate such call for more nuclear experts in their governmental decisions.

Second, the nucelar industry should interact more and better with national competent ministries so that the issue of availability of expert nuclear workforce is brought up onto the national political agenda more consistently.

Third, the nuclear industry and the universities could better interact so that the available and forecast nuclear workforce is monitored.

Fourth, universities have a responsibility to better communicate to the national policy-makers about the need to reinforce nuclear education and training programmes and to attract the younger generations of students towards nuclear education programmes.

Fifth, the European Commission can sustain these efforts by a macro-level monitoring and promotion of monitoring activities by national institutions on the supply and demand of nuclear experts in the 28 Member States. The collection of data by national authorities and the analysis of these data at a European, as well as national, level will allow us to have a better view on the current situation and produce more accurate predictions on future trends

Sixth, in the framework of the picture described in this paper, mobility of students and personnel across European universities, companies and institutions operating in the nucelar sector constitues a source of possible solution. This mobility could in fact solve problems of weak nuclear workforce in one MS by the employment of skilles ocming from other MSs of the EU. However, mobility raises several issues for its practical execution, namely the mutual recognition of qualifications and skills.

EHRO-N constitutes an important European initiative for improving the interaction among nuclear organizations on both the demand (e.g., nuclear industry) and supply side (i.e. universities) and for monitoring the presence and evolution of nuclear experts available in Europe. Therefore, the initiative has been supported by European institutions, national authorities, the nuclear industry and the academic milieu.

At EHRO-N, we envisage to focus during the following years on the following priorities:

- More collaboration with national initiative for the monitoring and analysis of the demand/supply of nuclear experts through the promotion of national surveys;

  Contribution to the development of nuclear skills in Europe by promoting national capabilities for HR development;

- Increase in the communication activity which we will adapt to the targeted audience, i.e. governmental, higher education, and private organisations;

- Exploration to channel this communication also to the EP and the Council of Ministers in order to influence policy developments at the EU level.

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NEW SIMULATION TOOLS ACTING LIKE A MAGNET TO ATTRACT YOUNG ENGINEERS

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ABSTRACT

"A third of all workers in US Nuclear plants will be eligible to retire the next five years". Such forecast along with the need of personnel for new nuclear units makes it imperative that nuclear business attracts, retains and develops their young staff.

But the new generations of young engineers who have been exposed for years to all types of gamings, are visual learners and need new learning environments. Therefore making it necessary to create interactive training environments and project an image of innovation and modernity in the nuclear industry.

Tecnatom, as a training center engaged with a full qualification process of young engineers, from their recruitment up to their assignment to nuclear plants in operation, has extensive experience in modeling and supplying any type of simulators in the power industry.

Nowadays Virtual Reality is a mature technology able to be integrated with simulation models and emulate the real world with high fidelity. Training environments, made up of accurate models with an interactive virtual reality based interface and the ability to run training scenarios in your own portable equipments, appear to be creative and motivating tools for young people.

To further analyze and implement such concepts Tecnatom has developed the following interactive training environments:

- Process Behavior 3D Visualizer

Because of the difficulty to understand the phenomena that take place in systems such as the nuclear island, an interactive environment based on high fidelity simulation models coupled with 3D virtual reality, allows the monitoring of the internal process in situations such as bubble generation in different flow regimes.

- Field Operators Training Environment

Local operations usually imply the need to access and stay in infrequently visited radioactive areas.
This training tool allows the extension of the use of full scope simulators to local operators by enabling them to handle local equipment and observe the plant response in real time. First, field operators have to access and identify the right equipment, walking through the different plant areas. Once the equipment, or control panel, is identified, they can interact and get the process response. Augmented reality strategies are also used to enrich the virtual world where the trainees are immersed.

1. Introduction

The aging workforce is one of the main concerns for the nuclear power industry. The largest percentage of the workforce population in US is represented by the baby boomers, workers between 50 and 67 years, implying that the number of retirements has already started being very significant and will follow this trend in the next years. According to the Nuclear Energy Institute, a third of all workers in US Nuclear plants will be eligible to retire the next five years. This situation is not so different from Spain, where the majority of nuclear plants were constructed in the 80's and consequently, nowadays they have an aging workforce that is beginning to retire in large numbers.
Such forecasts are not optimistic, as this large number of retirements implies a loss of experience and knowledge for the nuclear business, a business that requires thousand of skilled engineers to maintain and operate the current and new nuclear plants.

Facing this situation, attracting, hiring and retaining new engineers has obviously become a priority for nuclear plants and great efforts are focused on the training and development of this new personnel.
However, in this era when we mention new workers we are referring to the Generation Y, also called internet, net or digital generation as they have grown up with technology at their fingertips and consequently, they think, learn, communicate and process in ways that may be unfamiliar to those from another generation. Nevertheless, this is the new generation is coming and companies are forced to update their strategies to optimize new engineers' talent.

By analyzing the differences between generations, nuclear plants may define the next steps to be followed in order to ensure the transition to the next generation of nuclear industry workers.
Visual modes of learning have been preferred by a large percentage of the population, but they are especially important for this generation who grew up with lots of visual stimuli and so, this is one clearly notable characteristic of them, they are visual learners who prefer discover rather than be told.
In addition, another characteristic of this group is that they are often able to quickly switch from one task to another, and they are more comfortable when they are engaged simultaneously in multiple activities than just doing one thing.

The know-how transfer from experienced people to newcomers along with the reinforcement of safe behaviors, systematic training designed specifically to ensure the necessary competences in the different plant jobs and the process made in Information/Communication technologies for training, have been key factors for the change.

Tecnatom, with the aim of achieving a high qualification in the power plants personnel in order to make them capable to operate the plant in a safety and efficient way, has been offering training services in nuclear power plants for over 50 years. Tecnatom training services are addressed to different categories of personnel, such as licensed operation personnel, licensed radiological protection experts, non-licensed personnel and sub-contractors and include the recruitment, selection, training and assignment of the candidates to nuclear plants in operation.
With regards to the training scenarios developed by Tecnatom it is worth emphasizing the use of the Full-scope simulators and Interactive graphic simulators that Tecnatom develops with its own simulation technology, giving the models a highly accurate level of engineering with thermo-hydraulic and neutronic codes based on best estimate simulation technology adapted to real time.

With the goal to increase the quality in training services, and based on the experience gleaned over the more than 50 years in activities associated with the area of simulation and training, Tecnatom supports today the integration of Virtual Reality tools, nowadays a mature technology able to be integrated with simulation models and emulate the real world with high fidelity. Tecnatom has implemented it in its training services in order to simulate virtual scenarios for real world scenarios and visualize complex phenomena and thereby, adapting to the new learning methods of young engineers who are visual learners preferring learning by doing.

In line with this, student motivation has always been a factor in pushing students to become more successful and nowadays the trend to engage students, increase their motivation and improve learning outcomes is the game-based, including some of the common game elements as challenges, rewards, skill levels or recognition systems. Besides, new learning methods usually provide highly interactive technology that keeps students engaged with nonstop actions, realistic sounds and vivid colors while providing educational instruction. Training tools, provided by Tecnatom, disguised as games will capture and hold new engineers' interest. And more over as these applications reproducing training environments, made up of accurate models with interactive virtual reality based interface, can run in their own portable, tablet or any display device what makes them tools even more creative and motivating for young people.

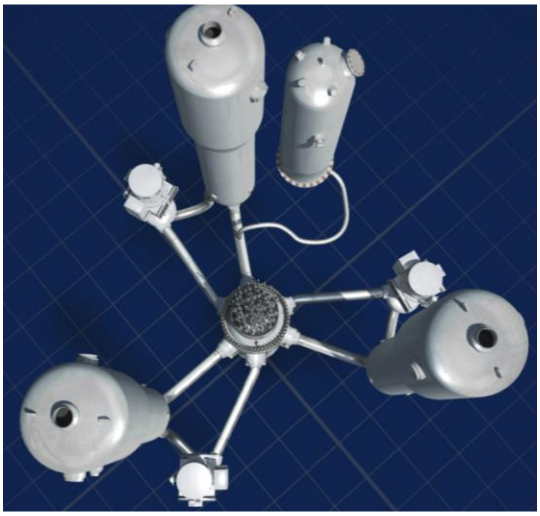
2. Recent experiences on creative training environment

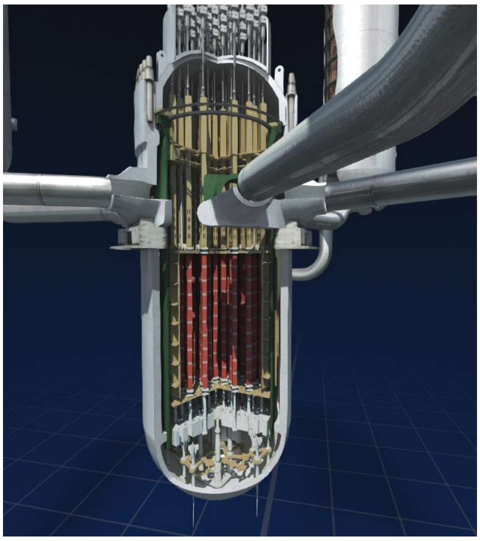
Full Scope Simulators are well known tools in the training programs of NPP personnel. A Full Scope Simulator (FSS) provides a high fidelity replica of the control room and an accurate representation of the real-time process. However, in order to understand the phenomena that take place in systems or how field operators learn to do the local operations, Tecnatom has developed new tools using the technology that can make these activities possible in an efficient manner.

Process Behavior 3D Visualizer

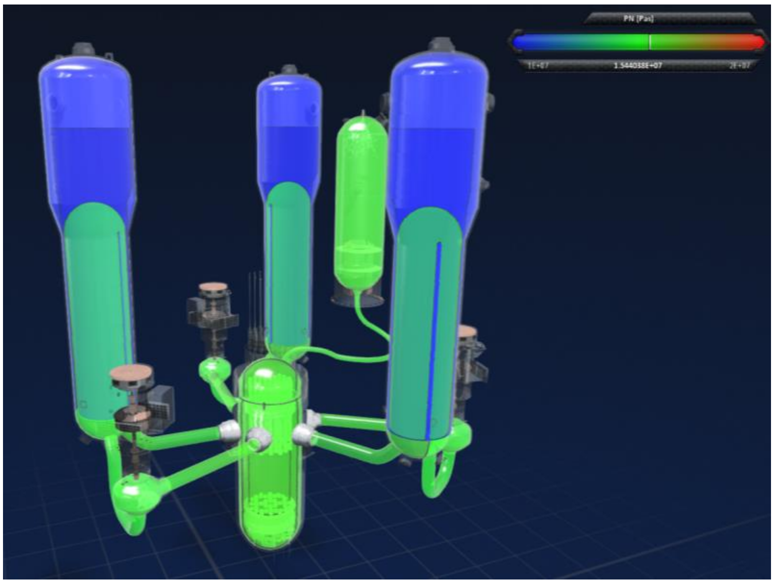
In order to easily understand thermalhydraulic phenomena inside the systems, Tecnatom has developed an interactive environment based on hight fidelity simulation models coupled with 3D virtual reality.

The Virtual Reality allows the visualization of the plant in 3D in a more realistic way to better understand the interaction between systems. Besides, it also allows to have the possibility to move around and to watch inside of the plant components.





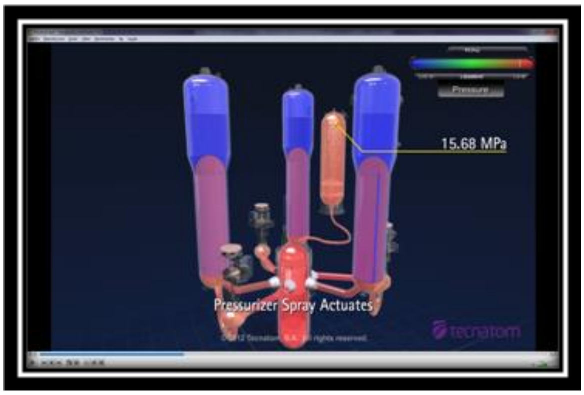
Furthermore, as the tool is coupled with accurate simulation models, once the application has established communications to the server, users are able to monitor any of the parameters calculated in the codes that will be displayed in a dedicated menu in the control area. The visualization is a continuous representation of the discrete nodalization, made using chromatic information supported by color interpolation to better highlight how the values propagate in the system and when a variable is selected its chromatic scale is presented on one side of the screen for reference. The entire system appears semi-transparent and the component cell variable values are shown as color gradients according to variable value and chromatic scale. Students will be able to appreciate the variable time evolution observing component cell color changes. Furthermore, they may change the parameter displayed at any moment choosing the most appropriate for each instant, and they decide the values of the maximum and minimum scale in order to understand at a glance what is happening inside the systems and how values propagate.

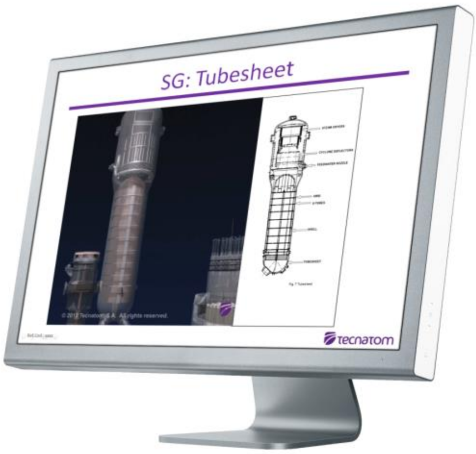


This application can be executed in any display device and students can interact with the tool whenever they desire. However, Tecnatom has updated its e-learning platform including the access to this Virtual Reality tool in its training lessons in order to reinforce in a visually manner the learning of the students who will be able to follow the lesson while interacting with the tool. As an example, when describing the components, or how systems interact between them, this tool offers visual features that help to better understand these steps of the training.

In addition, explanations about the systems behavior in nuclear accidents or normal situations where made using reading texts so far. Nowadays, Tecnatom has reproduced some scenarios in the simulator and displayed the output in its virtual reality tool. The results have been recorded and added as training material with which students can play, stop or backtrack to better understand the situation, and what is happening inside the systems.

These videos including additional information in text and audio format are aimed at reinforcing the understanding of the thermohydraulic phenomena and the behavior of the system after operators' actions and they have also been added as additional information in Tecnatom's e-learning platform.





By using the features of the application as a help for the training lessons, users easily understand how systems interact between them and what happens inside the system. By interacting with the simulator while students are having a visualization of the plant, students better understand the consequences of their actions.

Field Operators Training Environment

Field Operations play an important role in the global NPP behavior; consequently field operators have to be soundly trained to perform frequent and infrequent but critical actions under any plant condition. Especially in emergency situations, operator proper skills and a fast response time is crucial.
Traditionally, training of fields operators is performed following an on-the job approach implying an operator exposure to radiological environment. This strategy is also limited because the operator cannot perform real maneuvers for training purposes while the plant is in operation. Additionally, control room and field operators are trained with different programs without any meeting points in their training systems.

As a result the present training programs do not integrate both perspectives, showing relevant drawbacks, such as:

- Full scope simulators do not accurately reproduce local actions. They only have the so called remote functions, allowing the instructor to play a role of a field operator to perform certain local operations at the instructor station as demanded by the simulator trainees. This supposes a limitation to the training scenarios.

- Maintenance activity preparation implies visits to radioactive areas, which entails an increase in the personnel dose. To become familiar with the equipments and operation panels distributed throughout the plant as well to get the ability to localize and identify the right instrument it requires to stay long periods of time walking through the plant facility. When the equipments are located in a controlled area it is necessary to minimize the time spent to find the right equipment.

Tecnatom has considered that putting together in one integrated tool full scope simulation and virtual reality, it is possible to achieve an efficient solution to these problems and so, Tecnatom has developed a tool coupling Virtual reality with Process Simulation, so enable to integrate and coordinate both groups training needs.

Virtual reality allows us to “walk”,. ”see” and “feel” very close to reality without staying in radiological areas, providing not only images, but sounds and environmental characteristics, making the operator feel as if he were in the real plant. On the other hand, and related with the key factor of simulation itself, the accuracy in the expected functional fidelity will allow the field operator completing the action that he is supposed to do, and observe the consequences in the plant status.

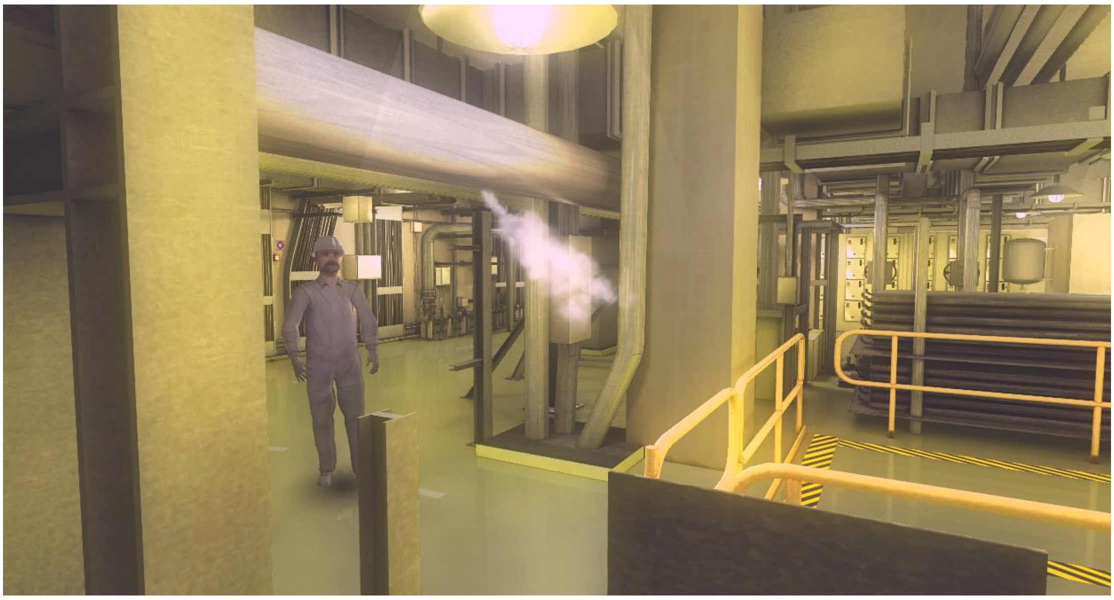
Once both technologies are coupled, the actions taken by the field operators will impact in the simulation system, and actions performed in the control room will change the information visible to the field operator. Coupled training will also improve the communication abilities in the team.

Beyond the features that the Virtual reality provides, we also highlight the Augmented Reality capability of the tool that enhances the virtual reality by overlaying graphic three dimensional images on the virtual world. As an example, dynamic trend diagrams can be activated-deactivated by the user anytime during the plant walkthrough or a task procedure.

This tool is undoubtfully very useful to be used in:

- Requalification of field operators together with license operators
- Initial Training of field operators
- Initial Training of license operators
- Supporting operation briefings
- Supporting plant modification design
- Preparing maintenance activities and related local actions (scaffolds,…)

- Local actions preparedness in adverse situations



3. Conclusions

The need of recruiting new employees due to the generational change has become a priority for the nuclear industry. New generation of young engineers is required to enter in the labor market and so, great efforts are focused on the training and development of these new personnel.

Taking into account the transfer of knowledge required and assuming new technologies are a magnet for young people, Tecnatom has developed new training tools in order to understand the phenomena that take place in complex systems and to help fields operators in local operations.

Each of these applications not only can run independently, using the diverse features implemented on them, but also can be connected with full scope simulators. This integration makes it possible the creation of new training environments where dynamic simulation and its visualization are integrated with virtual worlds.

In addition to training purposes, the ability to run training scenarios on any display devices appears to be a creative and motivating tool for young engineers.

CURRICULUM DEVELOPMENT FOR AN INTRODUCTORY COURSE IN NUCEAR SCIENCE AND ENGINEERING

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ABSTRACT

Recruitment of undergraduate students to any science or engineering discipline often involves offering an introductory course to attract and pique the interest of the learner. Competition for the student in specialized fields such a nuclear science and engineering is very keen with an array of choices to the undergraduates. In spring 2013 we introduced a new three credit-hour course entitled Concepts in Nuclear Science and Engineering to specifically attract students into our undergraduate Nuclear and Radiation Engineering Certificate within the Mechanical Engineering Department or the Radiation Physics option in the Physics Department. The self-contained lectures include a broad base of all topics and technologies encompassed in nuclear and radiation engineering history of nuclear science and noble prize winners, radiation in the environment, environmental effects of electricity generation, nuclides and isotopes, isotopes in everyday life, radioactivity, nuclear reactor theory, food irradiation, nuclear medicine, nuclear power and the need for the future, nuclear fuel cycle, nuclear terrorism, nuclear non-proliferation, nuclear security culture, homeland security, radium in the environment, nuclear and radiochemistry, and probabilistic risk assessment. Two on-line lectures are also given by the certified health physicist in health physics training. Three individual laboratories are given for a half-life measurement; simple radiation shielding; and determination of uranium in soil samples by neutron activation analysis. A 10-12 page paper on any aspect of nuclear science or engineering is also required along with a tour of the 1.1 Megawatt TRIGA research reactor.

1. Introduction

In the past several years there has been a noticeable increase in nuclear engineering and related programs in the USA, Canada and Europe. While some of these programs are fully fledged nuclear engineering degrees, many more are technical options, certificates, minors, etc. At the University of Texas at Austin an undergraduate nuclear engineering option has existed within the Mechanical Engineering Department for many years. However, in the past several years a serious effort was made to recruit more undergraduate students to the program from Mechanical Engineering and Physics. One of the key recruiting tools has been the introduction of a one-hour survey course given to undergraduate students to increase their knowledge of the various aspects of nuclear science and engineering and its applications. The lectures are also augmented by seminar speakers from the nuclear industry and national laboratories.

Since 1998, the successful one-hour elective course entitled *Concepts in Nuclear Radiation and Engineering* (ME 136N) has catered to students in Mechanical Engineering, Physics and various other departments. It was given every semester and has had an average of 20-30 students per semester. Topics have included global warming, alternative and renewable energy sources, nuclear medicine for various cancer treatments, maintaining nuclear power plants to reduce climate change and air pollution, and the uses of nuclear technology in enhancing industrial processes such as food irradiation, medical sterilization, etc. While the students have benefitted from such introductory concepts of nuclear science and engineering, the rigors of mathematical presentations and more in-depth analysis is not permissible for a one-hour course. The re-design of this course (ME 379M) essentially elevated the content of these topics to a fully-fledged three-hour elective. This more in-depth course, better prepares students that progress on to the more advanced nuclear engineering courses in their junior and senior years.

Within the nuclear industry nearly two-thirds of all in-coming employees are either mechanical or electrical engineers. In the USA more than 14 million tests are done using medical isotopes for early cancer and other disease detection. The shortage of molybdenum-99 (Mo-99), the single most popular diagnostic radiopharmaceutical in the USA and world, has spurred the US Congress to look into the production of this medical isotope in the USA. Currently, all the Mo-99 is imported from four countries and there have been unforeseen disruptions in its delivery. A US National Research Council report in 2009 supported a US domestic supply of Mo-99. Thus, the need for many nuclear science and engineering students in the field of medical physics will continue to grow in the near future. This new course covers nuclear medicine in more depth and also allows more meaningful presentations of current Department of Energy needs, including nonproliferation, nuclear forensics and robotics in handling of special nuclear materials. We have developed educational materials for comprehensive introductory nuclear engineering concepts for undergraduate students deciding whether to enter into the field of nuclear science and engineering. These modules are used in the Nuclear and Radiation Engineering Certificate, Radiation Physics Option at the University of Texas and the Big-12 Nuclear Consortium. Additionally, three Historically Black Colleges or Universities (HBCUs) Florida Memorial, Huston-Tillotson and Texas Southern University have access to the complete course curriculum on a BOX website which also be made available to high school and middle school teachers to use for their own teaching purposes.

2. Course Description

In the first years of the course the lectures were based on introductory parts of other courses and review articles. However, an excellent survey book on nuclear science and its many applications in the everyday life entitled *Radiation and Modern Life: Fulfilling Marie Curie's Dream* was published in 2004 and is now the core text for the course. A critical review of this book has also been published by Landsberger (1). The book is segmented into distinctive parts. It contains virtually no mathematical equations, just very effective explanations and illustrations of basic nuclear properties and the application of radiation in a wide variety of areas in science and technology as well as the major impact it has in the public domain. A comprehensible explanation of the origin of naturally occurring radiation in the environment as well as a synopsis of radiation effects at low and high doses is given in the second chapter. The basic concepts of radiation interactions are provided in the third chapter, in which fundamental processes are clarified in uncomplicated terms. Radiation in agriculture, medicine, and nuclear power is well explained in the next three chapters. Each of these areas is treated with detailed examples of the positive benefits of radiation, such as higher crop production, control of insect pests, improved medical diagnostic and therapeutic techniques, and the production of nuclear electricity. Sections on radiation applications in industry, transportation, and space exploration are equally well written. Topics include process controls, materials composition, cars and trucks, space missions, manned voyages, and the radiation-related health effects of space travel. Additional sections on applied radiation include topics related to terrorism, crime and public safety, arts and sciences, and environmental protection. Excellent descriptions of work in antiterrorism efforts, archaeological investigation activities, soil erosion, and air pollution studies are given. In an additional chapter, the impact of radiation on the economy is also very well described.

Lectures: There are a series of twenty modules which include the following topics: Animations of Radiation Sources, Pioneers and Events in Nuclear Science and Engineering, Radiation in the Environment, Radioactive Decay, History of Nuclear Reactors, Nuclides and Isotopes, Effects of Electricity Generation, Radiation in the Environment, Isotopes in Everyday Life, Food Irradiation, Nuclear Power, Nuclear and Radiochemistry, Radioactive Waste Forms, Nuclear Medicine and Mammography, Naturally Occurring Radioactive Material, Virtual Tour of the TRIGA reactor, Nuclear Fuel Cycle, Nonproliferation, Nuclear Security, Robotics Handling of Special Nuclear Materials, and Probabilistic Risk Analysis.

Since the topics are broad-ranging, this course provides an opportunity for the instructor to implement risk/benefit analysis of the use of nuclear methodologies in everyday life situations. Many undergraduate students in science and engineering are taught the concepts of reverse engineering, novel design techniques, problem solving, etc. in their core curriculum. However, risk/benefit analysis (the newer version of *pros vs. cons*) is seldom enunciated in the classroom. In fact, this type of analysis is the cornerstone of many industrial innovations, medical professions and even military decisions. In this redesigned course there was ample opportunity to elucidate these concepts in the context of the course material. For example, the student was required to assess the various energy strategies and economics of renewable sources versus traditional ones such as coal, oil and nuclear. In non-proliferation issues the impact of various national and international policies were examined as they pertain to international and homeland security. In medicine, the risk/benefit of being administered a nuclear isotope for diagnostic or therapeutic procedure was discussed. This redesigned course will hopefully act as a conduit to spur students to consider the important aspects of risk versus benefit in their academic and employment pursuits.

Homework: Several chapters in the book are assigned to answer homework questions. Included in the weekly homework assignment are on-line videos to watch and comment upon. The videos include: Atomic Café, Lessons from Nature for Waste Disposal, Dirty Bomb, Russia's Nuclear Navy, Medical Imaging, US Nuclear Officer Propulsion Program, Russian Nuclear Materials, Back to Chernobyl and Nuclear Terror. Additional homework assignments included questions on radioactive decay, table of isotopes, risk assessment, nuclear safety, etc.

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Research Reactor: A virtual tour of the TRIGA research reactor at the University of Texas was given to all the students before they actually visit the facility. This pre-tour visual lecture was very beneficial to explicitly discuss in detail the various operational procedures of the reactor so that the students can visually familiarize themselves before the visit.

Invited Guest Speakers: Whenever possible invited guest lecturers from national laboratories, industry representatives, regulators from Nuclear Regulatory Commission or on-campus Nuclear Navy recruiters present material which augments the classroom experience. These seminars are critical to give the students an appreciation of the employment and research opportunities.

Laboratory Component: The three experiments consisted of the following:

1) Half-life measurement using an isotope prepared by neutron activation analysis
2) Shielding of beta and gamma sources
3) Determination of uranium in environmental samples by neutron activation analysis

3. Course Delivery

In the last fifteen years there has been a variety of technological advances made in various educational endeavors. These began with simple PowerPoint lectures in the 1990's. Sophisticated *Distance Learning* platforms were more common in the late 1990's, while animations were being integrated in many different lectures in the science and engineering courses. Software animation programs such as Flash are now routinely used by many students in the arts, science and engineering departments. In the Nuclear and Radiation Program at the University of Texas animations have been part of several courses including Concepts in Nuclear and Radiation Engineering, Health Physics, Health Physics Laboratory and Radiochemistry. It is well known that a "picture is worth a thousand words", and animations, when used judiciously, can enhance the learning experience of science and engineering concepts. This is especially true when describing mathematical formulae or data such as that from gamma ray spectroscopy measurements or medical isotope production (2-8). The Faculty Innovative Center in the Cockrell School of Engineering has a team of computer graphic artists and animators that helped us develop more sophisticated nuclear engineering graphics and animations.

All lectures and homework assignments were placed on the University of Texas BLACKBOARD educational site in advance of the lectures. Answers to homework assignments are uploaded and seen on-line by the instructor or teaching assistant. Two in-class exams were also administered. At the end of the course, a ten-twelve page survey paper on any aspect in nuclear science and engineering was required to be handed in on the last day of class.

4. Grade Evaluation:

The grade evaluation of the students was made up of several components:

1) Assignments given from the course book
2) Two examinations
3) Laboratory experiments
4) Research paper

5. Course Evaluation

Evaluations for the course and instructor were done using the usual forms supplied by the University of Texas. These forms were filled out in private on the last day of class and then handed in to the teaching assistant to be submitted to the Department. The specific questions as well as overall course and instructor evaluation for this course are shown below. The University of Texas uses only the last two questions as means of evaluating the course and instructor. The first questions are given as guideline to the instructor of the strengths and weaknesses of the individual parts of the course. Each student also has ample space for hand-written comments. The students overwhelming gave high evaluations for all facets the course. The evaluation criteria are shown below with an overall course and instructor evaluation. Each grade is out of 5 with 0 being the lowest and 5 being the highest. As can be seen there was a very high degree of satisfaction with the course and instructor.

Question	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Average
The course was well organized.	0 (0.0%)	0 (0.0%)	0 (0.0%)	4 (25.0%)	12 (75.0%)	4.8
The instructor communicated information effectively.	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (12.5%)	14 (87.5%)	4.9
The instructor showed interest in the progress of students.	0 (0.0%)	0 (0.0%)	0 (0.0%)	2 (12.5%)	14 (87.5%)	4.9
The tests/assignments were usually graded and returned promptly.	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	16 (100.0%)	5.0
The instructor made me feel free to ask questions, disagree, and express my ideas.	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (6.3%)	15 (93.8%)	4.9
At this point in time, I feel that this course will be (or has already been) of value to me.	0 (0.0%)	0 (0.0%)	1 (6.3%)	1 (6.3%)	14 (87.5%)	4.8

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Question	Very Unsatisfactory	Unsatisfactory	Satisfactory	Very Good	Excellent	Average
Overall, this instructor was	0 (0.0%)	0 (0.0%)	0 (0.0%)	4 (25.0%)	12 (75.0%)	4.8
Overall, this course was	0 (0.0%)	0 (0.0%)	0 (0.0%)	4 (25.0%)	12 (75.0%)	4.8

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7. Acknowledgements

We gratefully acknowledge the US Nuclear Regulatory Commission for funding the development of the course.

MOTIVATING YOUNG STUDENTS TO BE PART OF THE GLOBAL RESEARCH IN NUCLEAR THROUGH THE SEMINAR OF NUCLEAR FUSION

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ABSTRACT

Jóvenes Nucleares (Spanish Young Generation in Nuclear, JJNN) is a non-profit organization that depends on the Spanish Nuclear Society (SNE). The Universidad Politécnica de Madrid (Technical University of Madrid, UPM) was chosen to host the Seminar as it is one of the most prestigious technical universities of Spain, and has a very strong curriculum in nuclear engineering training and research.

Both, the UPM and the SNE, supported strongly the seminar: the opening session was conducted by the member of to board of directors of the Spanish Nuclear Society and Nuclear Engineering professor of the UPM, Emilio Mínguez and the closing session was conducted by the director of the Nuclear Fusion Institute (UPM).

1. Introduction

Jóvenes Nucleares (Spanish Young Generation in Nuclear, JJNN) is a non-profit organization that depends on the Spanish Nuclear Society (SNE). The Universidad Politécnica de Madrid (Technical University of Madrid, UPM) was chosen to host the Seminar as it is one of the most prestigious technical universities of Spain, and has a very strong curriculum in nuclear engineering training and research.

Finishing 2011, JJNN and the UPM started to plan a new and first-of-a-kind Seminar in Nuclear Fusion. That Seminar was highly demanded by the Young Generation People for the last years, due to the need of information motivated by the huge fusion projects on-going in the world (ITER, NIF, etc.).

2. The Motivation

The goal of the Seminar was to give an overview of the nuclear fusion fundamentals and technology, introducing the audience to the research projects in nuclear. That was a great driver of the course as the participants were able to see what challenges are being faced and how much effort is being made in the energy research field. Their feedback told that it was motivating experience for them.

After a great effort from JJNN with the support of the UPM, the Seminar took place in November 2011 at the Industrial Engineering School (ETSII). The lessons were conducted by expert researchersin the field, who belong to the Nuclear Fusion Institute at the UPM.

3. The Development of the Seminar

The Seminar was structured in four sessions: introduction to the nuclear fusion fundamentals, inertial confinement nuclear fusion, magnetic confinement nuclear fusion and overview of the projects in nuclear fusion.

In the first presentation, Alberto Fraile clearly explained the beginnings and foundations of fusion technology, not excluding the references to the non-civil origins. The presentation included several videos and stories, with many interventions of the public in the question time.

The next presentation was developed by Manuel Cotelo, which clearly reflected the theoretical foundations of inertial confinement fusion technology and hinted ongoing projects and future prospects of this technology.

Later, Antonio Rivera introduced to attendees in the complex technology of magnetic confinement fusion, addressing its strengths and challenges, as well as deepen the theoretical concepts of this technology.

Finally, in the last session, Jesus Alvarez made a broad perspective of past, present and future projects of both technologies, highlighting the projects in which there are Spanish participants.

In the 2012 edition, thanks to the kindness of Santiago Sánchez-Cervera, the seminar was finished with a very interesting visit to the TJ-II Stellarator at CIEMAT facilities. That is why, besides the gratitude to the Technical University of Madrid, and in particular to the Superior Technical School of Industrial Engineers for the assignment of space we extend the CIEMAT, who very kindly attended the visit.

4. Conclusions

The seminar was very popular, with nearly 80 attendees each day, from the university, nuclear companies and research centers. After each session there were very interesting and animated discussions between the presenters and the public that demonstrated the interest of the attendees for the subjects taught.

Both, the UPM and the SNE, supported strongly the seminar: the opening session was conducted by the member of to board of directors of the Spanish Nuclear Society and Nuclear Engineering professor of the UPM, Emilio Mínguez and the closing session was conducted by the director of the Nuclear Fusion Institute (UPM).

The assistants were asked for a highly detailed feedback of each one of the lessons and those opinions have helped to review the program for the 2012 and 2013 Seminars, which took place also in November at UPM as well.

Figure 1. Public at the Nuclear Fusion Seminar

Figure 2. Attendees to the TJ-II visit in 2012

Figure 3. Announcement of the first Nuclear Fusion Seminar

INFORMING THE YOUNG GENERATION AND THEIR TEACHERS ABOUT THE CONCEPTS OF NUCLEAR ENERGY AND RESEARCH

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ABSTRACT

Preserving and extending nuclear knowledge, skills and competences at the service of society is a key function of the Belgian Nuclear Research Centre SCK•CEN. Extensive experience in nuclear science and technology, performing innovative research and the availability of large and unique nuclear facilities make our renowned nuclear research centre also an important partner for nuclear education and training.

In the interests of maintaining a competent workforce in industry, healthcare, research and policy, and of transferring nuclear knowledge to the next generations, the SCK•CEN Academy takes it as its mission to provide guidance for young researchers, to organise academic courses and customised training for professionals, to offer policy support with regard to education and training matters and to care for critical-intellectual capacities for society.

This paper focusses on our activities for final-year high school pupils and their teachers. These involve thematic educational tours that provide insights into its many applications in today's society, and a view of the daily practices in a research centre. On a monthly basis, final-year pupils and their teachers can participate in guided tours covering various nuclear themes such as research on radiation protection in space, the history and future of nuclear reactors, and the research concerned with finding solutions for the disposal of nuclear waste. The SCK•CEN Academy also provides supporting educational material and organises workshops for teachers. These workshops discuss the state of the art of nuclear research and share insights on the what, why and how of teaching a complex subject such as nuclear science and technology in class.

1. Introduction

Pupils have a wide attention span and are eager to learn. In our complex society, they should be able to develop an open and critical mind in order to gain more insight into the multi-faceted issues such as the risks and benefits of radioactivity and nuclear technology, and their possible applications. In this sense, the SCK•CEN Academy (http://academy.sckcen.be) interacts with high-school pupils and teachers in order to (i) explain the basics of radioactivity and discuss several nuclear applications in, for example, industry and medical, (ii) give an overview of the status of nuclear research and a flavour of what the daily life in a nuclear research centre comprises, and (iii) discuss with teachers how the standard education programme can integrate a pluralistic approach to complex technical issues such as the applications of radioactivity.

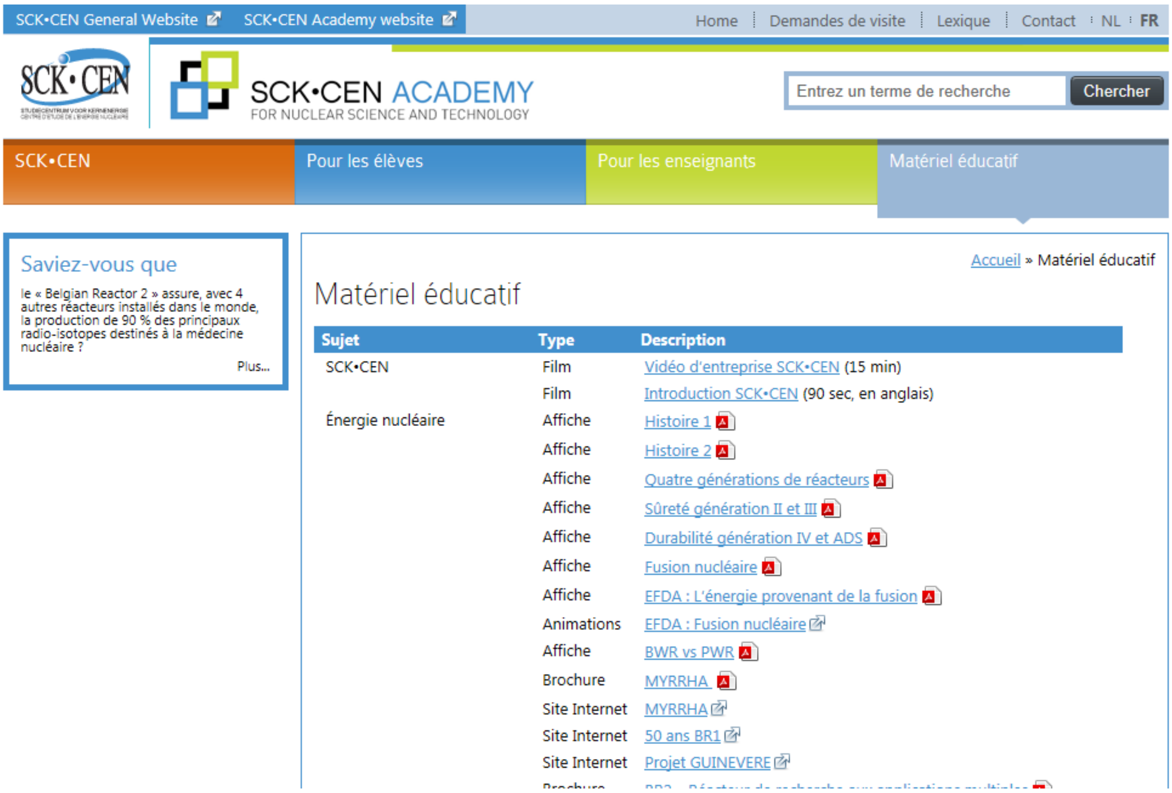
The tools used to support this aim are a dedicated website (http://jongeren.sckcen.be) in the two national languages French and Dutch with general information on nuclear science and technology, the organisation of guided thematic tours at SCK•CEN laboratories, and topical discussion sessions with high-school teachers.

2. A dedicated website

In addition to the general SCK•CEN website, the Academy developed a website which specifically supports the high-school students and their teachers.

The site (http://jongeren.sckcen.be) is available in Dutch and French, and has specific sections for pupils and teachers. It contains general information about the R&D topics treated at our research centre, as well as basic information on nuclear science and technology. In addition, educational material (pictures, summaries, videos, animations, etc.) that can be used in the classroom to support teaching on nuclear can be found on this site. The pupils can also test their level of nuclear knowledge with a questionnaire. A "did-you-know" column refreshes with each new visit and aims at stimulating the curiosity of the visitor with daily-life facts and figures.

In case a visit to the SCK•CEN laboratories is considered, pupils and teachers can find all necessary practical information regarding the scientific themes, when and how these visits are organised, how to register, requirements to access the domain of SCK•CEN, checklist of practical arrangements, etc.



3. Thematic guided tours at the SCK•CEN laboratories

3.1 The different topics treated

On a monthly basis, eight times per year during the school season, the SCK•CEN Academy organises four different thematic visits. In general guidance is foreseen by SCK•CEN experts working in the relevant laboratories. The tour is given in the language of the visitors, and the level is adapted to the scientific background of the high-school pupils and is supported by posters and short power point presentations.

Thematic tour 1: four generations of nuclear reactors

This guided tour is focusing on how radioactivity is used to produce energy. The scientists of SCK•CEN guide the high-school pupils through the history of radioactivity, with the historical discoveries and applications in nuclear energy. The different characteristics of four generations of nuclear reactor are illustrated, together with the nuclear fuel cycle.
The tour starts with a visit to the Belgian Reactor 1 (BR1), which is the oldest nuclear research reactor of Belgium, operational since 1956. This 4 MWth reactor is air-cooled and moderated with graphite with natural uranium as fuel. During the guided tour, the graphite configuration is shown, together with the control room. By demonstrating the advantages of this research reactor, insight is gained on the importance of nuclear research reactors for current applications in society, such as the production of medical isotopes, the irradiation of silicon and material testing. The tour continues with an explanation of the characteristics of the actual generations II and III, and ends with a description of the possibilities of future generation IV reactors. The SCK•CEN experimental facility VENUS and the GUINEVERE project are illustrated and the MYRRHA project, an accelerator driven fast spectrum research reactor with MOX fuel and liquid lead-bismuth cooling, is explained.

Thematic tour 2: radiation in space

Radiation protection is a major challenge in the industrial applications of ionising radiation, both nuclear and non-nuclear, as well as in other areas such as the medical and research area.To highlight the importance of protection of man and environment from potential hazards from ionising radiation, and the relevant research in this field, our research project regarding space applications is put forward as case study.
The visitors are invited to reflect on the extreme conditions outside the atmosphere. A demonstration is given on how radiation is measured, with a link to the exposure to cosmic radiation of a spacecraft with astronauts. The radiobiological effects on different tissues are explained, with an insight into the human immune system and the impact of radiation on fertility and the foetus. The pupils are guided through the laboratory of our radiobiology unit, and experience the different techniques to detect genome expressions. With longer space journeys in mind, the visitor is stimulated to discuss the implications of space travel. Our microbiology research group focuses on the presence and consequences of bacteria in space. In the laboratory of microbiology, culture and detection of bacteria is demonstrated, with a simulation of space conditions. In addition, one of the projects of the European Space Agency (ESA) is demonstrated where organic waste is recycled in a bioreactor into oxygen and food (MELiSSA, Micro-Ecological Life Support System Alternative). Although this guided tour does not contain a visit to a large nuclear infrastructure, these research topics surely trigger the imagination of this young audience.

Thematic tour 3: radioactive waste disposal

This tour focusses on the treatment and geological disposal of nuclear waste, a topic with an important socio-political, ethical and trans-generational dimension.
The economic interest group EIG EURIDICE (European Underground Research Infrastructure for Disposal of nuclear waste In Clay Environment), a collaboration between SCK•CEN and NIRAS/ONDRAF, possesses of a demonstration hall at the domain of SCK•CEN with interactive screens, videos, graphic representations and real scale demonstration models. It is at the disposal for these group visits and pupils can learn all about the safe containment and isolation of radioactive waste. When possible, a visit is made to the underground laboratory HADES, where research is done on a multibarrier system for geological disposal of highly active and long-lived radioactive waste. Experiments on waste form behaviour, container corrosion, radionuclide chemistry and migration, are highlighted and a first-hand experience on the excavation of Boom Clay is encountered. Also, a demonstration experiment is shown which examines the behaviour of the geological disposal system on a true operational scale. Since this guided tour involves visiting a research lab which is located 225 meters below the ground, this theme is quite popular for the high-school audience.

Thematic tour 4: reactor technology – from idea to reality

This topic was added recently and the tour was especially developed to show the importance of high-level and precise technical work, complementary to the scientific research needed to conceive and implement innovative nuclear applications. It specifically addresses students with a technical background, and focuses on the engineering aspects of reactor technology, with a visit to the technology building of SCK•CEN. In this tour, the pupils learn all about the different phases which are typical for research and development in the industry, going from the conceptual idea to the actual commissioning. In the technology building of SCK•CEN, new and innovative laboratory experiments are built on a semi-industrial scale. Currently, visitors can see an experimental loop for corrosion testing, experience ultrasonic visualisations and see several chemical behaviour experiments on liquid lead-bismuth. Most of these experiments are set up in the framework of research programme MYRRHA. In the same building, all instruments are built for irradiation experiments in the Belgian Reactor 2. The variety of experiments and the different profiles of scientists and engineers encountered during this visit, make the young visitor enthusiastic about the technical aspects of nuclear applications.

3.2 Participation and feedback

The SCK•CEN Academy started with the organisation of the first three thematic tours for pupils and their teachers in 2009; recently the fourth theme was added. From 2009 until November 2013, more than 500 high-school pupils have visited SCK•CEN, coming from more than 20 different schools. Most schools are located in the vicinity of Mol; about 30% comes from a place located more than 50km from our research centre.

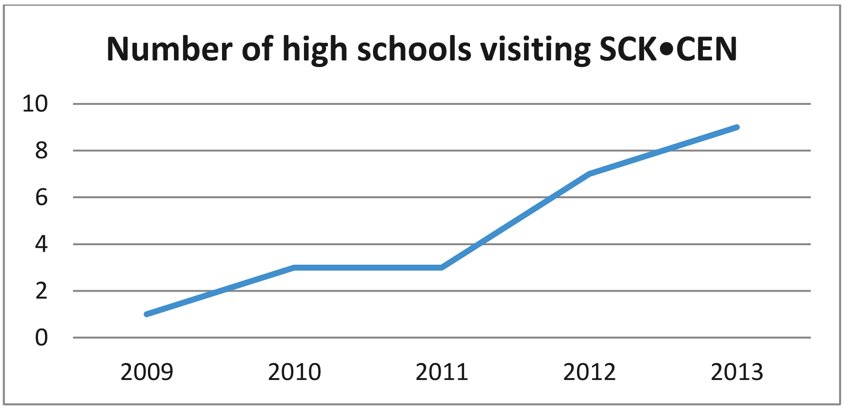


Figure 1: number of high schools visiting SCK•CEN

In 2012, extra sessions were organised prior to the open doors which was held on the occasion of the 60th anniversary of our research centre. These are not taken up in the graph shown below; 108 visitors coming from 10 different schools paid a visit to SCK•CEN on that occasion.

Figure 2 shows the participation per theme visit.

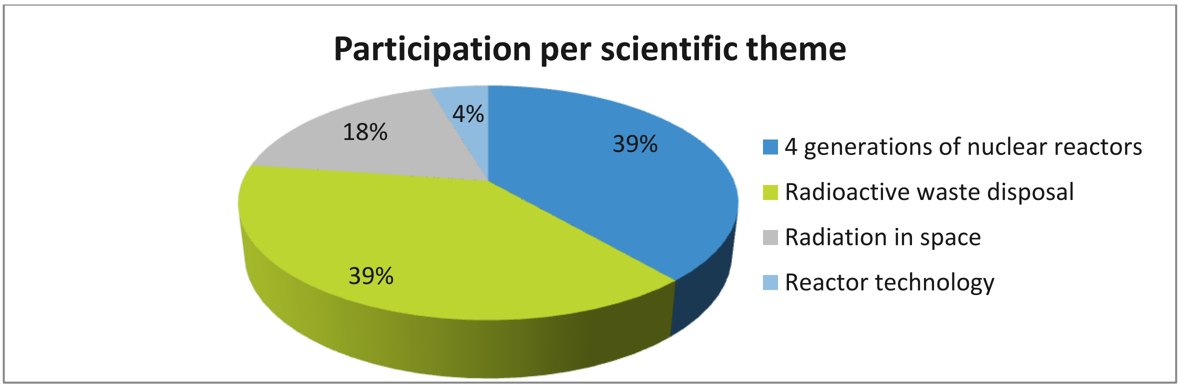


Figure 2: Participation per theme

In order to improve the overall quality of the scientific visits, the SCK•CEN Academy asked for feedback by means of a short questionnaire treating different aspects of the scientific visit. Of all questionnaires sent out since 2012, 81% response was received. Table 1 gives the summary of the feedback forms, indicating the satisfaction of the majority of the visitors

Table 1: Summary of the feedback of the school visits

Feedback item	very satisfied	satisfied	less satisfied
Content	53%	47%	0%
Documentation	42%	58%	0%
Tour guides	58%	42%	0%
Organisation	20%	77%	3%
Overall feedback of the visit	**70%**	**30%**	**0%**

In addition to filling out standardised scoring questions, the visitors were also invited to answer some open questions regarding their reason for visiting SCK•CEN, if they would recommend the visits to colleagues, if there were interesting topics not treated during their scientific visits, etc. From these open questions, some critical remarks were made towards the possibility to visit nuclear installations where access was restricted due to the safety and security policy. As a large nuclear infrastructure, it remains a challenge to be transparent in all research activities towards the public and at the same time deal with all necessary safety and security rules imposed by the authorities.

In general, we can state that these scientific 'field trips' are highly appreciated by the visiting high schools. The high-school teachers indicate that the treated topics are complementary to the regional imposed learning objectives, and welcome the demonstration of nuclear applications outside a classroom environment.

4. Workshops for high-school teachers

Complementary to the provision of educational material to be used in the classroom, the SCK•CEN Academy for Nuclear Science and Technology also discusses with teachers how the standard high-school education programmes can integrate a pluralistic approach to complex technical issues such as the applications of radioactivity, and what the most recent developments in nuclear research represent. During so-called "teachers' days", teachers visit SCK•CEN outside school hours, and discuss these topics with their peers and our experts. These workshops also aim to facilitate exchange of experiences related to perception of nuclear application, job opportunities, etc. by themselves and their pupils and how this potentially influences the choice of the pupil with regard to post-high-school studies.

The Academy also participates in workshops organised by regional associations of high school teachers in science. These events can be embedded into regional symposia, or exist as stand-alone continuous professional development initiatives for high-school teachers.

With these initiatives, the Academy aims to meet the requests of teachers who often express their lack of up-to-date information on nuclear science and technological evolution in different fields like industry and medicine. This additional information helps them to transfer correct information to the next generations.

5. Summary and conclusions

The SCK•CEN Academy for Nuclear Science and Technology highly values the young generation. By means of various initiatives for high-school pupils and their teachers, the current nuclear research and technology is brought into the classroom in an interactive way.

Educational material like illustrations, pictures, animations etc. are provided through our website.
In addition, visits to our research centre's facilities and discussions with our experts provide insights into the many nuclear applications in today's society, and give a view on the daily practices in a research centre.
While the science itself may not be controversial, its application often is. There is a growing awareness of the importance of being able to consider this wider context. The SCK•CEN Academy is unique in addressing this challenge by developing educational content and methods to raise awareness and stimulate thinking and discussion. This is also applied in these initiatives for high-school pupils and their teachers.

Through this mixture of theoretical approaches, on-site demonstrations, qualitative educational resources and an introduction of transdisciplinary aspects in the education at the undergraduate level, the SCK•CEN Academy stimulates an optimized knowledge transfer of nuclear science and technology to the young generation and contributes to development of critical-intellectual capacities for future society.

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