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MINA-2008: A RENEWED APPROACH TO MASTERING NUCLEAR ENGINEERING AND APPLICATIONS IN SPAIN

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ABSTRACT

Inspired by the nuclear renaissance, the challenge of preserving nuclear knowledge and expertise and the bases of the European Education Area, CIEMAT has initiated a renewed venture in nuclear education and training: MINA (Master on Nuclear Engineering and Applications). MINA intends to build an actual bridge between University education and professional skills demanded at present by nuclear industry and organizations. In short, MINA will enable graduates to fit nuclear sector needs. To do so, CIEMAT counts on a broad support from both nuclear industry and universities, some of which welcomed MINA as a part of their MASTER cycles. This paper outlines the major characteristics, the development phases and all the mechanisms set-up to brew and organize MINA-2008.

1. Introduction

CIEMAT is a Public Research Agency for excellence in energy and environment, as well as in many vanguard technologies. Since its creation in 1951, education and training in the nuclear field has been a priority, a proof of which was the creation of the Institute for Nuclear Studies in 1964. Since then a course on Nuclear Engineering has been held (nearly on a yearly basis). The first editions were focused on specific education and training on construction and development of nuclear power plants and facilities [1]. The course has been updated throughout the years according to the national trends on nuclear technology. As a result of this long “journey”, more than 600 professionals have been formed.

As consequence of the renewed interest in the nuclear energy (sometimes called “nuclear renaissance”) [2] and other national factors, like generation renewal, the Spanish nuclear sector is demanding engineers, technologists and scientists. CIEMAT has been sensitive to these changes and has implemented an ambitious and encouraging approach to face the challenge ahead: the Master in Nuclear Engineering and Applications (MINA).

2. Objectives and scope

MINA is born as a multi-academical Master defined in close collaboration with nuclear industry and Academy to fill the existing gap between graduates and nuclear professionals. This entails to provide students with an exhaustive and extensive vision of the disciplines involved in the current and future applications of the nuclear technology, without giving up fundamentals. Three specific objectives have been set:

- To review fundamentals of nuclear technology
- To deepen in subject of burning importance for present nuclear technology.
- To draw up current and near-, mid- and long-term applications of nuclear technology.

MINA is to last around 1500 hours (the first edition will extend from October 2008 to June 2009). One third of that duration (around 500 h) will be allocated to develop an individual project many of which will be supervised by the Industry. This is a major feature of MINA, usually referred to as a “project-driven” master.

3. Fundamentals

Four are the pillars of MINA: professional projection, integral approximation, sector integration and educational excellence.

3.1 Professional projection

A professional profile in terms of sound skills required in a nuclear professional has been defined by the Spanish nuclear sector. By surveying companies, utilities, agencies, etc. in the nuclear sector, several subjects have been scored as shown in Figure 1. MINA will ensure a background according to this profile, so that master graduates become attractive to any organization involved in the nuclear business.

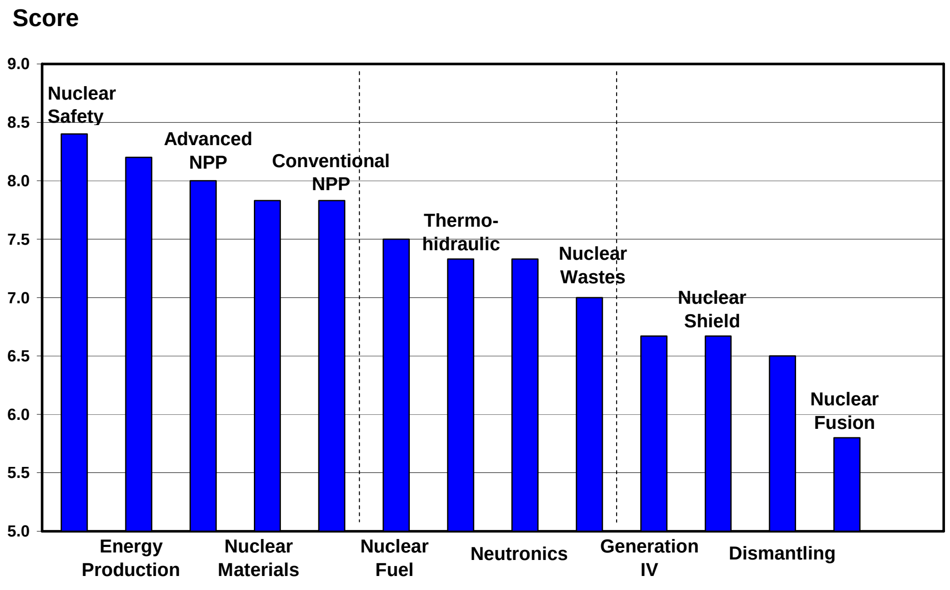

Figure 1. MINA target-profile

3.2 Integral approximation

MINA has high expectations both at the input of the education and training process (i.e., a high interest in last-year university students) and at the output (i.e., a high employment rate in the nuclear sector). To achieve it a sound and global involvement of the nuclear sector in all the elements shaping MINA (i.e., thematic structure, active participation in the training activity and logistic provision) is necessary. The final goal pursued is to turn MINA into a profitable investment for nuclear industry. The strategy followed is depicted in Figure 2 (the lines thickness indicates qualitatively the contribution weigh of industry, institutions and Academy, both in definition and in funding).

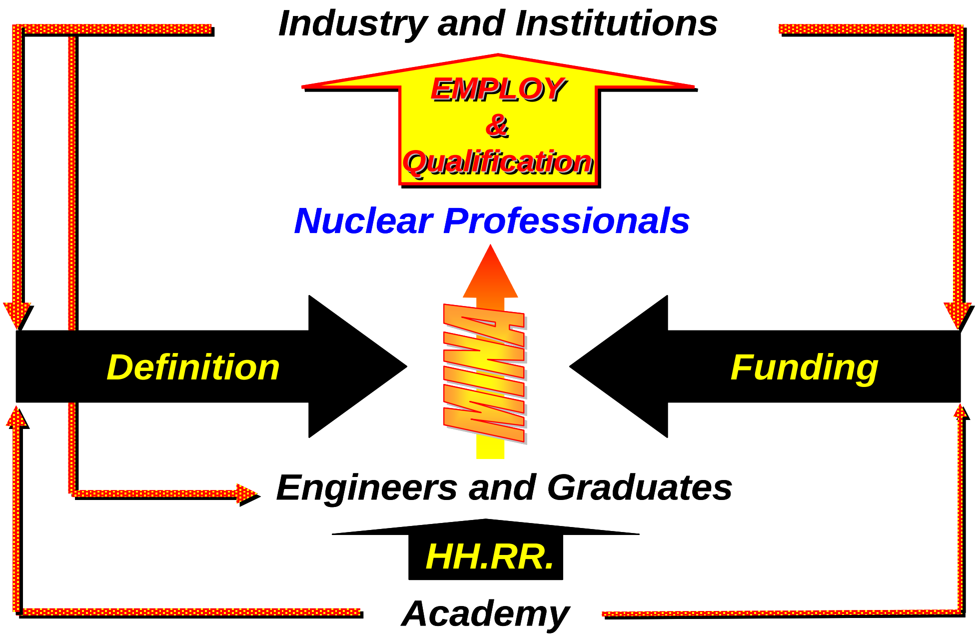

Figure 2. Integral approximation of MINA

3.3 Sector integration

An advisory committee set up by members of Academy and nuclear sector will provide recommendations and suggestions to MINA. Such an activity is to be integrated in the Spanish Technological Platform on Nuclear Fission (CEIDEN), that coordinates the different plans and national programs and the participation in the international programs of R+D. Figure 3 shows this link between CEIDEN and MINA. As shown all kind of organizations participate in the detailed definition of MINA (i.e., thematic areas).

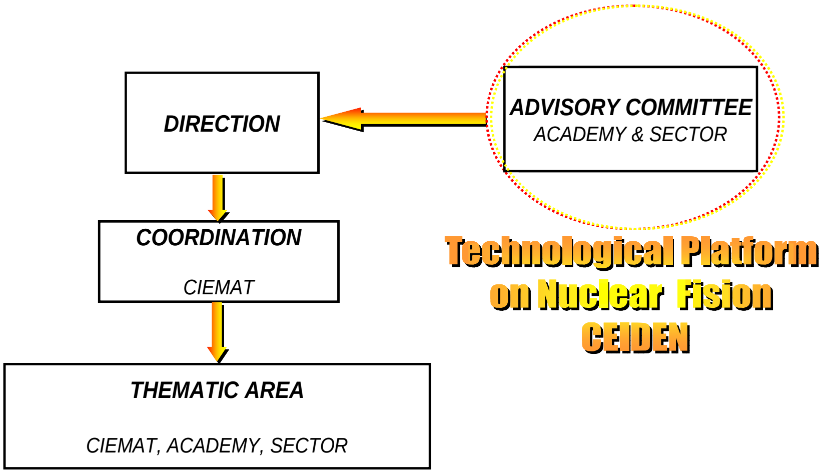

Figure 3. Relation of MINA and CEIDEN.

3.4 Excellence in education and training

Excellence is pursued by means of (Figure 4):

- Multiple participation. All kind of organizations (Academy, Industry and Institutions) will be involved in teaching.
- Distributed dedication. Institutions involvement will be selective. Thus, most of Academy weight will be linked to Fundaments and, to less extent to Technologies and Applications. On the contrary, Industry will be mostly focused on Applications. CIEMAT, as a technological research organization, will have a practically uniform contribution in all the areas, acting as a buffer between Academy and Industry.
- Thematic specialization. Each participant will highlight areas of knowledge and know-how where they have a preferential position. This has allowed identifying group leaders in the definition of subjects.

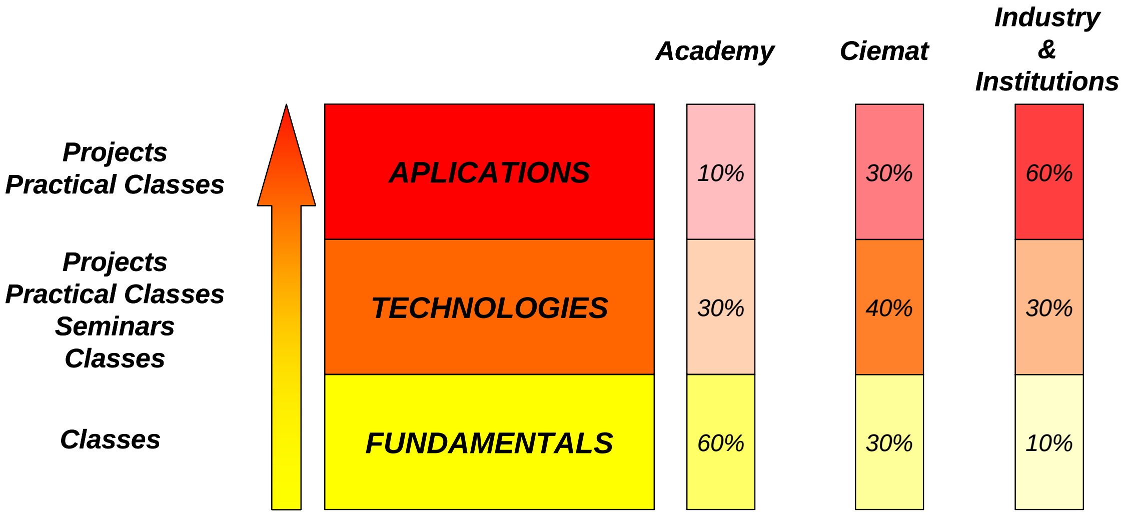

Figure 4. Organizations share in MINA.

4. Structure and approach

The MINA structure relies on three main elements:

- Theoretical lectures (750 h.). They will be focused on introducing concepts and methodologies. These classes will be supplemented with specific seminars given by acknowledged national and international specialists.
- Laboratory sessions (250 h.). Experimental technologies and/or methodologies of analysis in different areas of the Nuclear Technology will be handled. They will supplement the theoretical lectures of the main subjects.
- Final Master project (500 h.). It is the key part of MINA. A set of projects will be defined beforehand by the sector at the beginning of each MINA edition, so that contents of subjects can be adapted to enable students to face with the project challenge. All the projects will be supervised by a tutor.

According to the MINA profile outlined in Figure 1, the master subjects have been categorized as follows:

- Burning topics. Considered both fundamental and of an unquestionable relevance nowadays, they will be granted with the highest number of lecturing time (75 h).
- Fundamental topics. Essential for a sound nuclear engineering background, they will be given a high importance in the lecturing time allocation (50 h).
- Supplementary topics. Farther in the temporary horizon, their extension will be less than the above ones (25 h).

The individual contents of the subjects have been already developed. A group of experts was set up (each one integrated by Academy, nuclear sector and CIEMAT) where leadership was always given to an acknowledgeable organization on the matter. Once the individual contents defined, a review committee entrusted to guarantee avoidance of unnecessary overlapping and essential contents missing. This is sketched in Figure 5.

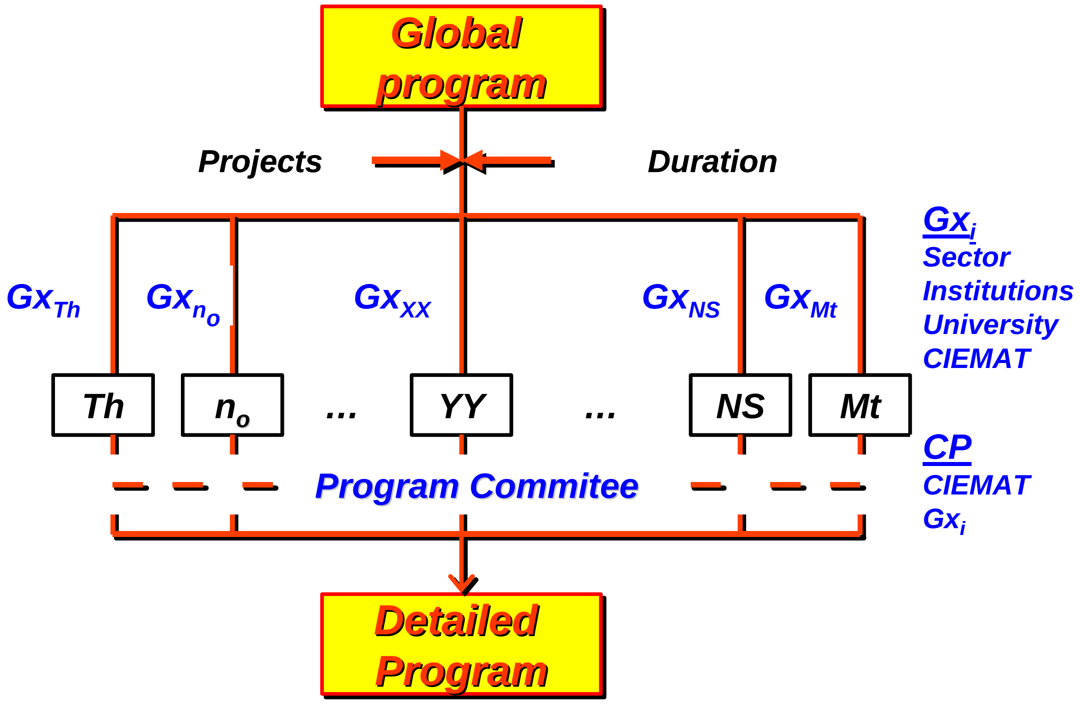

Figure 5. Protocol to define contents of the MINA subjects

5. Current status

MINA is presently ready to be submitted to several Spanish universities for their official acceptance as a master. At the same time a broad announcement campaign is about starting through different means, both in Spain and other Spanish speaking countries overseas. One of the means that will be put in place in the upcoming months is the MINA presentation to last-year students of Faculties and Polytechnic Schools with any link to nuclear technology.

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INDUSTRY-UNIVERSITY COLLABORATION: THE AECL-CRSNG-POLYTECHNIQUE COLLABORATIVE RESEARCH AGREEMENT

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ABSTRACT

The Natural Sciences and Engineering Research Council of Canada, an agency of the government of Canada, has a program of Collaborative Research and Development Grants for approved industry-university agreements. In the context of this program, application was made and a grant received for a three-year collaborative research agreement on “Advanced CANDU Reactor Computational Reactor Physics” between Atomic Energy of Canada Limited and the Institut de génie nucléaire at École Polytechnique de Montréal. Here we describe how this collaborative research and development agreement works. We also present some of the constraints both for the university and for the industrial partner, resulting from the presence of the Natural Sciences and Engineering Research Council of Canada as a major player in the agreement. Finally we discuss the major milestones achieved with this agreement that has now reached its conclusion.

1. Introduction

The Natural Sciences and Engineering Research Council of Canada (NSERC) is an agency of the government of Canada that supports university research in science and engineering through scholarships for graduate and postdoctoral students as well as research grants to university professors. Research projects involving partnerships among universities, governments and the private sector are also supported by this agency through various programmes including the “Collaborative Research and Development” (CRD) program for industry-university agreements.[1] This program is aimed at supporting financially well-defined research projects involving university researchers and their industry partners. The direct total costs of the project are shared by NSERC in the form of a research grant to the professors and the industrial partner from whom the funds may come in the form of research funds or as in-kind contribution (engineers’ time for example).

Atomic Energy of Canada Limited (AECL), the designer of the CANDU family of nuclear reactors and the industrial partner in this research agreement, is currently developing the Advanced CANDU reactor (ACR).[2,3] This Generation III+ reactor that AECL is proposing to the national and international market is being designed to adhere to very strict requirements both from the point of view of safety and of performance. These requirements have a large impact on the modelling of the reactor. For example the reduction in the lattice pitch from that in the standard CANDU-6 and the use of fuel bundles containing enriched uranium and burnable poisons with light-water coolant (the CANDU-6 is fuelled with natural uranium and cooled with heavy water) all have a large impact of the neutron flux distribution inside core. The intensity of the research effort required by this new design spans many domains of nuclear engineering, including reactor physics, where the validity of the tools used for CANDU-6 design and operation can be questioned.

Recognising this research opportunity a group of professors at Institut de génie nucléaire (IGN) of École Polytechnique de Montréal and research scientists at AECL decided to set up a collaborative research and development agreement on the physics of the ACR. The first component of this agreement consisted in analysing the physics of the ACR using the reactor physics computer software developed at the IGN and comparing these results with those obtained by AECL using their own tools and methods. The second and more research-based component of the agreement was related to the development of advanced methods in the IGN software, which will provide more reliable safety analysis tools than those currently available. Work on the research program began in December 2004, and will be completed in May 2008.

The main interest for École Polytechnique is in the research and development area as well as in providing high-quality training to students. However, another important mission for École Polytechnique is the transfer of technology to the industry of advances made in research and development, in particular in the form of computer programs and mathematical methods for application to reactor physics. From the point of view of AECL, in addition to increasing its effective research efforts, bright students working on this research will eventually be the “new blood” that fuels AECL future research capabilities.

In Section 2 of this paper we provide a general description of the NSERC collaborative research and development agreement as well as the constraints for each of the partners of the agreement. A description of the ACR project can be found in Section 3, while in Section 4 we present the major achievements in research and development resulting from this agreement. Finally, in Section 5, we conclude.

2. NSERC collaborative research and development agreement

The general objectives of this NSERC grants program are set forth in this paragraph:

> “The Collaborative Research and Development (CRD) Grants program is intended to give companies that operate from a Canadian base access to the unique knowledge, expertise, and educational resources available at Canadian postsecondary institutions and to train students in essential technical skills required by industry. The mutually beneficial collaborations are expected to result in industrial and/or economic benefits to Canada.”[1]

This statement illustrates well the two main mandates of NSERC: to ensure the formation of highly qualified personnel and the transfer of knowledge and technology from the university to the industry.

These objectives are made even clearer in the grant proposal that the industry-university team must fill out. In addition to providing a detailed plan of the work to be performed based on a direct collaboration of personnel from both institutions, the number of graduate students involved in each subproject must be clearly identified. These grants are generally used to cover research agreements that last from 3 to 4 years.

The transfer of knowledge and technology to the industry is controlled by a “Policy of intellectual property” (PIP) that must be signed by all parties and accepted by NSERC. NSERC does not participate in research contracts with industrial partners that expect to gain total control of the work performed by the university personnel and their students. The PIP must include permission to publish significant advances in science and technology in the open literature. Students and professors remain free to disseminate their results, use it in their teaching, and defend theses. On the other hand, the industry is protected against unauthorized or untimely divulgation of proprietary information. A publication agreement must be included with the proposal that describes the procedure and the maximum period of time for revision of papers to be submitted for publication.

The main advantage that the industry-university partnership obtains from such a collaborative agreement is that NSERC contributes to the university an amount in cash that is equivalent to the amount invested by the industry. As a result, the industry doubles the impact of its own contribution to the research effort. The contribution in cash from the industry must represent a minimum of 50 % of the total amount requested from NSERC, the remaining contribution being provided in-kind (instruments, software, or engineers' time). Note that because of NSERC rules, the industry is also assured that both its contribution and that of NSERC are really directed towards the research effort, since these funds can only be spent on financial supports for students, travel fees for conferences and meetings, and only marginally on scientific equipment.

As with all NSERC grant applications, the quality of the proposal is evaluated by an international peer review panel that judges the grant request using six criteria: 1) the scientific merit of the proposal to generate innovative ideas; 2) the research competence of the university team to carry out the work with success; 3) industrial relevance, where the company must demonstrate the expected benefit for the Canadian economy; 4) private-sector support including the cash and in-kind contribution; 5) contribution to the training of highly qualified personnel including the number of M.Sc. and Ph.D. students and postdoctoral fellows involved in the project, as well as research associates and company personnel; and finally 6) the economic, social and environmental benefits to Canada.

Once the proposal has been accepted by NSERC, the grant is given on a yearly basis, based on the success of an annual evaluation of the progress of the work by the industrial partner. The university team also prepares an annual progress report and a final project report.

3. CRD Project for the ACR

The objective of this CRD project is to provide AECL with an alternate set of computational tools, namely the lattice code DRAGON[4] and the finite-reactor code DONJON[5], developed at École Polytechnique de Montréal, for the design and analysis of the ACR. The main goal to be achieved consists in evaluating and using these tools, and determining the biases and uncertainties in the neutronic behaviour of the core resulting from the application of the AECL standard toolset.[6,7] The project is subdivided into three main components that we now describe.

3.1 Computational schemes for the ACR core and for ZED-2 critical experiments

This part of the project is mainly devoted to the production and validation of various computational models to be used as input to the DRAGON and DONJON codes. These models are defined in terms of physical quantities and engineering data and the calculation procedure that consists in selecting the sequence of calculations to be performed, as well as the numerical methods to be used for each calculation step.

Here, the goal is to propose a series of more or less refined ACR computational schemes, to analyze the ACR core using the codes DRAGON and DONJON and to select an optimal model that can be used for safety analysis. Typical refinements in the full reactor model involved different group structures and spatial discretisation levels for the DONJON core calculation. Finite difference, finite element and nodal solutions to the diffusion equation have also been considered. Similarly, the selection of an optimal lattice model for the ACR is based on an extensive survey of the effect of lattice discretisation on resonance self shielding and flux and burnup calculations that were performed using DRAGON. These

results were compared with reference AECL calculations based on the codes WIMS-AECL[6] and RFSP[7] and differences between the AECL and IGN codes explained and resolved.
The ZED-2 facility at AECL's Chalk River Laboratories is a research reactor that is used to measure criticality and fine-mesh flux distributions in cores simulating the ACR lattice. These experiments were modeled using the codes DRAGON/DONJON, and the code biases for this type of lattice were evaluated.

3.2 ACR Physics Studies

This project deals with specific physics studies performed for the purpose of obtaining a better understanding of the physical phenomena taking place in the ACR core. These studies also serve to further refine the DRAGON/DONJON computational schemes developed in the above studies and to evaluate the domain of validity of our models and methods.

The first part of the study deals with the coolant void reactivity (CVR), which represents the change in core reactivity resulting from the removal of coolant from the core. In principle, both positive and negative values for the CVR in the ACR can be obtained depending on the fuel enrichment, burnable-poison content, lattice pitch and cell environment. A negative full-core CVR is a design requirement in the ACR, to increase the passive safety features of the reactor. Discrepancies were observed when comparing the CVR computed using WIMS-AECL and DRAGON. These were traced back to differences in the leakage and resonance self-shielding methods used by the two codes. This led to a comprehensive study of the DRAGON and WIMS cell calculations using different resonance self-shielding and leakage models. Finite-reactor sensitivity studies for the CVR are also required because changes in macroscopic leakage also play a role in establishing a negative CVR.

An important postulated accident scenario for ACR safety studies is the loss-of-coolant accident (LOCA). In the case where the CVR is negative, a loss-of-coolant accident leads to a reduction of the core reactivity and hence in a reduction in power. Nevertheless, even after this reduction in the core reactivity, there is still a considerable amount of energy produced in the fuel that is no longer extracted by the coolant. This could lead to an increase in the fuel temperature and possible fuel failures if the shutdown systems do not intervene rapidly. The main question to be answered is whether or not the reactor safety system can detect this accident sufficiently rapidly and shut the reactor down before severe consequences to the core integrity ensue.

3.3 Developments in DRAGON and DONJON

The project dealt with improvements in the codes DRAGON and DONJON to increase their ability to deal with the complex physics of the ACR core. Several new features to be implemented in these codes were considered including:

1. A multigroup analytic nodal model with discontinuity factors in DONJON/NDF.
2. A fuel-management optimization procedure that takes into account exit burnup, fuel enrichment and burnable-poison concentration.
3. A multi-parameter reactor database to store and retrieve all the nuclear data produced by the lattice code.
4. New models in DONJON including a Thomas-Raviart finite-element solution of the diffusion equation and a SPN transport-solution approach.
5. A HELIOS[8]-like subgroup approach to resonance self-shielding calculations in DRAGON.
6. 3-D modelling capabilities in DRAGON that are able to treat assemblies of clusters.

4. Major Achievements

A total of five professors and research scientists from the IGN and four engineers from AECL were involved at one time or another in this research project. In addition, the CRD was used to support three postdoctoral fellows, four Ph.D., five M.Sc. and four undergraduate students.

The scientific output of this collaboration is also important. A large number of internal reports describing the progress of the work were produced in addition to four articles published in Conference Proceedings, with three more accepted for future conferences, plus four papers (three published or accepted and one being prepared) in scientific journals.

Other benefits of this work include:

1. A more profound understanding of the ACR and indirectly of the CANDU-6 physics gained by all the participants.
2. The codes DRAGON and DONJON developed at the IGN have now been tested on very difficult reactor-physics problems and have performed very well.
3. The experience gained in using our set of codes for the simulation of physics experiments on the ZED-2, including foils-activation analysis.
4. The new models we developed in our codes were also applied to CANDU-6 analysis and are already being used in the industry for safety analysis.
5. The number of new students that were attracted in our nuclear engineering programme because of this project.
6. The number of students supported by this grant that are now pursuing their studies in the reactor-physics field or working in the industry.

This project also increased substantially the level of collaboration between AECL and École Polytechnique. Meetings with presentations in an informal setting helped the various participants understand their respective position from the point of view of simulation needs and the quality of the results generated.

5. Conclusions

We feel that the AECL/NSERC/Polytechnique collaborative research and development project for the ACR that was undertaken has been very successful and that it has achieved all of its goals. The research efforts, which are required to put on the market a new reactor, have been increased substantially by this collaboration. The goal of forming a large number of highly qualified personnel for the industry has been reached. Finally the modifications in the analysis tools that were the result of this common development effort of the industry and the university have improved the physics codes available for next-generation reactors as well as for current reactor designs.

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UNIVERSITY-BASED NUCLEAR EDUCATION AND RESEARCH IN THE UK

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ABSTRACT

The announcement in January 2008 by the UK government to encourage private operators to build a new fleet of reactor has been widely anticipated. There has been a reinvigoration of nuclear education and research in the university sector, supported by both the research councils and the nuclear industry. The recent developments in higher education and university-based research are described. This includes a description of the national NTEC university research consortium which offers Masters-level education in Nuclear Science & Technology, and the Nuclear Engineering Doctorate programme which is run in partnership with the industry.

1. Background

Before discussing the current direction of university-based nuclear education and research in the UK it is worthwhile taking a retrospective look at recent history to appreciate where we have come from.

In the 1970s the public sector investment in nuclear fission R&D was approximately £500m per year. This included expenditure on all aspects of the nuclear fuel cycle including development of the fast reactor to provide energy security for the UK which was truly at the cutting edge of nuclear development. Much of this R&D expenditure was concentrated into The UK Atomic Energy Authority (UKAEA) and with British Nuclear Fuels Ltd (BNFL) formed to take forward industrialisation of the fuel cycle.

In the 1980s the situation changed with the discovery of North Sea Gas and the Chernobyl accident. These events subsequently resulted in the UK moving away from its commitment to nuclear energy in terms of energy security. In the 1990s with the Department of Energy subsumed into the DTI, a decision was taken to split UKAEA and privatise those parts of the Authority considered appropriate for commercialisation.

This led to significant fragmentation of the skill base with many nuclear R&D facilities closed and consolidated. The “strategic blueprint” for investment in nuclear R&D was lost which subsequently led to a reduction in university based nuclear engineering and research. Private sector organisations that secured parts of the UKAEA’s nuclear capability moved into new markets and there was little investment in provision of long-term nuclear skills. Nuclear R&D was also not the remit of the UK’s Academic Research Councils and by the end of the 1990s public sector investment in nuclear fission R&D had declined to virtually zero with only roughly £1m per year invested. Effectively, there had been a year-on-year decline since the hay-day in the 1970s. At the same time, university nuclear engineering research groups were in decline and by 2000 there was not a single undergraduate degree programme in the UK with the word “nuclear” in its title.

BNFL were first to appreciate the imminent loss to the UK of expertise in some key technology areas. Towards the end of the 1990s/early 2000s BNFL established four University Research Alliances dedicated to supporting critical areas of capability needed to support its business operations. These Alliances not only performed R&D to support the industry but were also designed to have critical mass of capability. Without these centres UK nuclear capability in universities had distilled down to only singleton expertise which would disappear when individuals retired. The four centres established by BNFL to redress the situation were in Radiochemistry (Manchester University), Particle Technology (Leeds), Waste Immobilisation (Sheffield) and Materials Performance (UMIST). Manchester University and UMIST have since merged to form The University of Manchester. These centres were designed to have a critical mass size of approximately 30 people (staff and researchers) in each centre. This approach also meant BNFL was able to consolidate its vast portfolio of academic research into a few key universities and build strength where needed.

In 2002/3 BNFL worked with the Research Councils which also recognised their role in supporting the skills base in light of the Government Energy policy to keep the nuclear option open. The skills issue was also recognised by the DTI which published its Coverdale Report [1] in 2002 that concluded “the sector will require 50,000 recruits over the next 15 years, excluding potential for new build”. Of those recruits, it was estimated that about 1,000 per year would be graduates from university physical sciences and engineering degree courses.

BNFL had therefore by default assumed the role of “national champion” with responsibility for the sustainability of the skills base. In particular they were instrumental in encouraging the research councils to recognise their own responsibilities in supporting university-based postgraduate nuclear education and research, and progress in this direction in the last four years as been remarkable. However with the advent of the Nuclear Decommissioning Authority in 2005, BNFL recognised it would be under much tighter commercial pressure and therefore unable to support skills and R&D in the interest of the UK as a whole. Therefore the responsibility for the custody of the UK’s skills base was transferred to the NDA whose principal focus is the safe decommissioning and clean up of the UK’s nuclear legacy.

2. University education in the UK

Figure 1 shows a simplified nuclear education ladder for the UK. The pre-university rungs of the ladder (Schools, national vocational qualifications, foundation degrees) comes within the remit of the National Skills Academy for Nuclear (NSAN) with regional centres based near concentrations of nuclear activity. National Skills Academies are an initiative of the UK Government to enable hands-on involvement by employers in the design and delivery of skills. The NSAN aims to create, develop and promote world class skills and career pathways to support a sustainable future for the UK nuclear industry. The construction of the first regional node of the academy is underway in West Cumbria referred to as The Nuclear Academy.

The top half of the ladder belongs to the higher education institutes (universities) and covers undergraduate degrees, MSc programmes and doctoral research degrees (Ph.D., D.Phil., Eng.Doc.). The undergraduate degrees include 3-year "bachelors" degrees (B.Eng., B.Sc.) and 4-year undergraduate-masters degrees (M.Eng., M.Phys., etc.). Students on the 4-year degree have to satisfy certain academic criteria at the end of their second year to be allowed to progress. Otherwise they must transfer to the Bachelors programme. PhD students are normally recruited directly from M.Eng. and M.Phys. graduates.

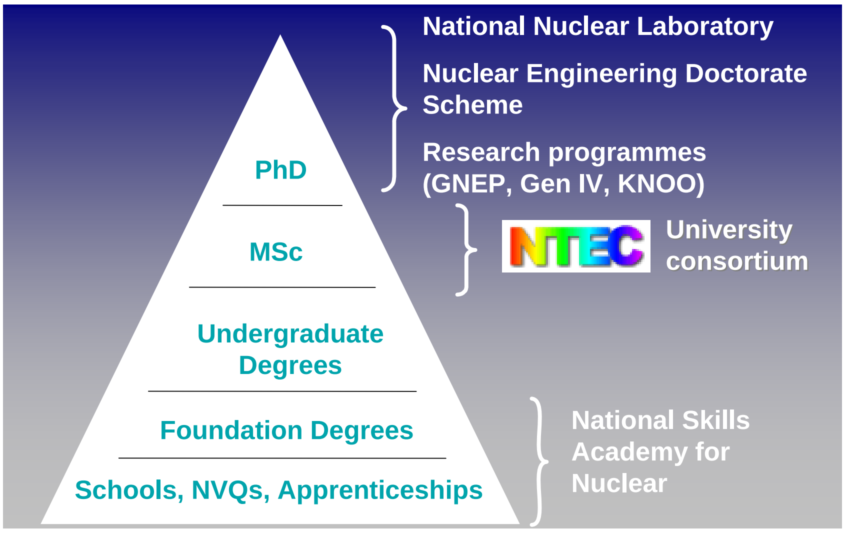

Figure 1. The educational ladder in the UK

The UK MSc degree serves a different purpose to the European Masters. It is a one-year programme (48 weeks duration rather than two semesters, and equivalent to about 75 ECTS) which can be used by students wishing to move across into a different field. Thus students from general engineering or physical science undergraduate degrees can acquire the necessary nuclear knowledge from an MSc programme to allow them a favoured route into the nuclear industry or to start PhD research in a nuclear-related area. There is little enthusiasm in the UK to make the MSc Bologna-compatible.

A recent survey of nuclear-related programmes offered by UK universities at undergraduate and postgraduate levels is available from the Dalton Nuclear Institute website [2]. It shows only one university offering undergraduate nuclear engineering (Lancaster University) although there will soon be more universities offering nuclear engineering options within their existing degree programmes. At MSc-level the choice of nuclear engineering programmes has traditionally been between courses offered by the Nuclear Department, HMS Sultan, and Birmingham University's MSc in Physics & Technology of Nuclear Reactors, a programme that has been running for over half a century.

3. New initiatives

The declining trend in university nuclear education and research has been effectively reversed in the last five years by a series of key initiatives taken by the Engineering and Physical Sciences Research Council (EPSRC). These initiatives are summarised below:

- £1m to establish the Nuclear Technology Education Consortium (NTEC) involving 11 Higher Education Institutions coordinated by the Dalton Nuclear Institute at The University of Manchester.

- £5m for an Engineering Doctorate programme in nuclear technology coordinated by the Dalton Nuclear Institute at The University of Manchester in partnership with Imperial College with support from four other universities with specialist capability.

- New research programmes: £6m for "Keeping the nuclear option open" which involves a large consortium of UK universities with Imperial College as Principal Investigator; £2.3m for "Sustainability assessment of nuclear power" involving the universities of Manchester, City and Southampton; £4m for "Nuclear waste management and decommissioning.

- £0.5m support to initiate two new Chairs in Radiation Sciences and Decommissioning Engineering at the University of Manchester.

- Establishment of the "Letter of Agreement" group which is a grouping of lead nuclear industry players (Nexia Solutions, NII, MoD, AWE, NDA) led by the EPSRC which looks for means to support and invest in nuclear R&D and skills issues common across the industry

3.1 NTEC – the Nuclear Technology Education Consortium

A single proposal was invited by EPSRC from a consortium of higher education institutes to bid for a stand-alone Collaborative Training Account. The proposal was to offer broadly-based Masters-level nuclear education in a format that could be used as part of a degree programme or taken by those already in industry for their professional development. The outputs from the various skills surveys were used to define the scope of the programme. It was much wider than a conventional nuclear engineering programme - one of the surveys had identified 18 essential skill areas across the main subjects of: Chemistry, Materials, Engineering, Physics, Earth Sciences, and Socio-economics that would be needed to support the government's nuclear power policy. The large proposed consortium of nine universities and two HEIs contained expertise across all these areas. Partners would teach to their particular strengths but would not be required to teach material they were less familiar with.

The module syllabuses were designed after extensive discussions with the nuclear industry and regulators. These involved a sector skills council survey carried out by Cogent, an Industry Day at Manchester and many follow-up one-to-one meetings with individual companies. Twenty-three letters were received from the industry to support the funding application to EPSRC. The bid was successful and the programme was launched in September 2005. The NTEC portfolio currently contains 21 modules providing for pathways in "Nuclear Technology" and "Decommissioning". Details can be found on the NTEC website [3]. The programme is accredited by the Institution of Mechanical Engineers and other learned societies. The “short-course” format of each module is designed particularly for those already in industry. They need only be away from their place of work for the one week’s intensive direct teaching. Pre-module preparation and a post-module assignment and exam are done in the students own time in evenings or week-ends. From September 2008 the core modules will be offered in an alternative “distance-learning” format with an identical syllabus and learning outcomes.

3.2 Nuclear Engineering Doctorate

The Engineering Doctorate scheme is EPSRC’s flagship scheme for doctoral training. They invited a consortium bid for a new programme in nuclear technology. This was awarded in September 2006 to a consortium led by the University of Manchester in partnership with Imperial College London which included the universities of Bristol, Leeds, Sheffield and Strathclyde [4]. The objective of the Eng.D. scheme is to provide outstanding young Research Engineers with intensive, broadly based training in collaboration with industrial companies so that they are equipped to take up senior roles within the nuclear industry. In addition to obtaining a high quality qualification, the Research Engineers gain experience of working in an industrial research and development environment. The four year programme involves the Research Engineer being based within an industrial company in the UK. The programme comprises four elements: a doctoral-level project of portfolio of projects; a Diploma in Enterprise Management; taught technical modules; and a professional development programme. The programme scope was defined by the research council to cover reactor technology, waste management, decommissioning, materials, and socio-economic aspects.

3.3 Research programmes

University-based research groups can only thrive if there are able to win funded research projects. This is looking more promising now than at any time in the last twenty years. The UK government is creating the National Nuclear Laboratory to protect the skills of Nexia Solutions. The National Laboratory and the facilities at the British Technology Centre, as well as research council funding, will provide universities with new research opportunities, and the future looks rosy. None of the new initiatives from the research council would be possible without the existence of close partnerships between university groups and the industry.

4. Acknowledgements

The author thanks Mr Warren Richards, Business Manager, Dalton Nuclear Insitute, for his help in preparing this manuscript.

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THE KARLSRUHE NUCLIDE CHART:
AN EDUCATIONAL TOOL FOR THE NUCLEAR SCIENCE COMMUNITY

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ABSTRACT

A new 7th edition of the Karlsruhe Nuclide Chart was published in 2006. For almost 50 years, it has provided scientists and students with structured and accurate decay data on all known radionuclides. The Chart is of great didactic value in education and training in the nuclear sciences and provides a record of scientific progress on the discovery of new elements, nuclides, and decay modes.

1. Introduction

The Karlsruhe Nuclide Chart (KNC) is a unique tool for the nuclear science community that presents structured and accurate information on the radioactive decay of nuclides. In the 1950s, in order to meet the demand for professional training and education in developing fields of nuclear engineering and radiochemistry, the Radiochemistry Institute in the Karlsruhe Nuclear Research Centre held courses on radiochemical isotopes. The Karlsruhe Nuclide Chart was created within the scope of this teaching activity. Through the successive editions dating back to 1958, the chart has evolved to reflect scientific progress and breakthroughs. The discovery of new elements, modes of decay, and nuclides far from the stability region is reflected in the various chart editions. The latest 7th edition (2006) [1,2] contains new and updated decay data on 619 nuclides.

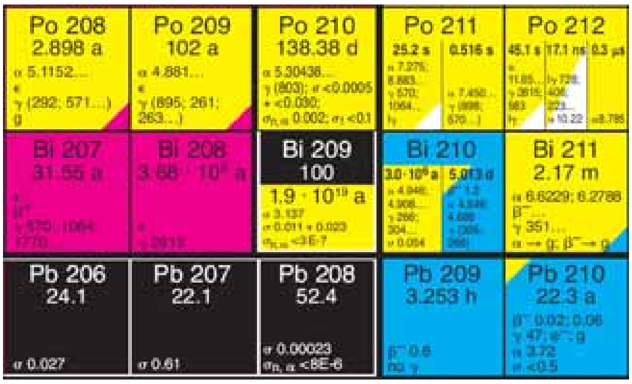

Fig 1. Section of the Karlsruhe Nuclide Chart, revised 7th edition 2007.

The Karlsruhe Nuclide Chart is based upon the proton-neutron model of the nucleus and is basically a plot of the number of protons versus the number of neutrons in stable and unstable nuclei. In contrast to many other data compilations and databases [3] which include calculated or theoretically predicted values, the data in the Karlsruhe Nuclide Chart is based primarily on experimental work. For example, nuclides are included in the chart only if the half-life or the mass has been measured or the nuclide has been clearly identified. As the chart was not developed for a specific purpose and with specific data needs (e.g. nuclear reactor community), the presented data is of general use in health physics and radiation protection, nuclear and radiochemistry, nuclear medicine, astrophysics, etc.

The current 7th edition [1,2] contains nuclear data on 2962 experimentally observed nuclides and 692 isomers. The accompanying brochure includes a history and overview of nuclear science. The multi-lingual "Explanation of the Chart of the Nuclides" has been extended from the original four languages (English, German, French, and Spanish) to include Chinese and Russian. Recently, a KNC wiki page [2] has been created to provide users with additional information. A dedicated forum is also available [1], and a FAQ page is under development.

2. Use of the Karlsruhe Nuclide Chart: some examples

Each nuclide is represented by a box containing basic nuclear data as shown in Figs.1 & 2. This data is composed of general decay data with half-life, decay modes and energies of decay radiations.

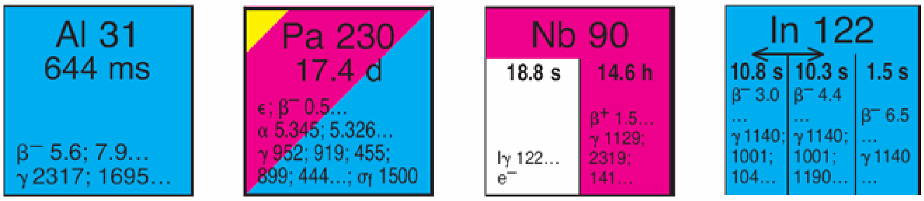

Fig 2. Nuclide representation in the Karlsruhe Nuclide Chart.

An important characteristic of the boxes is the use of colours to denote the modes of decay. There are in total 9 main decay modes, namely proton (orange), α (yellow), β^- (blue), neutron (light blue) and cluster emission (violet), β^+-emission and ε electron capture (both red), spontaneous fission (green) and isomeric transition (white). Some of these modes can have multi-particle emission. As a result of the decay process, a daughter nuclide will result. The main radioactive decay processes are shown in Fig. 3.

The branching ratios of the decay modes are not given explicitly in the chart, but are indicated by the relative sizes of the coloured areas. Pure decay modes, with a branching ratio of 100%, are indicated by a single colour. For nuclides with two decay modes, a small triangle indicates a branching ratio smaller than 5%, for example 2.5% or 10^{-7}%. The major mode has conversely a branching ratio greater than 95%. If the branching ratio of the minor mode is in the range 5 to 50%, and that of the major mode in the range 50 to 95%, the box is divided into two equally sized triangles. Three decay modes are also possible, with similar minor decay mode conventions.

The types of radiation emitted (e.g. α, β^-, etc.) are presented on the chart together with the energies of the most important emissions. The main gamma lines are presented in order of decreasing probability. Where the γ corresponds to a transition following β-delayed particle emission, the γ-energy is followed by an asterisk.

Some examples of nuclides from the KNC are shown in Fig. 2. The first nuclide shown, ^{31}Al (denoted "Al 31" in the nuclide chart), has a half-life of 644 ms. The colour blue indicates β^- decay. The fact that the box is entirely blue implies that the branching ratio for β^- decay is 100%. The β^- particle energies with the highest emission probability (5.6 MeV) and highest end-point energy (7.9 MeV) are given. These particle emissions will generally lead to daughter nuclides in excited states which de-excite through gamma emission. The resulting gamma energies are shown in order of decreasing emission probability, i.e. 2317 keV and 1695 keV. Since they result from β^- decays, these gammas are associated with the parent ^{31}Al rather than the daughter.

The second nuclide shown, ^{230}Pa, has a half-life of 17.4 d. The three colours indicate three modes of decay: yellow: α-decay, red: ε/β^+-decay, and blue: β^--decay. The small yellow triangle indicates that the α-decay branching ratio is less than 5%. The red and blue coloured regions indicate branching ratios greater than 5% for electron capture ε (red colour) and β^- emission (blue colour). The fact that electron capture has a higher branching ratio than β^--decay is indicated by the text "ε; β^-" (i.e. electron capture is first, β^- second).

The third nuclide, ^{90}Nb, shows another feature - an isomeric state of the same nuclide. The ground state (14.6 h half-life) is located on the right hand side and the isomeric metastable state (18.8 s half-life) to the left. The ground state, which is coloured red, decays by positron emission (β^+) with a branching ratio of 100%. The metastable state ^{90m}Nb decays by isomeric transition Iγ (indicated by white) also with a branching ratio of 100%. Emission of conversion electrons, denoted by e^-, is specified only if the emission probability for electrons is higher than that of the gammas. This is the case for ^{90m}Nb. Note also that metastable states for isomeric transitions are only indicated if the half-life is greater than 1 s.

The fourth nuclide shown in Fig.2, ^{122}In, is an example of a nuclide which has more than one isomeric state. ^{122}In has two metastable states indicated by ^{122m1}In and ^{122m2}In. All three states i.e. the ground state and the two isomeric states decay by pure β^- emission indicated by the colour blue. Where there is uncertainty on the assignment of the properties to a particular metastable or ground state, this is indicated by the double arrow shown in Fig. 2.

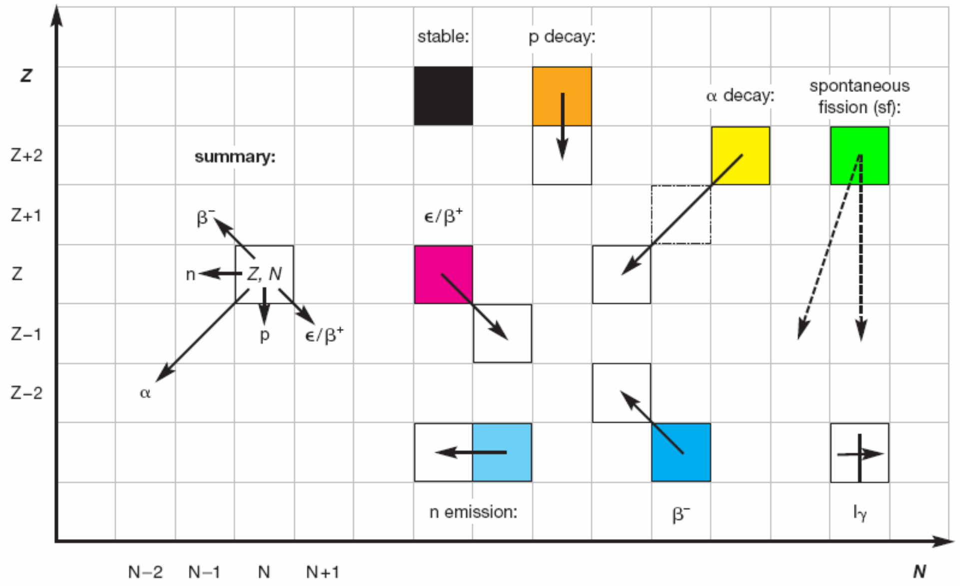

Fig 3. Radioactive decay processes on the nuclide chart. A nuclide parent with coordinates Z, N transforms to a daughter nuclide through the decay processes shown [1,2].

3. The Karlsruhe Nuclide Chart: A Record of Progress in Nuclear Science

Since the discovery of natural radioactivity by Becquerel in 1896 and isotopes by Soddy in 1913, improvements in scientific techniques have led to the discovery of artificial elements, new nuclides and decay modes. This progress has been reflected in the various editions of the KNC as shown in Fig.4. Some examples are described in the following sections.

3.1 New Elements and Nuclides

The first transuranium elements were synthesized with successive neutron capture reactions in long-term irradiation in high flux reactors [4]. Through the work of Seaborg and colleagues eight artificial elements with Z = 93 (Neptunium)-100 (Fermium) were produced in the period up to around 1955. Elements heavier than Fermium were synthesized using projectiles of ions (see below) which resulted in "hot" compound nuclei which then decay via neutron and gamma emission. In general, these "hot" compound nuclei undergo fission into two fragments - neutron emission occurs only in about 1% of the reactions. The synthesis of elements heavier than 106 (seaborgium Sg) became possible only after the discovery of the so-called "cold-fusion reactions". In these reactions, targets of "magic" nuclei, e.g. ^{208}Pb and ^{209}Bi, were bombarded by ions heavier that argon. The resulting compound nucleus, which has a much lower excitation energy, decays through the emission of one or two neutrons.

Element 101, Mendelevium, the ninth transuranium element to be discovered, was first identified in 1955 as a result of the bombardment of ^{253}Es with helium ions. Sixteen isotopes of Mendelevium are listed in the latest edition of the KNC. *Element 107*, Bohrium: In 1976 scientists at Dubna announced they had synthesized the element by bombarding ^{209}Bi with heavy nuclei of ^{54}Cr. *Element 108*: The element 108, Hassium Hs, was first synthesized in 1984. A lead target was bombarded with ^{58}Fe nuclei to produce 3 atoms of ^{265}Hs. *Element 118*: The discovery of element 118 was announced in Oct. 2006. Three nuclei were observed via collisions of ^{249}Cf and ^{48}Ca ions [4].

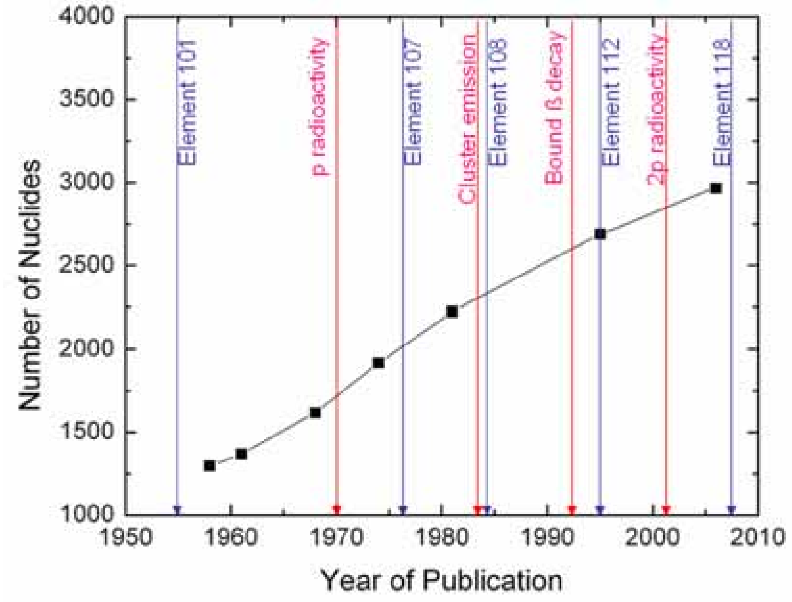

Fig 4. Number of nuclides in the various editions of the Karlsruhe Nuclide Chart.
A timeline of related major discoveries is also shown.

The recent discovery of two new neutron-rich nuclides [5], ^{40}Mg and ^{42}Al, has provided additional insight into the exact location of the neutron drip-line. The drip-line is the limit of how many neutrons can bind to a given number of protons. Because of the interplay between single particle and collective quantum effects, the drip-line can only be predicted for the lightest elements.

3.2 New Decay Modes

Proton Emission: proton emission was first observed in 1970 [6] with the nuclide ^{53m}Co. There are over sixty proton emitters reported in the Karlsruhe Nuclide Chart. This is an active area of research as it provides a unique way of mapping the proton drip-line.
Cluster Emission: An intermediate decay process, between alpha decay and spontaneous fission, was discovered by Rose and Jones in 1984. This "new kind of natural radioactivity" [7], consists in the emission of a light nuclide such as: ^{14}C, ^{20}O, ^{23}F, ^{24}Ne, ^{25}Ne, ^{28}Mg, ^{34}Si. There are currently 16 cluster emission nuclides cited in the chart.
Bound Beta Decay β_b: when a stable atom is fully ionised, the resulting ion may be unstable. These nuclei give rise to a special kind of β^- emission in which an electron is liberated from the nucleus, through transformation of a neutron to a proton, and captured into one of the empty energy shells of the atom. This “bound beta decay” was observed for the first time in 1992 [8]. There are now four such isotopes known in nature: ^{163}Dy, ^{187}Re, ^{193}Ir, and ^{205}Tl. The isotope ^{187}Re is included because of its extremely long half-life (5 x 10^{10} y). Bound beta decay was first observed with highly charged ions of the stable nuclides ^{163}Dy and ^{187}Re provided by the synchrotron and stored in the storage cooler ring at GSI Darmstadt. The ionised $[^{163}\mathrm{Dy}]^{66+}$ is observed to decay with a half-life of 47 d by β_b emission to ^{163}Ho. For the almost stable ^{187}Re, the fully ionised $[^{187}\mathrm{Re}]^{75+}$ shows a decrease in the half-life of 9 orders of magnitude from 5x10^{10}y to 32.9y. In addition to the ^{163}Dy/^{163}Ho transmutation under extreme conditions, other such reaction pairs are ^{205}Tl/ ^{205}Pb and ^{193}Ir/^{193}Pt and these may have an impact in stellar nucleo-synthesis where terrestrial and stellar half-lives may be different.

Two-Proton Radioactivity: Two-proton radioactivity was first observed in 2002 [9,10]. The first direct observation of two proton decay emission in the decay of ^{45}Fe was reported in 2007 [11,12] and is shown in Fig.5 (from [13]).

Beta-delayed Proton Emission: For neutron deficient nuclides, there exists the possibility of proton emission from excited states populated in the daughter nuclide via a β-decay. ß$^{-}$-delayed two-proton emission was first reported in 1983 in the decay of ^{22}Al and ^{26}P. The first observation of ß-delayed three proton emisison in ^{45}Fe was reported in 2007 [13] through the use of a newly developed ionisation chamber. The first photographic recording this process is shown in Fig.5. Through these new experimental observations, the information on the nuclide ^{45}Fe in the Karlsruhe Nuclide Chart will be updated in the next edition. The updated nuclide box, reflecting these discoveries, is also shown in Fig.5.

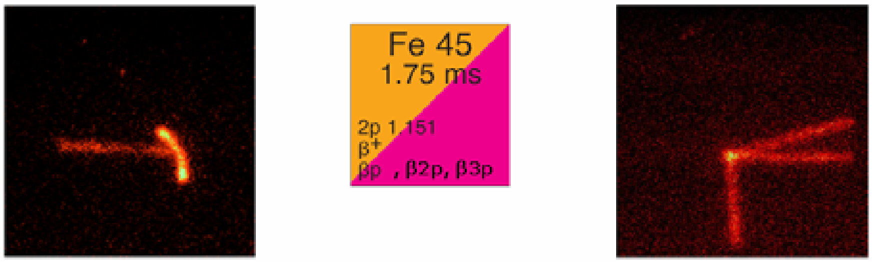

Fig 5. Camera recording of 2p and β3p decay events in ^{45}Fe [11]. *Left:* A track of a ^{45}Fe ion entering from left. The two short tracks are protons of ~0.6 MeV. (image courtesy of M. Pfützner). *Right:* three tracks of protons following the β^{-} decay (Reprinted with permission K. Miernik, et al., Phys. Rev. C 76, 041304 (2007). Copyright (2007) by the American Physical Society). *Centre:* updated nuclide information for ^{45}Fe shown in the nuclide chart.

4. Conclusions & Future Work

The 7th edition of the Karlsruhe Nuclide Chart has been produced by the European Commission's Joint Research Centre at the Institute for Transuranium Elements. Support for the current and future editions is ongoing to reflect scientific progress in nuclear science. In the future, new versions of the Chart will be available in electronic form (e.g. CD ROM, Web portal) in addition to the paper-based version in line with developments in information technology.

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A NETWORK TO ENHANCE COOPERATION FOR HIGHER EDUCATION ON NUCLEAR ENGINEERING

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On behalf of the CHERNE Network

ABSTRACT

The educational capacity of many Institutions of Higher Education in Nuclear Engineering decreased under the combined effect of a declining interest among students as well as from academic and political authorities. An increasing cooperation at the international level on educational efforts is necessary. The CHERNE network is an initiative mainly focussed on teaching and learning activities to develop a wide-scope open academic network to enhance cooperation, competence and equipment sharing between its partners. Typical activities organized within the network include workshops, intensive courses, seminars and conferences. The CHERNE network and its main objectives as well as the activities developed since its foundation are presented. Special attention is given to international intensive courses (SPERANSA, JUNCSS, ICARO, ...) organized for students of the member institutions. The common feature of these courses is a strong practical part in specialized facilities, including in some cases access to large equipment like research reactors and accelerators.

1. Introduction

The educational capacity of many Institutions of Higher Education in Nuclear Engineering has been decreasing sharply during the last decades under the combined effect of a declining interest among students as well as from the academic and political authorities. Furthermore, financial restrictions have made it increasingly difficult to maintain and develop facilities, equipment and academic staff needed for practical training of students as well as for basic research in the involved institutions.

Each university and country presents a different situation, but many departments that were initially able to propose a large panel of orientations in this field had to reduce their offer and to concentrate it on a few specialities. On the other hand, a significant number of professionals at different levels of education continue to be required for safely operating and managing the nuclear industry and all other activities involving the use of radiations.

Industry, research institutes and universities need to work together to co-ordinate more effectively their efforts to encourage the younger generation and to develop and promote a program of collaboration in nuclear education and training. Mechanisms should be set in motion for sharing best practices in promoting nuclear education. The obvious solution is an increasing cooperation at the international level on the educational efforts. For this reason, several networks have been developed, some of them focused on specific domains, others concentrated on high level professional training, some strongly structured and others not.

The CHERNE network, created in 2005 and presently involving 14 Institutions (mostly from Europe), is an initiative mainly focussed on teaching and learning activities to develop a wide-scope open academic network to enhance cooperation, competence and equipment sharing between its partners. The aims and rules of the network were established in a declaration, signed by all partners, containing specific details concerning organization, membership and activities. This declaration can be downloaded from the network web site: www.upv.es/cherne/.

Typical activities organized within the network include workshops, intensive courses, seminars and conferences on topics like radiation protection, nuclear measurements, radiochemistry, safety analysis, reactor and accelerator operation and applications, etc. In this paper, the CHERNE network and its main objectives are presented as well as activities developed since its foundation. Special attention is given to international intensive courses (SPERANSA, JUNCSS, ICARO, ...) organized for students of member institutions.

2. The CHERNE network

2.1 Members of the network in 2008

The network was created in 2005, involving now 13 European Institutions and one from United States. The list of members in alphabetic order is the following:

- Alma Mater Studiorum - Università degli Studi di Bologna (Italia)
- ČVUT, České Vysoké Učení Technické v Praze (Czech Republic)
- Dipartimento di Fisica ed Astronomia, Università di Catania (Italia)
- Dipartimento di Fisica, Università degli Studi di Messina (Italia)
- Dipartimento di Ingegneria Nucleare, Politecnico di Milano (Italia)
- DIQN-UPV, Departamento de Ingeniería Química y Nuclear, Universidad Politécnica de Valencia (Spain)
- ETSEIB - UPC, Escola Tècnica Superior d'Enginyers Industrials de Barcelona, Universitat Politècnica de Catalunya (Spain)
- ISIB, Institut Supérieur Industriel de Bruxelles (Belgique)
- ITN, Instituto Tecnológico e Nuclear, Lisboa (Portugal)
- KSU, Kansas State University (USA)
- UAS Aachen, University of Applied Sciences Aachen, Campus Jülich (Germany)
- UAS Zittau-Görlitz, University of Applied Sciences Zittau/Görlitz (Germany)
- Universidade de Coimbra (Portugal)
- XIOS, Hogeschool Limburg, Diepenbeek (Belgium)

It is a wide-scope open academic network mainly focussed on teaching and learning activities, whose objectives are to enhance cooperation, competence as well as equipment sharing between partners.

A declaration, signed by all partners, contains details concerning organisation, membership and activities. This declaration can be consulted at the web site www.upv.es/cherne/

2.2 Origin of the CHERNE network

The CHERNE network has its origin on some ERASMUS Intensive Programmes (IP) organised during last years [1] with the participation of CVUT, DIQN-UPV, ISIB, XIOS and UAS Aachen. The IP "PAN: Practical Approach to Nuclear techniques" was organised in 2002, 2003 and 2005 in Prague, and in 2004 in Mol-Brussels. A second IP (SPERANSA, Stimulation of Practical Expertise in RAdiological and Nuclear SAfety) was supported by the Erasmus programme in 2006 (Mol-Jülich), 2007 (Prague) and 2008 (Mol-Brussels).

A larger partnership was considered necessary to extend the scope of this collaboration, and it was initiated with the constitution of the CHERNE network in 2005 during a workshop organised in Valencia (Spain) by UPV [2].

2.3 CHERNE organisation and membership

CHERNE has a minimal administrative organisation, ensured by the secretary elected at the annual meeting. The secretary manages a Web page through which the activities of the network are communicated. The partners of CHERNE meet once a year to evaluate the activities of the network and discuss any proposal to extend or modify them. For the moment no fee is foreseen for CHERNE membership.

Academic institutions, research institutions, companies or individuals are accepted as members on presentation by two members, including at least one European academic member. Documents for this presentation as well as the list of partners can be found at the official Web site.

3. CHERNE activities

3.1 Description

Cooperation between the institutions should enhance the mutual support by learning from each other, by exchanging experiences, and by regular mutual reflections on what we can do to counteract the 'less interest among students' and the 'less interest among the academic and political authorities' and also on what we can learn from more successful or from less successful partners.

The scope of CHERNE is not limited and any activity related to higher education in radiological and/or nuclear engineering can be proposed.

CHERNE activities will be organised mostly for students of members, mainly at Master level. They should include at least a one-week/2 ECTS module. It's necessary to include practical training in activities for students, including when possible access to large facilities. Teaching modules are clearly seen as a possible kind of activity, but other types of cooperation may be also developed such as material for modules conveniently adapted in each university, e-learning, etc. The language used in CHERNE activities is English.

The CHERNE activities will be organised at no cost, or very low fee, for students coming from other partner institutions. The organising partner will find and propose cheap accommodation for the students coming from abroad. When possible, the organisation of CHERNE activities will be included in ERASMUS exchanges. Therefore, the partners are encouraged to sign bilateral ERASMUS agreements.

Research collaborations are not the main goal of the network. However, they are quite naturally developed as a consequence of the frequent exchanges for educational cooperation. [3, 4, 5]

3.2 CHERNE activities developed or proposed

Activities already realised or planned for the near future as well as a resume of the collaborations between the CHERNE partners can be consulted at the official Web site. They include seminars, courses, intensive courses, and research collaborations.

Activities developed at each partner institution are usually presented at the annual workshops held in Valencia (2005) [2], Valencia (2006) [6], and Prague (2007) [7], and foreseen next 26-28 May 2008 in Favignana Island (Italy). Furthermore, the activities developed by the network have been presented at previous conferences: ETRAP 2005 [1], First EUTERP Platform Workshop [8], and European Nuclear Conference 2007 [9].

In the next paragraphs a special attention is given to the international intensive courses organized. The common feature of these courses is a strong practical part in specialized facilities, including in some cases access to large equipment like research reactors and accelerators.

3.2.1 Radiation protection and nuclear measurement in non conventional sectors

Two editions (2007 and 2008) have been held of this 2-week course organised by ISIB Brussels and XIOS Diepenbeek (Belgium). Students from UAS Aachen, Bologna, UPV, ISIB and XIOS participated in these courses.

The program developed includes lectures on natural radiation, exposure of air crews to cosmic rays, indoor radon, natural radioactivity in building materials, radioactivity in the waste and recycling sector, and exposition to NORM/TENORM in the non nuclear industry. As well practical exercises are proposed on the following topics: software calculation of air crew dose, indoor radon measurements (charcoal, track-etch, continuous), soil radon measurements, radon risk evaluation (ECRS software), visit of detection portals for radioactivity in scrap or waste, simulation of intervention, measurement of NORM by gamma spectrometry, and measurements by liquid scintillation.

3.2.2 SPERANSA: Stimulation of Practical Expertise in Radiological And Nuclear SAfety.

The third edition of the IP SPERANSA, a 2-week course sponsored by EU and coordinated by CVUT Prague (Czech Republic) has been organised at SCK-CEN, Mol and ISIB Brussels from 24 February to 7 March 2008, participating 24 students from Czech Technical University of Prague, Universidad Politecnica de Valencia, Politecnico di Milano, Fachhochschule Aachen in Jülich, XIOS Diepenbeek, and ISIB Brussels.

The lectures (approx 6 h) introduced the theoretical and regulatory aspects of the practical exercises (approx. 45 h), which include: reactor operation, accelerator operation and applications, hot cell operations on radioactive material, radiation emergency (in SCK-CEN Mol and IRMM Geel); and X-rays non-medical applications, neutron measurements, decontamination, indoor and soil radon measurements, TL dosimetry, quality control and patient protection in nuclear medicine and radiotherapy, and control of environmental radioactivity (in Brussels). For some facilities such as underground radwaste laboratory, and radwaste treatment facility, where a direct operation by the students is not possible, visits with demonstrations were done. Finally, 3 round tables (approx. 6 h) were organized, on two topics: ethical aspects of radiological and nuclear safety; and nuclear/radiological techniques and safety for sustainable development; and also for synthesis and evaluation of the course.

3.2.3 JUNCSS: Jülich Nuclear Chemistry Summer School.

The success of the Summer School (2-week course) organised by UAS Aachen in Jülich from 19 to 31 August 2007 stimulated to organisers together with other CHERNE partners to submit an Erasmus IP to the EU for the 2nd edition, in fact for academic years 2008-2010. The program was approved for 2008 and the course will be held from 17 to 29 August with the participation of ISIB, XIOS, UPV, Bologna and UAS Aachen.

The contents of the course include some theoretical lectures, but mainly practical exercises to acquire skill in working techniques in the radiochemical laboratory. And this on the following topics: measurement and shielding of radioactivity, radiation safety, practical measurement of nuclear radiations (α, β, γ, n), working with open sources, production of radionuclides, radiochemical separation and radioanalytical techniques, radiolabelling techniques, applications of tracers, and chemistry of radioelements.

3.2.4 ICARO: Intensive Course on Accelerator and Reactor Operation and applications.

Another Erasmus IP project has been submitted for the 2009-2011 period, coordinated by Politecnico di Milano with a first organisation (2009) proposed to ITN Lisbon. Almost all CHERNE partners are involved in this project, as foreseen participants will be students and professors from XIOS Hogeschool Limburg, Universidad Politécnica de Valencia, Università degli Studi di Catania, Alma Mater Studiorum Università di Bologna, Ceské Vysoké Ucení Technické V Praze, Universidade de Coimbra, Universitat Politècnica de Catalunya, Institut Superieur Industriel de Bruxelles, Aachen University of Applied Sciences, and Politecnico di Milano.

The program includes lectures (about 15 hours) on radiation protection, radiation shielding, radiation safety, interaction of radiation with matter, ion beam techniques, reactor physics – statics and kinetics, and accelerator principles. Nevertheless, the major feature of the course is represented by experiments (about 32 hours) divided in three groups: accelerator-related experiments (accelerator operation and calibration, Rutherford backscattering spectrometry, and PIXE –particle induced X-ray emission); reactor-related experiments (start-up, rod calibration, and isotope production and measurement); and exercises related to radiation protection, radiation safety, radiation shielding, dosimetry, and radiation detection and measurement.

4. Conclusions

On the basis of an existing collaboration between some institutions, the creation of the CHERNE network permitted to enhance the educational cooperation among partners.

The main target of the CHERNE network is to develop teaching activities for the benefit of students of the institutions belonging to the network.

The network is still young and small, and does not yet propose many activities, but already represents a clear added value for the students, in particular with the intensification of Erasmus exchanges between the partners. Consequently, the exchange of students has been clearly increased.

A clear result obtained so far with the network, more specifically with the intensive courses already developed, is the enhancement of the interest of students and academic authorities on Nuclear Engineering.

The perspective of the network is to gradually propose more activities, while admitting new partners who can contribute to the network's life with new activities and more students benefiting of them.

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THE BELGIAN NUCLEAR HIGHER EDUCATION NETWORK A GROWING INTERNATIONAL NUCLEAR ENGINEERING PROGRAMME

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ABSTRACT

The Belgian Nuclear higher Education Network (BNEN) is a master-after-master academic programme organised through a consortium of six Belgian universities and SCK•CEN, the Belgian nuclear research centre. This paper introduces the programme, gives some statistics on the programme and discusses the problems encountered. We have seen a steady growth in the BNEN programme. However, recent indications show that we are influenced by two countering effects: the renewed interest in nuclear energy and the very high demand for engineers on the job market. The first clearly has a beneficial effect on the student numbers and the quality of the programme: industry demands well trained engineers to prepare themselves if a new nuclear wave is initiated. However, the demand from industry for "fresh" engineers is so high that it becomes very difficult to attract students who wish to postpone their career with one year to enter the BNEN programme first.

1. Introduction

In a country where a substantial part of the electricity generation is (about 58% of Belgian electricity production is of nuclear origin) and will remain of nuclear origin for a number of years, there is a need for well educated and well trained engineers in this area. However, there was no nuclear engineering programme at the engineering level (in these days, the Master level) for a long time. Some nuclear engineering related subjects where available to students taking the specialisation of physics engineering or mechanical engineering. In order to fill this gap, two interuniversity programmes, one in the Flemish speaking region and one in the French speaking region, offered a specialized one-year post-engineering degree in nuclear engineering. These programmes existed for several years but suffered from strongly reduced student numbers, mainly due to the negative connotation associated with nuclear energy at the time. Because of education decrees, demanding a certain number of students, these programmes became endangered. It is therefore, that from the worry that Belgian education could no longer "produce" knowledgeable nuclear engineers and with support from the Belgian nuclear industrial partners, that five Belgian universities and the Belgian nuclear research centre SCK•CEN signed a consortium agreement to create the BNEN [1], a Master-after-Master, one-year equivalent degree in nuclear engineering. In 2006, a sixth university joined the consortium. The universities involved are now: KUL (Leuven), UG (Ghent), VUB (Brussels), UCL (Louvain-la-neuve), ULg (Liège) and ULB (Brussels).

2. Structure and modalities of the BNEN

The BNEN academic programme is a one-year (60 ECTS) Master-after-Master programme open for holders of a five-year Master degree in engineering. Holders of master degrees in exact science or industrial sciences can be allowed to the programme if they are prepared to first do an individually drafted make-up programme: the science degree holders have to deepen their knowledge on engineering subjects while the holders of an degree in industrial sciences need to take up some science courses.

The programme (see Table 1) consists of ten courses to be followed mandatory (41 ECTS), the opportunity to select a number of advanced courses at will (up to 4 ECTS worth) and a Master thesis (15 ECTS). The advanced courses either broaden the field of education or deepen a particular subject. Topics that have been addressed are among others MOX fuel, severe accidents and radioisotope production. The Master thesis typically relates to the current professional activities of the student or the SCK•CEN, the Belgian nuclear research center provides every year a substantial list of possible thesis subjects.

	BNEN Module	ECTS	
BNEN block I	Introduction to nuclear energy	3	First semester (October to January)
	Introduction to nuclear physics	3	
	Nuclear materials Part I	3	
	Nuclear fuel cycle and applied radiochemistry	3	
	Nuclear materials Part II	3	
	Advanced/Elective courses	4	
BNEN block II (ENEN block)	Nuclear reactor theory	8	
	Nuclear thermalhydraulics	6	Second semester (February to June)
	Radioprotection and nuclear measurements	6	
BNEN block III (ENEN block)	Operation and control	3	
	Reliability and safety	3	
	Thesis/Internship	15	

Table 1: The BNEN modules

All courses are given in a modular fashion. The main advantage of this system is the easy planning for both students and professors for all lectures in a course. Also for foreign students either in an exchange programme like Erasmus or the ENEN programme, this modular system is easier to cope with. The disadvantage is clearly a heavily loaded period when a course is given (from one up to three consecutive weeks), there is little time to digest the material between two consecutive sessions in a course.

Attention is paid to the fact that most courses are not only theoretical ones, but many of them have exercise sessions and laboratory sessions associated with them. These sessions are organised and taught by the scientific staff at SCK•CEN. Many of the laboratory sessions use the infrastructure available at SCK•CEN like the BR1 reactor, the radiodosimetry laboratory and the material hot cells. These hands-on sessions clearly have an added value for the BNEN students. Many visits are organised to specialised labs at the SCK•CEN to show the students all facets of nuclear energy.

The programme, student issues and general policy is governed by the BNEN Steering Committee in which each university has one member present together with the Administration Manager of SCK•CEN and the BNEN secretary. The Steering Committee is chaired by a professor of one of the six universities for a mandate of two years. He (or in the current situation she) is supported by a vice-chair also appointed for the same time period.

The SCK•CEN, although it offers all the facilities for the programme, is not an academic institute and hence cannot deliver a degree. Students enrol at one of the six universities at their own choice and it is this university that issues the BNEN degree upon succesful passing of the exams.

3. The BNEN audience

The number of students enrolling for the BNEN has seen a serious growth since the start of the initiative as indicated in Figure 1. The programme does not serve only "full-time" students, i.e. people having just obtained their Master degree and who decide to take a one-year degree extra. Also a lot of young-professionals employed at different industrial stakeholders (nuclear power plants, regulatory body, engineering bureau …) enrol for the programme. Total numbers over the past five academic years are shown in Figure 2. They typically spread the one-year programme over two or three years to combine their job with these studies. It is clear that they need and get the full support from their employers, sometimes because they need the degree to be allowed in crucial positions in the company.

The BNEN programme is also a founding father of the ENEN programme (European Nuclear Education Network). Students are encouraged to take up courses in a foreign university to broaden their views. If a student obtains 20 ECTS or more in a different country than the one he is enrolled in, he can obtain next to his degree the ENEN certificate. The BNEN programme or some of its courses are quite popular with foreign students. This academic year we have registrations from more than ten foreign students who decided to use BNEN courses in their curriculum.

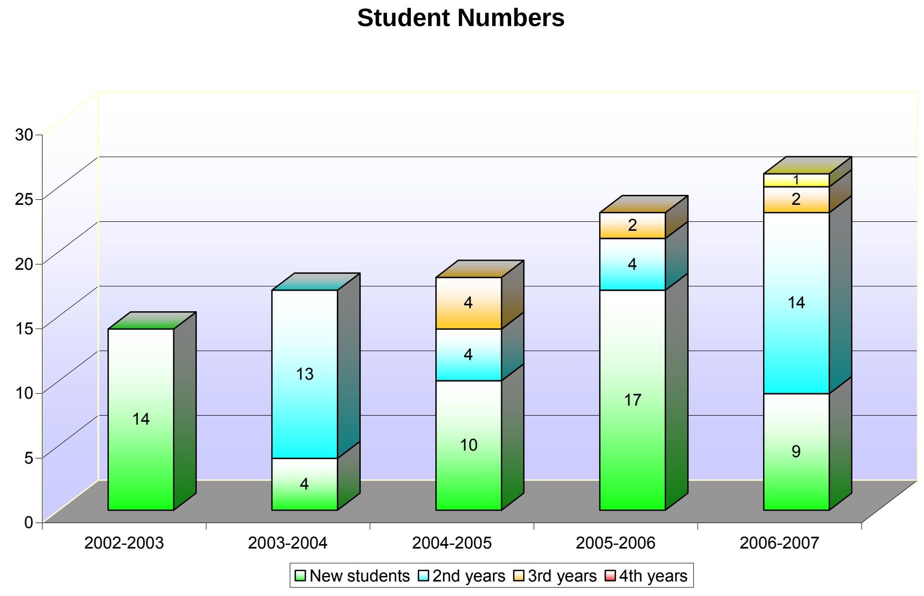

Fig 1: Student numbers registered for the full BNEN programme.

Courses are also available on a one-by-one basis. Young (but also not so young anymore) professionals are more than welcome to increase or refresh their knowledge on nuclear engineering topics. Admittance to a course is in the hands of the Steering Committee based on the credentials of the candidate.

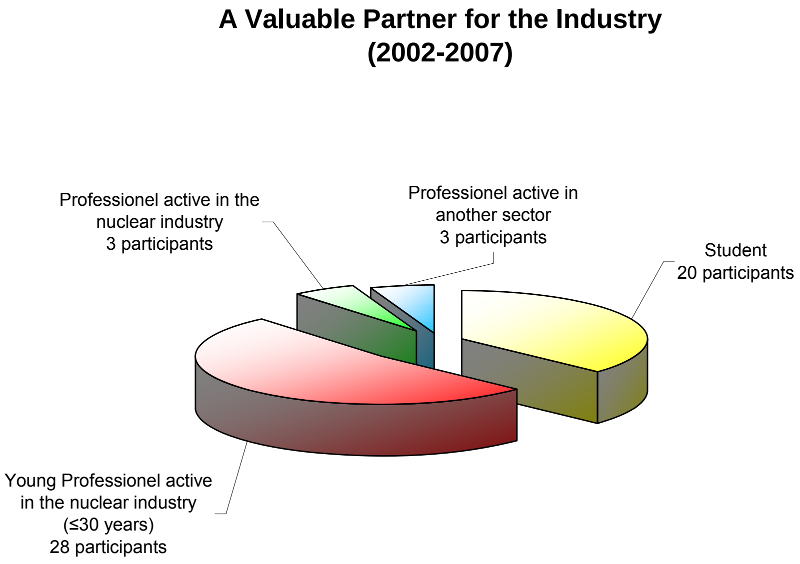

Fig. 2: The different types of students in the BNEN programme

4. Challenges for the (near) future

Over the past years, several challenges have been put to the BNEN and the Steering Committee. One of the specific issues for the federal state Belgium is the fact that education is a regional matter in which the Flanders and Walloon region can have different legislations. In a consortium with universities from both sides of the country and hence two education decrees to follow, this has posed and still poses a difficult equilibrium exercise in which specific matters like student enrolment, examination rules and recognition of previous earned ECTS credits are being resolved by a pragmatic approach of the Steering Committee. Quite recently, members of the student administration of some major Belgian universities have rung the alarm bell on the consequences of the student flexibility in the Bologna decree and the ECTS credits. A very large number of the students are off the "regular" track and they see more and more students failing due to postponing exams and mixing courses from different academic years.

A second challenge is the continuous quality assurance of the courses and the program as a whole. Within the 6th European Framework project, a Self-Assessment Report was written indicating both strong and weak points of the programme **Error! Reference source not found.**. This SAR is the result of an internal analysis of the strengths, weaknesses, opportunities and threats of the BNEN programme The evaluation methodology has been based on the well-established protocol of the Dutch Universities and has benefited from advices of a panel of international experts. To prepare this report, a large set of questions have been submitted to students, former students, BNEN professors and teachers, to the BNEN secretariat and to the BNEN Steering Committee. The SAR bundles and analyses the different answers and provides strengths, weaknesses, opportunities and threats on different aspects of the programme: the objectives of BNEN, the teaching staff, the facilities and also the students. Figure 3 gives the appreciation of the BNEN programme by the students. The BNEN also has assigned a quality coordinator who watches over the contents of all courses, the quality of the material, the coherence of the full programme and the practical matters. The Steering Committee tries to organise on a two-yearly basis a quality meeting where all professors are expected to attend to work on an improvement of their courses. All courses are evaluated by the students and these evaluations are the primary input for these meetings.

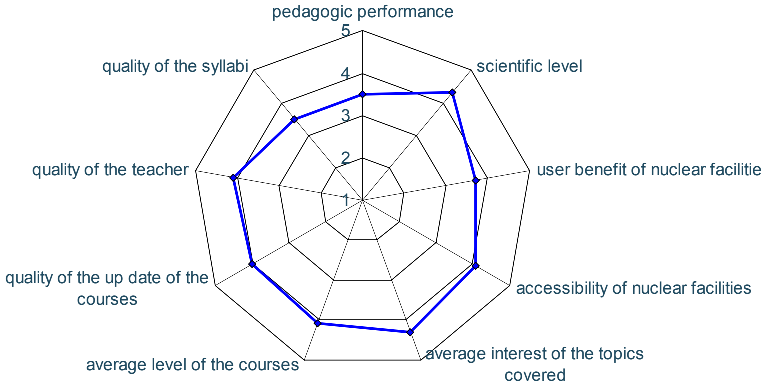

Fig. 3: Self Assessment report, student evaluations

Thirdly, the BNEN must acknowledge the support of some major industrial stakeholders who sponsor the programme financially (and sometimes in kind by allowing their specialists to give an advanced course for free). Without this support, the programme would be quite costly either for the partners in the consortium and/or in the end for the students. Of course, it is from these stakeholders that almost all young-professionals enrolled in the BNEN programme originate. Therefore, the Steering Committee guards quite strongly their academic independence and endeavours to avoid any possible hint of a conflict of interest.

Finally, a challenge that has arisen quite recently is the enormous shortage of engineering students combined with a very high demand from the industrial job market. The last and the current academic year, we have seen very little "full time" students. The dilemma between accepting a well paid job in industry or postponing this step (and risking a less favourite job market) in joining the BNEN programme is unfortunately quickly resolved, not in favour of BNEN. Those who end up in a nuclear industrial player know either from the job interview or quickly after that they, if needed for their position in the company, can be sent to the BNEN programme. This poses a problem not only to BNEN, but also to the SCK•CEN as a research centre since full time BNEN students often take a Master thesis subject at the research centre. In a second step, these Master thesis students are a perfect fishing pond for possible PhD candidates, since the SCK•CEN researchers already have a good idea of the quality of the candidate.

5. Conclusions

In Belgium, but also in Europe, we hear the words "nuclear renaissance" echoing. In some European countries (in some more than in others), the nuclear phase out is under discussion. In two European countries, new nuclear power plants are even under construction. If indeed, there will be a new wave of nuclear power plants built; there will be a high need of well-educated nuclear engineers. But the success of BNEN does not solely depend on this path. The programme also contains courses on nuclear waste treatment, nuclear safety and safeguards. In any case, nuclear engineers will be needed for a long time to ensure safe operation of the current nuclear power plants and the waste treatment and disposal facilities.

It stands without doubt that the organisation of the BNEN has had, and probably still has, to overcome hurdles created by the changing higher education landscape, the Bologna decrees, but also the peculiar Belgian situation where different universities are joined in associations and where education is not a national but regional jurisdiction. Up to now, these issues have been dealt with in a very pragmatic manner, not neglecting Belgian and/or regional educational law.

Acknowledgements

The author acknowledges the continuous drive of the BNEN Steering Committee to improve the BNEN programme and to make it attractive to engineers all over the world. He also acknowledges the support of the European Commision in the 6th Framework Programme of the project "Open Acces to the Belgian Nuclear higher Education Network".

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LEADING THE RENAISSANCE – TEACHING NUCLEAR ENGINEERING TO UNDERGRADUATES IN THE UK

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ABSTRACT

In this paper we describe the origins of the only nuclear engineering degree currently to be offered in the UK. The background to the nuclear skills shortage in the UK is provided as context and then the philosophy behind the introduction of the new degree is described. The justification for the introduction of the degree, against a field of general engineering degrees, is explained and the structure of the course is described in detail. The results of a short research exercise with the students currently on the course are provided as evidence for the ambitions and perspectives of students opting for nuclear.

1. Introduction

In 2000 the Nuclear Energy Agency of the OECD (Organisation for Economic Co-operation and Development) published a report, "Nuclear Education and Training: Cause for Concern?" that confirmed what many had suspected for some time: namely, that nuclear education in the UK was in a fragile state. Two subsequent reports by the HSE-NII did nothing to dispel this view. Indeed, the leading conclusion of the second report (Nuclear Education in British Universities, February 2002) stated "If nuclear education were a patient a hospital it would be in intensive care." At the undergraduate level, all that remained of nuclear education were a few taster modules within mainstream science degrees. At the postgraduate level, only a handful of courses with an appreciable nuclear content struggled to survive.

The concern was not so much that nuclear education had declined compared to the halcyon days of the 50s and 60s when the industry was expanding and university courses were abundant at all levels, but, rather, that it was no longer robust enough to meet the changing needs of the industry. In particular, the need for a guaranteed supply of suitably qualified technical graduates to ensure the safe operation of nuclear facilities in the UK.

A number of events had led to this situation but the two most significant were the deregulation of the energy sector and the funding of higher education. The personnel needs of the industry declined as it sought to be more competitive. With universities run on a business footing the result was that under-subscribed nuclear courses were replaced by those pertinent to other industries where there was a demand and financial support.

2. Philosophy

Paradoxically, because there was a paucity of nuclear courses there was also a need for them. Following discussions with a number of organisations, Lancaster University, Engineering Department, identified the pressing requirement for a safety related course. It was decided that this should be at the masters level as the funding at this level is more flexible than the bloc funding found at the undergraduate level. Started in 2001, the course, Safety Engineering, has run every year since its inception.

With the rapid increase in decommissioning work and the promise of new build, the profile of the nuclear industry in the UK has risen dramatically. No longer dismissed as a sunset industry, it is now an appealing prospect to undergraduate students. The time seemed ripe to attempt an undergraduate course.

The proven philosophy behind the masters course was applied to the new course. Namely, that it should balance the needs of the industry with the intellectual stimulus and challenge required by the students. Like the masters course, the undergraduate one was deliberately designed not to be 100% nuclear but, through a modular approach, to have a variable nuclear content. This allows the student to find his or her own level and it is also a way of importing expertise from other sectors into the nuclear industry.

3. Justification for introducing an undergraduate course

From a university perspective, running post graduate courses are low-risk. If the uptake does not materialise, or declines to an uneconomic level, they can be axed comparatively easily. This is not the case with undergraduate courses. By their nature they run for a longer period of time and are more deeply embedded in the university infrastructure. Before embarking on a new one, it is necessary to justify the reasons why.

Many engineering companies in the nuclear business prefer to recruit graduates from generic engineering disciplines because of the flexibility this offers them in the development of these people in directions that might be subject to change in the future. The specific ‘nuclear’ aspects of their training that are necessary, beyond the fundamentals covered in their undergraduate degree, are often covered by a combination of industry-based training and informally as a result of focussed mentoring by in-house expertise.

Despite this effective approach to nuclear specialisation on an industry basis, there is a strong justification for a dedicated nuclear engineering undergraduate course for three main reasons:

a. The level of nuclear content in many generic engineering degree schemes has become very low, and in some cases there is no nuclear content whatsoever. Furthermore, since it is not essential to have studied physics and/or chemistry at school prior to studying for an engineering degree, an engineering graduate can progress into industry with very little formal nuclear training. This can mean elementary nuclear fundamentals are absent.

b. Some companies in the high-integrity nuclear sectors, such as defence, require significant specificity in the nuclear theme. In contrast with the engineering companies requiring breadth in an engineering degree scheme, these companies require *depth* in nuclear that goes beyond generic degree schemes. These companies represent the important minority that require nuclear engineering specialists.

c. There is a tangible demand by school leavers for a nuclear engineering degree. The potential renaissance in civil nuclear power, fusion, medical applications and nuclear decommissioning has provided high-profile publicity to the nuclear field. Nuclear engineering offers a varied career in a number of sectors and is a challenging course offering intellectual challenge. This latter issue is very important for a university department because nuclear engineering offers a means for diversifying admission opportunities without compromising the accreditation of the professional engineering institutions.

4. Structure of the undergraduate course in Nuclear Engineering at Lancaster

All students at Lancaster University study three themes in their first year. This is designed to provide them with the prerequisites to choose from a variety of potential major schemes in subsequent years. Undergraduates in Engineering at Lancaster usually study Mechanical Engineering, Electronics and Maths, with which they have the option of study for General, Mechanical or Electronic Engineering amongst a variety of other courses. Nuclear Engineering students also study a general foundation to their degree studying the same three themes in their first year. This enables students to choose ‘nuclear’ at the end of their first year, or vice versa.

The primary level of specialisation begins in the second year of the Nuclear Engineering degree scheme. In addition to further general themes such as Engineering Mathematics, Thermodynamics and Computing, students study three specific nuclear topics:

- **Nuclear Engineering:** This unit introduces the fundamental physics and engineering associated with matter, radioactivity, fission, neutron propagation and reactor systems. A historical perspective on the genesis of the nuclear sector is also included to provide students with a context as to the origin of some reactor designs.
- **Nuclear Chemistry:** This unit covers the necessary chemistry fundamentals, the periodic table, bonding and then specific issues associated with the actinides, separation chemistry and reprocessing.
- **Nuclear Decommissioning:** This unit covers the decommissioning project lifecycle, decommissioning techniques, site characterisation and monitoring techniques.

In their third year, students at Lancaster spend a significant proportion of the study on an individual project. For Nuclear Engineering students, these projects are focussed on specific nuclear topics. In many cases these are spawned from research expertise in the Engineering Department at Lancaster, such as nuclear instrumentation, control, tele-operated robotics and decommissioning challenges. The third-year project has a duration of eight months and is often a collaboration with an industrial sponsor.

In addition to the project, third-year students also study a number of units alongside which include the generic requirements of integrated systems design, engineering management, manufacturing technology and leadership in technology. In the nuclear context students study Nuclear Instrumentation and Nuclear Medicine. The former comprises all the specific instrumentation requirements of nuclear systems for the detection and measurement of radiation. Students explore a variety of practical aspects, including neutron and γ-ray monitoring systems. They also learn the fundamental concepts of efficiency, resolution and intensity. In Nuclear Medicine, students learn about the variety and justification for the use of nuclear systems in medicine, especially the applications of radiology, radiotherapy and nuclear medicine.

In the fourth year of the Nuclear Engineering MEng, students move to a scheme in which they study in intensive two-week blocks. The first week is dedicated to contact time i.e. lectures and seminar-based learning. The second week of each module is dedicated to a short project relevant to the first week of material. Interspersed between each module, students study in teams on a long project that runs for the whole of their final year. For nuclear students this would normally be a nuclear-related project, often sponsored by an industrial collaborator.

In their fourth year, Nuclear Engineering students study the generic themes of the design and modelling of systems, mechanics and actuators and intelligent system control. The nuclear specialisms at this level comprise Nuclear Safety, including the fundamental elements of the safety case and the study of major accidents, and Monte Carlo techniques, which is a practically-based module in which the students learn to design shielding for the storage of radioactive sources using Monte Carlo methods.

5. Current status and student perspectives

During the early years of the Nuclear Engineering MEng course at Lancaster, the first cohorts of students have been studied by the staff at Lancaster in order to get a better grasp on the ambitions and perspectives of young people embarking on a nuclear career for the first time. A combination of methods have been used to do this, including ad-hoc gathering of information at open days, during lectures and social events – which is forthwith termed *unstructured research*, and dedicated questionnaires sent to the students in email, forthwith termed *structured research*.

Unstructured research results

Students who have been brought up close to sites in the UK nuclear industry, such as power stations and naval installations, demonstrate significant degrees of interest in the Nuclear Engineering MEng. Their interest is a result of a long-established personal interest in nuclear technology and its future implications. They are also interested in the prospect of a career in the industry that has been part of the lives for a long time and offers them a beginning to their career that will start close to home. Students with parents or relatives in the industry are often inspired to take up academic study in it.

Structured research results

The students were asked to following questions:

- What motivated you to choose to study a nuclear topic in your degree?
- Where do you see the benefit to your careers in the nuclear aspects you have learned so far?
- In your opinion, where is the nuclear industry going?
- Which part of the nuclear industry is most attractive to you, and why?
- What are the competing industrial sectors for your skills and career?

Students responded that they were impressed by the prospect of being amongst a handful of pioneering students qualifying for nuclear engineering amongst a much bigger pool of engineering graduates. They cited the nuclear industry as being a sector that cultured personal interest in them and an example of a sector that will play a huge role in the future of the UK energy production, sooner rather then later.

Students perceive a broad impact of what they have learned so far in the nuclear engineering degree. In addition to learning about reactor systems, they value to breadth of the course which encompasses the fuel cycle – from mining through to enrichment and reprocessing. They also value the chemistry fundamentals which provide a basis to learning the nuclear fuel cycle. This breadth, they understand, will open many different avenues in the nuclear industry in their future careers.

Students' perception of the nuclear industry is that it is definitely 'on the up' and that the recent permission to build in the UK, the future of the industry looks very promising indeed. Perhaps a little naively given the current decline through shutdown of existing power plants and the replacement of this contribution through new build, students anticipate consistent growth in the proportion of UK energy that is generated by nuclear means.

Students are interested in a broad number of aspects of the nuclear business, included fuel production. However, not surprisingly, the most exciting career prospect is that of commissioning and building a new nuclear power plant. With regard to competing industrial sectors, students cite the aerospace sector, energy, construction and manufacturing.

6. Summary

The nuclear engineering degree is at present the only UK specialist route to an accredited MEng degree qualification in a nuclear specialism. As a result of the nuclear renaissance in the UK and across the world it is almost certainly to be joined by other schemes from other UK universities. The skills required to conceive, design and commission the future nuclear energy supply of the UK and indeed the world are likely to be in short supply for the foreseeable future whilst the graduates of courses such as the one at Lancaster hone their craft and develop into tomorrow's nuclear professionals. The prospects for such graduates appear to be in little doubt. The challenge is with the universities and the nuclear businesses to ensure that this resource has the tools to meet the task ahead.

Growing Fusion Education Program in Hungary

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[2] *Budapest University of Technology and Economics*
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Fusion research has a long history in Hungary. A small tokamak (major radius 0.4 m, minor radius 0.08 m) named MT-1 was installed at the Department of Plasma Physics of the KFKI Research Institute for Particle and Nuclear Physics (*KFKI- RMKI*) in 1979 and upgraded in the late 80's. Back in those years the education of diploma and PhD students was concentrated in face-to-face conversations and learning seminars given by the elder group members. Due to the shortage of financing the tokamak was shut down in 1998, but this did not mean the end of fusion research in Hungary. One year later the EURATOM Association HAS was established signing a contract between the Hungarian Academy of Sciences and the European Commission. Hungary became a full member of the EURATOM Treaty that opened new horizons and perspectives for the Hungarian fusion research. The leading force is the KFKI-RMKI (*Research Institute for Particle and Nuclear Physics of the Hungarian Academy of Sciences*) and the following institutions are also members of the Association:

- KFKI Atomic Energy Research Institute (*KFKI - AEKI*),
- Budapest University of Technology and Economics, Institute of Nuclear Techniques (*BME - NTI*),
- Budapest University of Technology and Economics, Department of Applied Mechanics (*BME - MM*),
- Research Institute for Technical Physics and Material Science (*MFA*),
- Széchenyi István University (*SZE*),
- Institute of Nuclear Research of the Hungarian Academy of Sciences (*ATOMKI*).

Soon after the foundation of the Association, the improved financial situation, the perspective to work in an international environment and in a dynamically expanding field started to attract students in a growing number. It immediately became clear that the new students need a new educational strategy.

The Institute of Nuclear Techniques of the Budapest University of Technology and Economics seemed to be a straightforward stage for an introductory fusion course into the students' curriculum. The idea of collaboration between RMKI and NTI in the field of education of fusion students was very welcomed by the leaders of BME-NTI, and the fruitful interaction between KFKI-RMKI and NTI still prospering. This very first introductory course had covered the full field of fusion from basic plasma physics to advanced tokamak technology.

A few years later a practical course (called SUMTRAIC=SUMmer TRAIning Course) was established in collaboration with the Institute of Plasma Physics of the Czech Academy of Sciences. This course was a one week series of measurements on the Prague tokamak CASTOR. In the first year, SUMTRAIC had only Hungarian students, but thereafter participants from all across Europe and even from Africa and Asia came to Prague to learn plasma physics. Three years ago it was decided that the Prague tokamak will be replaced by a bigger device and so CASTOR was shut down. Until the new tokamak comes into operation (planned in late 2008), NTI is hosting the SUMTRAIC. Since there is no tokamak in the NTI, a glow discharge plasma source was developed on which the students can make Langmuir probe and spectroscopy measurements. This plasma source is quiet versatile and easy to use and there are plans that after the return of SUMTRAIC to Prague this plasma source will serve as a basis for establishing a set of standard students' measurement instruments in NTI. The Figure 1 shows the plasma source along with the three Langmuir probes.

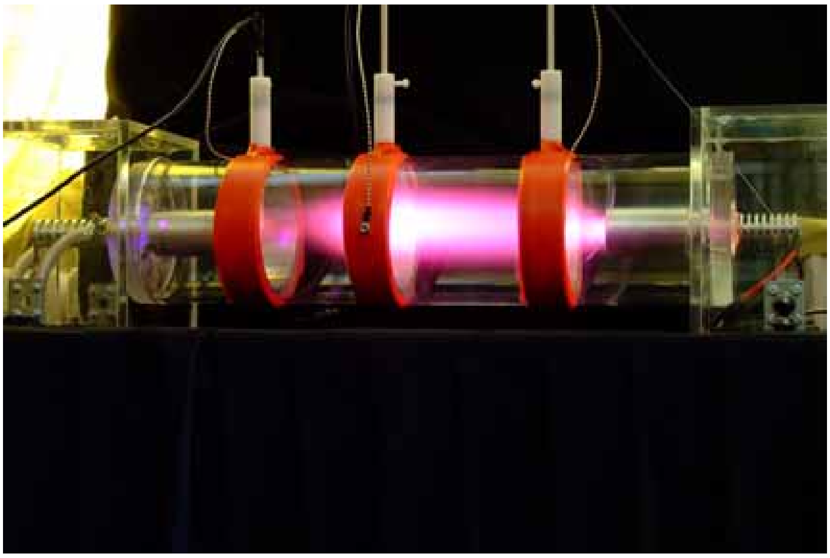

Fig.1. Glow discharge in student experiments

As the number of students interested in fusion had at least tripled in the past five years, a diversification of courses became necessary. At first the introductory course was split into two, full semester courses (one on basic plasma physics and one on fusion devices) and lately specific fusion diagnostic and technology courses have widened the palette. The summary of the available fusion related courses at BME is (as of April 2008) is summarized and visualized on the following Figure 2.

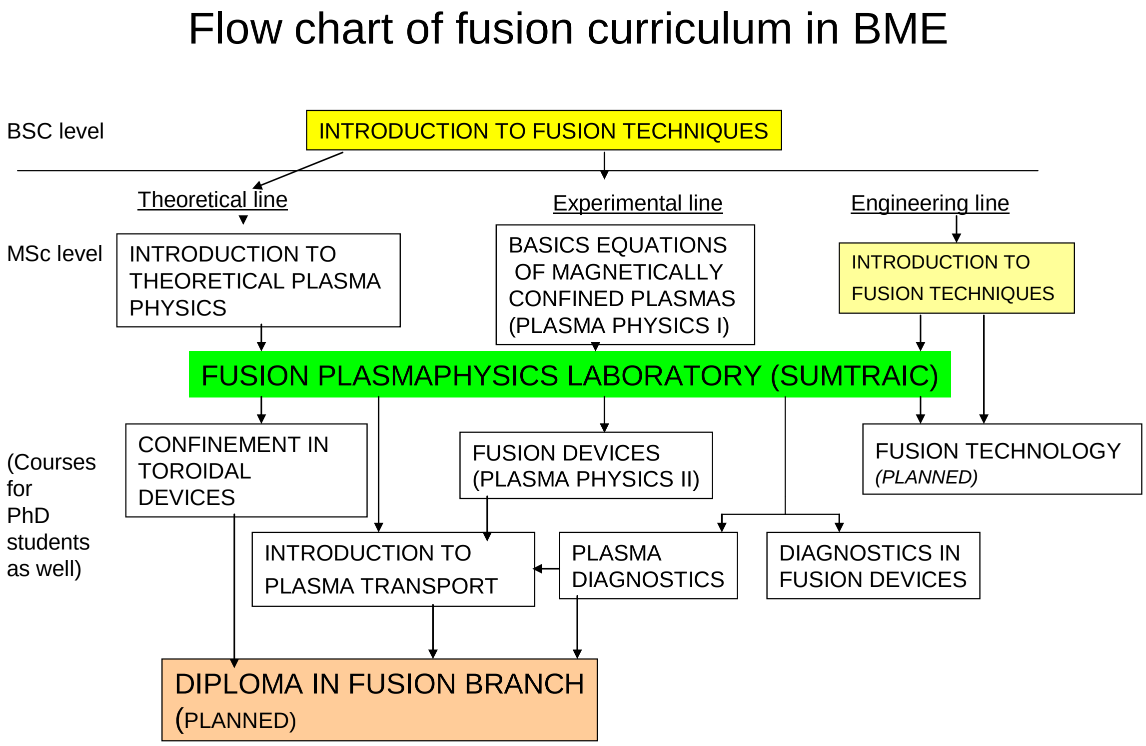

Fig.2. The structure and the courses of fusion education curriculum in BME

On the students' level, the strongest feature of our educational program is that it forms – so to say – a triangle, one side of which is the scientific work done by lower undergraduates, the second side is the diploma work of MSc students and the third one is the scientific research work and education of PhD students. Here we follow the old, Anglo-Saxon traditions. Elder researchers, mainly from KFKI-RMKI, and also from BME NTI work together with students on different research projects, teaching them in a face-to-face manner. This is a pure tutorial system, which selects the best students typically when then step from the BSc level to the MSc level. After proving their ability to work individually as well as in research groups they can publish their work in real scientific papers, which is a precondition to become a PhD student. During the years of their education, our students typically spend about 25% of their research time in research or educational establishments of foreign countries.

An excellent opportunity to increase further our activities in fusion education is the FUSENET fusion educational network to which three Hungarian institutions (RMKI, NTI and SZE) had joined. The budget of the Network had already been approved by the Commission, but the formal foundation of the FUSENET is expected to happen in mid 2008.

In summary: the education of students in the field of fusion and plasma physics is a key to the formation of a proper rising generation. In Hungary, the availability of different courses at all levels of university education from BSC to PhD fulfills the requirements of successful training of all-round future fusion experts.

NUCLEAR ENGINEERING EDUCATION PROGRAM AT UPC-BARCELONA: NUCLEAR POWER PLANT CONCEPTUAL SIMULATOR AND MULTIMEDIA NUCLEAR REACTORS.

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ABSTRACT

Since 1954 ETSEIB-UPC has an education program on Nuclear Engineering. From 1964 to 1977 the experimental education program was developed using an experimental nuclear reactor called Argos (Argonaut type reactor). UPC is providing every year about 130 ECTS on purely Nuclear Engineering oriented courses, with a PhD program on Nuclear Engineering. Nowadays, UPC has started the process to adapt these education programs to the Bologna philosophy, with a Degree and Masters Program model. Those curricula will be fully implemented in the course 2009-2010. The experimental education activities are developed with the Nuclear Power Plant Conceptual Simulator SIREP-1300, and with the experimental laboratories of nuclear physics, modern physics, radiation protection, ionization technology and some research laboratories. In collaboration with nuclear industries we organize experimental work in a full scope nuclear power plant simulator and visits to the Nuclear Power Plants of Vandellós II or Ascó I, II. Some UPC students have obtained the European Master of Science in Nuclear Engineering (EMSNE) in the frame work of ENEN.

1. Introduction

Since 1954 ETSEIB-UPC has an education program on Nuclear Engineering.

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2. Nuclear Power Plant Conceptual Simulator

The Nuclear Power Plant Conceptual Simulator SIREP-1300 reproduces a 1350 MWe PWR with 4 loops. In the course of Nuclear Reactor Physics (5 ECTS), the students perform 5 experiences with this simulator, and in the course of Nuclear Power Plants (5 ECTS), they also accomplish 5 experiences, each one taking two hours [1,2].

P1: Reactor kinetic parameters. Prompt neutrons and delayed neutrons. Kinetic equations. Reactor period and doubling time. Estimation of the delayed neutrons proportion. Prompt Jump.

P2: Approach to criticality from subcritical state. Reactor zero power states. Hot and cold zero power states. Subcritical multiplication factor calculation. Start-up sources. Boron dilution. Reactivity evolution after refuelling. Chemical and volume control systems.

P3: Temperature effects on Reactivity. Feedback concept. Feedback due to temperature. Doppler effect and Moderator effect. Feedback coefficients calculation. Influence on reactor stability.

P4: Isothermal coefficient and moderator coefficient. Moderation relation. Isothermal coefficient of reactivity and moderator temperature coefficient of reactivity determination. Design principle of intrinsic security. Boron limit concentration determination.

P5: Start-up and reactor load variations. Reactivity balances. Poisoning effects. Xenon-135 and Samarium-149. Negative reactivity. The poisoning effect in control. Use in relation to reactor power drop.

P6: Reactor standard states. Transition from hot full power to hot zero power.

P7: Reactor standard states. Transition from hot zero power to cold zero power.

P8: Control rods calibration.

P9: Reactor auto stabilization.

P10: Electric network disconnection and house load operation.

Figures 1 and 2: Nuclear Power plant Conceptual Simulator SIREP-1300 at ETSEIB-UPC

Figure 3: Works station for one student

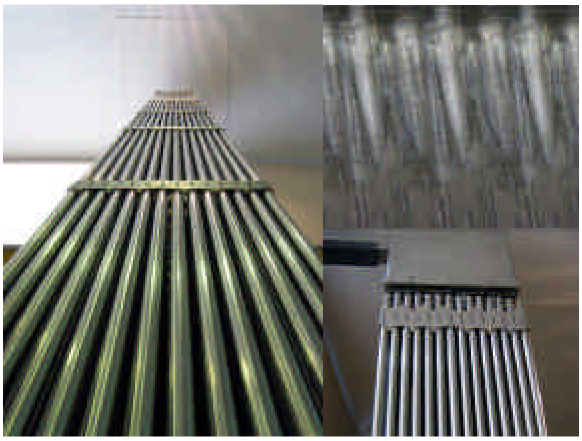
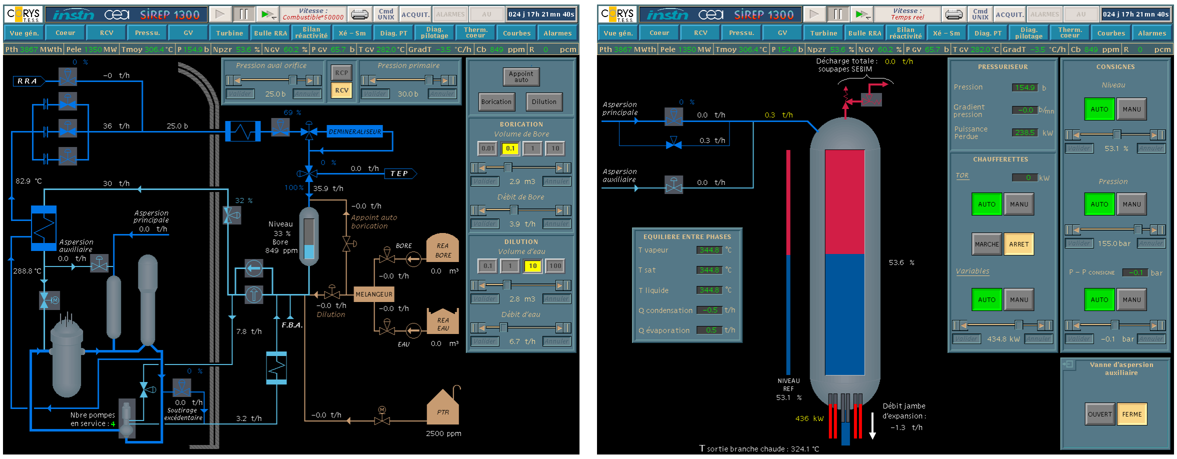


Figure 4: Fuel assembly



Figures 5, 6: Screen Simulator (Chemistry and Volumetric Control System and Pressurizer)

3. Multimedia on Nuclear Reactor

In order to improve education quality, a Multimedia on Nuclear Reactor Physics is being developed. Nowadays, this multimedia has about 770 slides and the text is in Spanish and English. The teacher uses the multimedia during his lectures and students use it at home to study this course. Part of the multimedia has been used during last courses and the students consider this material very useful.

The Multimedia on Nuclear Reactor Physics version 3.0 will be published very soon as:

-DIES, J.; PUIG, F.; PEREIRA, C.; “Nuclear Reactor Physics Multimedia” (languages: Spanish and English) “, cd-rom, v. 3.0, 770 laminas, Barcelona, 2008.

-DIES, J.; PUIG, F.; PEREIRA, C.; “Nuclear Reactor Physics Multimedia “, (language: English) v. 3.0, pag. 385, Barcelona, 2008.

-DIES, J.; PUIG, F.; PEREIRA, C.; “Multimedia de Física de Reactores Nucleares“, (language: Spanish) v. 3.0, pag. 385, Barcelona, 2008.

Samples of Nuclear Reactor Physics Multimedia (language: Spanish)

Figure 7: Main menu

Figure 8: Some nuclear power plants pictures

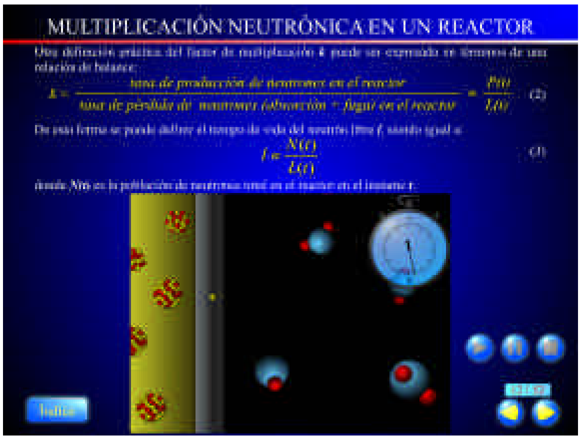


Figure 9: Animation on neutron livetime.

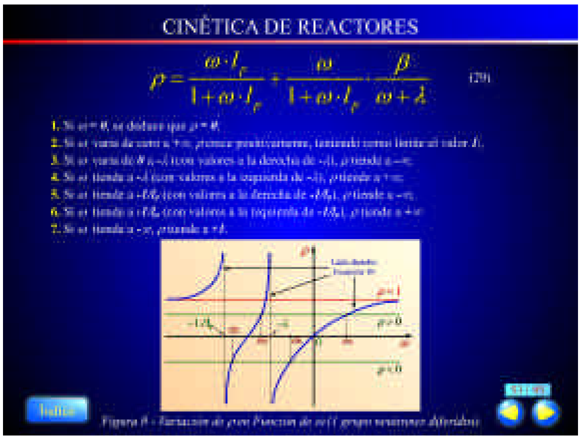
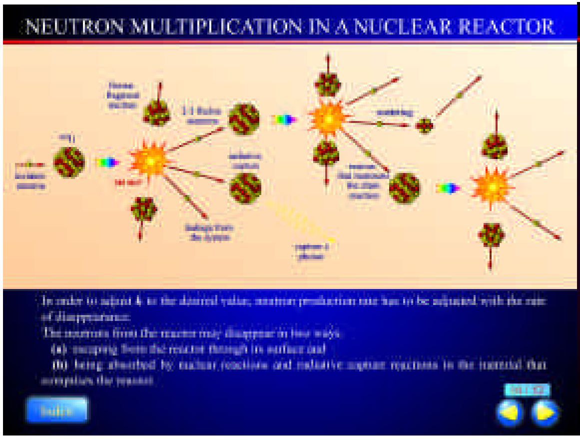
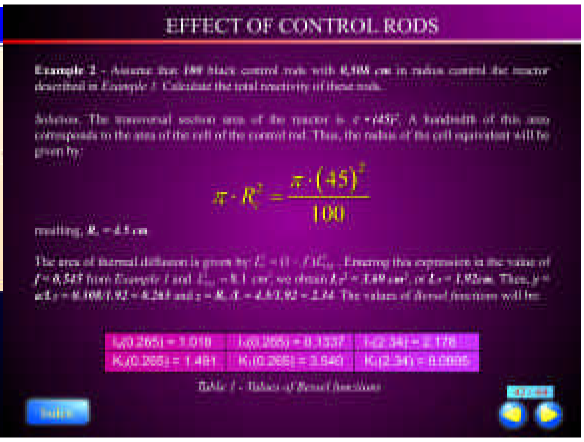


Figure 10: Reactor kinetics

Samples of Nuclear Reactor Physics Multimedia (language: English):



NEUTRON MULTIPLICATION IN A NUCLEAR REACTOR

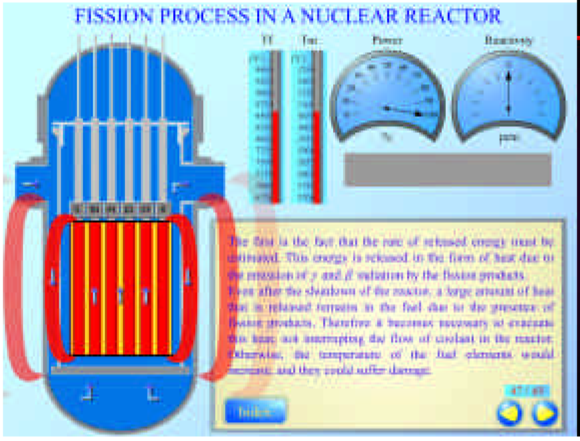


EFFECT OF CONTROL RODS

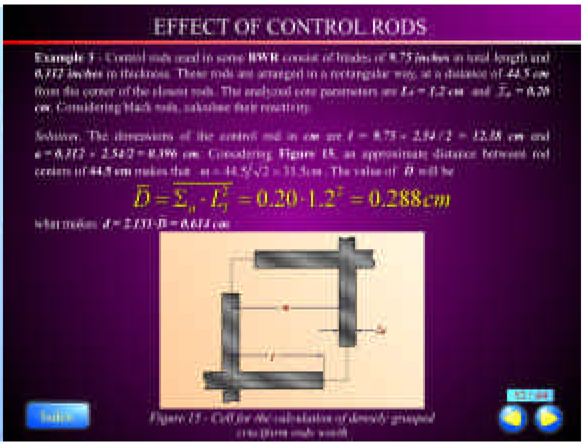
$$\pi \cdot R^2 = \frac{\pi \cdot (45)^2}{100}$$

Figure 11: Neutron multiplication in a nuclear reactor

Figure 12: Effect of control rods.



FISSION PROCESS IN A NUCLEAR REACTOR



EFFECT OF CONTROL RODS

$$\overline{D} = \overline{\Sigma_a \cdot L_T^2} = 0.20 \cdot 1.2^2 = 0.288\,cm$$

Figure 13: Fission process in a nuclear reactor

Figure 14: Effect of control rods.

4. References.

1-DIES, J.; TAPIA, C.; PUIG, F.; VILLAR, D.; “Programa de formación práctica en el área de Ingeniería Nuclear mediante el Simulador Conceptual de Central Nuclear DFEN-ETSEIB-UPC”, (language: Spanish), Ed. CPDA, pág. 206, Barcelona, 2005.

2-DIES, J.; TAPIA, C.; PUIG, F.; VILLAR, D.;   “Nuclear Engineering Education Program with Nuclear Power Plant Conceptual Simulator DFEN-ETSEIB-UPC”, (language: English), Ed. CPDA, pág. 206, Barcelona, 2008.

01.76

INTERNATIONAL AND POSTGRADUATE EDUCATION AND TRAINING IN BUDAPEST

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ABSTRACT

The international and postgraduate education program of the Department of Nuclear Techniques of the Budapest University of Technology and Economics (BME) is presented. The experimental laboratory practices offered for the students at the Training Reactor of the BME are listed, and the history, background, status and curriculum of these courses are shown.

1. Introduction

The Training Reactor (TR) of the Budapest University of Technology and Education (BME) was built in 1971. It was designed and constructed in Hungary, by Hungarian nuclear experts and engineers. Only the EK-10 (10% enriched uranium oxide) fuel assemblies of the reactor were imported from the Soviet-Union. The upgrade of the active core has been made in 1981, and the maximal allowed power was raised to 100 kW.

The TR is situated in the campus of the Budapest University of Technology and Economics. The Institute of Nuclear Techniques (INT) is charged with the use and operation of the Training Reactor. The INT consists of two departments: the Department of Atomic Energy is responsible for the reactor operation, and the Department of Nuclear Techniques organises all education and training activities. The TR is declared as an inter-university institution: it accepts students not only from the BME, but also from several Hungarian universities. Bilateral and multilateral agreements assure the access for international applicants: students come now regularly from neighbouring countries in the region, and also from distant parts of the world. The level of the education extends from undergraduate practices to postgraduate education, including diploma works and PhD thesis. The Department of Nuclear Techniques also organises upgrading and vocational training courses for engineers working already in nuclear installations. Also a wide research program is carried out using the many different irradiation facilities and laboratories of the TR. In this paper we concentrate only on the international and postgraduate educational programs.

2. Cooperation with the IAEA

The cooperation with the International Atomic Energy Agency consists of

- Organising IAEA training courses in the BME
- The professors and lecturers of the BME give lectures in IAEA training courses abroad
- Staff members of the BME perform expert work – also education – in many different countries of the world

2.1 IAEA Training Courses

The first IAEA training course organised in Budapest was in 1979 about the use of research reactors. The curriculum of this course was composed of theoretical lectures and of laboratory work. A similar training course was organized also in 1983. The participants of theses courses came from Bangladesh, Colombia, Czechoslovakia, Egypt, Iran, Jamaica, Korea, Libya, Malaysia, Pakistan, Philippines, Romania, Spain, Thailand, Turkey, Uruguay, Venezuela and Viet Nam. Fig. 1. shows a hand-writing of the IAEA Director General Hans Blix after this course.

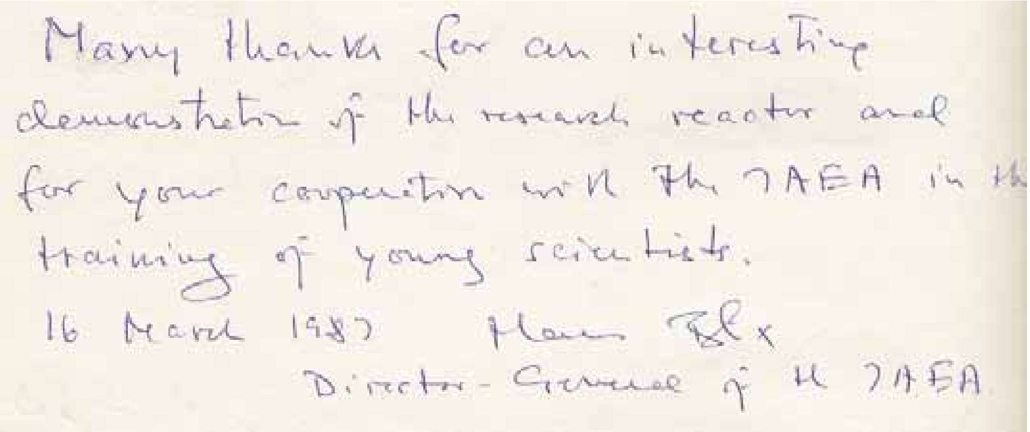
Many thanks for an interesting
demonstration of the research reactor and
for your cooperation with the IAEA in th
training of young scientists.
16 March 1987 Hans Blix
Director-General of the IAEA

Fig. 1. Thanking words of IAEA Director General Hans Blix

A much longer IAEA Training Course was organised for reactor operators between 10th Sept. and 14th Dec. 1984. We show the list of the theoretical lectures (75 hours) and the laboratory work, since it demonstrates well the wide range of capabilities and expertise of the INT.

The theoretical lectures were the following:

- Radiation protection principles
- Radiation measurements in dosimetry
- Radiation shielding
- Reactor physics
- Heat transfer and fluid flow
- Reactor instrument and control
- Reactor protection system
- Reactor safety, accidents and hazards
- Research reactor technique and technology
- Nuclear material control
- Radioactive waste management
- Water chemistry
- Licensing procedures, regulation and codes
- Survey of reactor experiments and experimental facilities
- Reactor management, organization, commissioning, maintenance
- Emergency planning
- The training reactor of the TU Budapest

The program of this course comprised 100 hours of laboratory work:

- Radiation protection and shielding measurements in mixed *n* and γ fields
- Measurements with TLD
- Measuring activity of water and air
- Measurement of thermal utilization factor
- Measurement of resonance escape probability
- Determination of *n* dose in the core
- Determination of the reactivity worth function
- Cricital and subcritical experiments
- Thermal *n* flux measurement in the core of the reactor
- Determination of delayed *n* parameters and U content
- Control rod calibration techniques
- Measurement on the reactor simulator
- Reactor operation training
- Determination of gamma-emitting isotopes in the primary water circuits
- Determination of enrichment of ^{235}U in uranium sample by NAA
- Hot cell technology practice
- Isotope production practice

The participants of this course came from Argentina, Bangladesh, Colombia, Greece, India, Indonesia, Iran, Iraq, Libya, Malaysia, Mexico, Pakistan, Thailand, Turkey and Viet Nam.

2.2 IAEA experts' missions and IAEA fellows received

Beside the IAEA training courses the staff members of the Institute of Nuclear Techniques have performed several IAEA expert missions in developed countries (Austria, Belgium, The Netherlands, Italy, Germany, and USA) as well as in developing countries (Iran, Pakistan, Viet Nam, China etc.) In the last 20 years we accepted 25 IAEA fellows coming from 17 different countries of the world, who performed research work at the Training Reactor. The subjects of their research work included tomography, radioanalysis, environmental and radiation protection, reactor physics, reactor instrumentation etc. As an example some of the names, country and research topics are listed in Table 1.

Name	Country	Research topic
Yelena Kuyanova	Kazakhstan	Natural radioactivity
Maka Khvedeliani	Georgia	Alpha- and gamma-spectrometry
Dagmar Bursova	Slovakia	Analysing Sr and Ra content
Tahseen Alabed	Jordan	Natural radioactivity
Ibrahim Al Hamarneh	Syria	Alpha- and gamma-spectrometry
Rositza Karayvanova	Bulgaria	Sr-analysis
Hasan Mohammad	Syria	Environmental protection
Marieta del Rosario de Infante	Panama	Water chemistry
Thomas Solo	Nigeria	Neutron Activation Analysis
S. Pinam	Indonesia	Neutron-metrology
Bassem Jerby	Syria	Environmental monitoring
Frank Waiharo	Kenya	Neutron Activation Analysis
Mohamed Shhub Ballut	Libya	Sr-analysis
Lorna Palad	Philippines	Sr-analysis

Tab 1: Data of a few selected IAEA fellows

3. International Cooperation with universities

Beside the worldwide cooperation performed in the framework of the IAEA, the Institute of Nuclear Techniques has long-standing bi-lateral or multi-lateral cooperation with universities. The largest multilateral cooperation occurs within the framework of the European Nuclear Education Network (ENEN) Association [1], who has currently 45 members. In the following we concentrate on the cooperation on smaller scale.

3.1 Cooperation with the Slovak Technical University of Bratislava

The cooperation with the Department of Nuclear Energy at the Faculty of Electrical Engineering and Informatics of the Slovak Technical University of Bratislava looks back for almost three decades. We have a student exchange program, where 5-10 energy engineering students arrive to Budapest annually for laboratory exercises at the Training Reactor, and about the same number of Hungarian engineering physics students spend a week in Slovakia on a technical tour visiting power plants and other nuclear facilities. The student exercises in Budapest usually include: criticality experiment, reactor operation exercise, measurement of delayed neutron parameters, thermal neutron flux measurement, reactor-dosimetry and neutron activation analysis. The students also visit the Maintenance Performance Improvement Centre and the Simulator Centre of the Paks NPP and laboratories at the Atomic Energy Research Institute. Last year also a 4-day long neutronics computation course was held for the Slovakian students.

The technical tour in Slovakia include visits of the Gabcikovo hydro power plant, the crisis center of the Slovak nuclear authority, the Mohovce NPP and the LLW and MLW disposal site, the radioactive waste processing plant at Bohunice and the Cerny-Vah pumped storage hydro plant.

3.2 The “Eugene Wigner Course for Reactor Physics Experiments”

The Wigner Course [2] is a joint venture of the following European universities (in alphabetical order): Atominstitute of the Austrian Universities (Austria), Budapest University of Technology and Economics (Hungary), Czech Technical University Prague (Czech Republic), and Slovak Technical University Bratislava (Slovak Republic). The participants of the course perform reactor physics experiments on three different nuclear research reactors in three different countries. The *Quality Assurance Committee* of the European Nuclear Education Network Association (ENEN) assessed this course and suggested that the course uses the quality label *ENEN International Exchange Course*. The IAEA provided financial support to some of the participants of the course. Since 2003, the course is being organized annually. The participants work in groups consisting of 4-5 students. In forming the groups special care is taken to mix the students of different nationality and gender. This way the international character of the course is emphasized, and the use of English language is encouraged. The students in a group travel and work together, and they also prepare the reports together. However, they are evaluated and graded individually. The evaluation is done at each experimental site by oral evaluation of the laboratory report by the experiments’ supervisor, and at a common “final evaluation” session. The course starts with a few theoretical lectures in Bratislava and continues with technical tours to a NPP and radioactive waste treatment centre near Bratislava. The experimental part consists of laboratory practices in Budapest, Vienna and Prague. Detailed information about the Wigner Courses can be found on the Internet: http://www.reak.bme.hu/Wigner_Course Here we list only the experiments at the TR of BME:

- Reactor operation exercise
- Determination of delayed neutron parameters and uranium content of a sample
- Measurement of thermal neutron diffusion length in graphite
- Reactivity worth of neutron absorbers
- Neutron activation analysis

3.3 Cooperation with ‘École de Mines’ Nantes (France)

The French École des Mines de Nantes and the BME INT agreed in 2000 that they organise a joint student project annually for 5 - 5 undergraduates specialised in nuclear science and engineering. From that time on these projects are being organised so that the two universities take turn in hosting the project. The work starts with a preparatory period when students study the state of the art and exchange their views in e-mail. The project itself takes 4 – 5 days that include a site visit, on-site sampling, co-operative work in evaluating the results and compiling a final presentation. The presentation is open to interested faculty members.

Topics of the recent projects:

- Sorption of boron and molybdenum on argilite used for confinement of high-level nuclear waste in France;
- Site remediation of an abandoned uranium mine in Hungary;
- Clearance and exemption levels in EU, their application in French and Hungarian nuclear regulatory practice;
- Environmental monitoring in the vicinity of the Püspökszilágy low-level radioactive waste disposal site,
- Impact of TENORM waste originating from the phosphate industry on the environment.

3.4 International summer training school SUMTRAIC

SUMTRAIC is a summer training school in the field of experimental plasma physics for controlled fusion experiments. The first SUMTRAIC was held in 2003 in Prague at the tokamak CASTOR attending only by Hungarian students. After this successful start the course became widely international and was always organized at CASTOR. The aim was to provide a hands-on experience to university and PhD. students on a small and flexible tokamak experiment. Since

CASTOR has been shutdown due to the installation works of tokamak COMPASS (where the future courses will be held), the students of this course do the measurements on a linear plasma device built in Budapest, where the basic plasma physics processes can be studied.
Students have to understand the operation of the machine, perform experiments, write their own data evaluation programs using the IDL data evaluation language, process data and finally present results on the small workshop on the last day. During the course students get a full overview how a researcher works at a real plasma experiment.

Course programme

Students are grouped into groups of 4 participants each. Each group is assigned to one of three research topics: probe measurements, spectroscopy and turbulence measurements. Each group writes data evaluation programs for its own topic and on the last day prepares a presentation of the results of their experiment. The other two topics are studied as well, but mostly using the programs and help of the responsible group [3].

4. Postgraduate education

4.1 PhD program

The INT BME takes part in the PhD school of the Faculty of Natural Sciences of BME. As an example of the wide spectrum of the research work done we show a selection from the successfully defended theses in Table 2.

Year, name	Subject of the thesis
2001: Szabolcs Czifrus	Design and realisation of a neutron field in the irradiation tunnel of the TR, suitable for BNCT
2003: Sándor Kiss	Analysis and assessment of noise diagnostic signals from NPP
2003 János Végh	Support of safe operation of NPP by use of online information systems
2004: Zoltán Hózer	Modelling leakage of fuel-elements
2004 Éva Kabai:	Investigation of behaviour of long-lived radioisotopes in the soil-plant system
2004 Tamás Pázmándi	Space-dosimetry using a 3-axis Si-detector telescope, and the ’Pille’ TLD dosimeter system
2005: Márta Balla	Provenance Study of Qumran Pottery by Neutron Activation Analysis
2005 Áron Brolly	Investigation of accelerator driven actinide transmutation systems from reactor physical point of view
2005 Anikó Kerkápolyi	Study of hot particles
2005 Eszter Rétfalvi	Small angle neutron scattering study of radiation damage in steels
2006 Péter Pál Ember	Decreasing Matrix Effect in PGAA
2006 Khaled Sayed Mahmud	Numerical Modeling of Reactivity Excursion Accidents in Small Light Water Reactors
2007 Attila Bencze	Investigation of plasma fluctuations and turbulent flows in fusion plasmas
2007 László Temleitner	Structural disorder studied by neutron diffraction and computer simulations

Tab 2: Data of a few successfully defended PhD thesis

4.2 Continuing education

The INT regularly organises Training Courses for engineers working in different nuclear fields. Typically we have trainees from NPP, from nuclear authorities, sometimes also from dry storage facility. Usually those engineers are trained, who have got their MSc degree in electrical- or mechanical engineering and they do not have enough nuclear background. We organise a two year course of Continuing Education Program in Reactor Physics and Reactor Technology. The courses are in Hungarian, thus their description is only available in Hungarian language on our Hungarian WebPages [4].

The course contains the following elements:

- Applied Mathematics I, II, III
- Reactor Physics I,II,III,IV
- Reactor Technology I,II
- Radiation Protection and Dosimetry
- Environmental Protection
- Nuclear Measuring Techniques I, II
- Thermohydraulics I,II.
- Nuclear Power Plants I,II
- Operation of Nuclear Reactors
- Control Technology I,II
- Electrical Devices and Grids
- Energy Systems
- Laboratory Practices I, II, III, IV, V, VI

5. Summary

The main features of the international and postgraduate education program of the Department of Nuclear Techniques of the Budapest University of Technology and Economics was presented. The BME INT invites students interested in doing hands-on experiments and research work at a nuclear reactor, as well as students for MSc diploma and PhD work. Also applications for the annually organised Wigner Courses are encouraged.

6. References

[1] http://www.enen-assoc.org/
[2] http://www.reak.bme.hu/Wigner_Course
[3] http://www.rmki.kfki.hu/plasma/sumtraic_007/
[4] http://www.reak.bme.hu

DEVELOPMENT OF NEW NUCLEAR ENGINEERING STUDY PROGRAMS AT KAUNAS UNIVERSITY OF TECHNOLOGY

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ABSTRACT

Taking into account the approaching start of construction of a new NPP in Lithuania and growing needs for nuclear expertise in Lithuanian energy sector, the new State National Program for preparation of highly qualified nuclear engineering specialists is prepared and being implemented. This program includes: reorganization of existing system of nuclear education, creating or updating of training facilities and methodology, modernization of pedagogical personnel's competency improvement system, creating or updating systems for re-qualifying of currently working nuclear and non-nuclear specialists, systems for nuclear competency maintenance and improvement, nuclear knowledge retention, measures for advocating of positive features of nuclear energy and improvement of public perception. The first steps for implementation of the above mentioned program – establishment of the two new Nuclear Engineering Study Programs at Kaunas University of Technology – are described in this work.

1. Introduction

A broad and deeply rooted nuclear competence is essential for proper, safe and effective operation of nuclear facilities. However, several negative indicators currently can be observed in the nuclear knowledge management area: an imbalance between the public perception of the extent of nuclear energy use and growing needs for nuclear expertise, aging of existing NPP's personnel and high retirement expectations, insufficient investments in nuclear research, education and training, lack of popularity, pre-interest and motivation of young people to study nuclear engineering. Such circumstances can cause difficulties to meet future operational and regulatory requirements and result in serious problems during construction, staffing and commissioning of a new NPP and development of entire nuclear infrastructure.

The analogous challenges are typical for the most modern and well developed countries; but they are yet more sharpened at relatively small countries with limited human and financial resources like Lithuania. Success of planned upgrading of the used nuclear technology and remaining of Lithuania in the family of nuclear states will depend on timeliness and effectiveness of organizational, technical, and managerial measures taken, including modernization of nuclear education system.

2. Forecast of needs for nuclear engineering specialists

Human resource development needs strongly depend upon the accepted approach to fill the staffing needs of new built NPP through indigenous development or purchase the required capabilities through a turn key project. Even if a turn key project is the preferred approach, consideration of developing indigenous capabilities should be considered for the long term. For each nation it is desirable to develop its own educational and training capabilities to better assure the long term availability of the crucial human resource and to provide opportunities for its citizens. While the development of human resources requires investment, this investment brings overall benefit to the economic development of the nation [1].

Needs for nuclear engineering specialists also depend upon installed power of nuclear power plant, number of units, accepted industrial and human resources policy, level of the operator's expertise, level of subcontracting during periodic repair and maintenance and other factors.

Trying to determine quantified future needs for nuclear engineering specialists to be trained in the context of the approaching construction of a new NPP in Lithuania and developing entire nuclear infrastructure the specific study was performed at Kaunas University of Technology in 2007 [2]. The following issues were examined in this study:

- Situation in the Lithuanian job market concerning supply and demand of qualified engineering specialists for energy plants was analyzed;
- Available data about numbers and qualification of personnel working at nuclear power plants in different technologically well developed countries were explored;
- Preliminary needs for nuclear engineering specialists were determined and tentative schedule for their preparation was worked out.

Currently demand for highly qualified specialists of technology is about 1.5 times bigger than offer (for mechanical engineering specialists this ratio reaches 1.66). So, situation in the job market is not favourable for construction of a new NPP.

Numbers of personnel employed at different NPP's were compared, using generalized parameter – relative number of workers, falling to 1 MW installed electric power. Value of this parameter varies from 0.25 – 0.30 worker/ 1 MW(e) in nuclear power plants of USA, France, Switzerland and other western countries up to 1.5 – 1.6 worker/ 1 MW(e) in nuclear power plants of Russian Federation. It was observed, that type of reactor has no big impact to relative number of personnel. Much more important is organizational strategy of activities during operation and periodic maintenance – repair sessions and number of energy units. In the western-type of NPP's maintenance and repair personnel is not included in the staffing list of the plant, and the relative number of the permanent workers is low. During the period of scheduled maintenance and repair number of engaged subcontracted personnel in such plants grows up significantly (up to several times). Another strategy is used in the Russian – type NPP's: the total number of personnel here permanently includes all kinds of specialists involved in the operation, repair, maintenance, safeguard and other supporting services, and these results in a higher value of relative number of workers.

The existing best organisational practice concerned with staffing of NPP's can be summarised as follows:

- Total number of personnel of NPP during the period of normal operation should be determined on the basis of the value of relative parameter equal 0.3 worker/1 MW(e);
- During period of the scheduled maintenance and repair there should be available the subcontracted technical personnel totally resulting from the value of 0.7 worker/1 MW(e);
- The "genuine" nuclear energy specialists comprise about 30% from the total number of personnel of NPP and its supporting organizations.

On the basis of such assumptions, taking into account that the planned total installed power of a future new NPP in Lithuania with two energy units will be 3000 – 3200 MW(e), the approximate total number of permanent personnel of such plant should about 1000 (temporary subcontracted personnel not included).

3. Feasible staffing ways of a new NPP

Probably the most effective approach of staffing of a new NPP seems to be using a mix of experienced personnel in key positions, balanced with entry level positions staffed with young people from universities and technical schools.

At the end of 2007 the total staff of Ignalina NPP was approximately 3100 persons. The majority of these personnel are highly qualified, well trained and experienced specialists. According to the decommissioning programme approved in 2005 number of personnel at

Ignalina NPP is annually reduced on the average by 250 persons. After closure of Unit 2 gradual reductions of the personnel should lead to number about 1600 in 2015 specified in the final decommissioning project. Thus, a big reserve of human resources having valuable nuclear knowledge currently exists at the Ignalina NPP. However, the big part of personnel currently is of the age of 46-50 years, and in 2015 it will be the personnel approaching a retirement age. Employment of these specialists in a new NPP is problematic due to various reasons, and the possible staff contribution from the existing Ignalina NPP to the new one seems to be not more than 20-30 %. Consequently, the reminder of the staff required for a new NPP should be prepared at Kaunas University of Technology and other Lithuanian educational institutions (see Fig. 1).

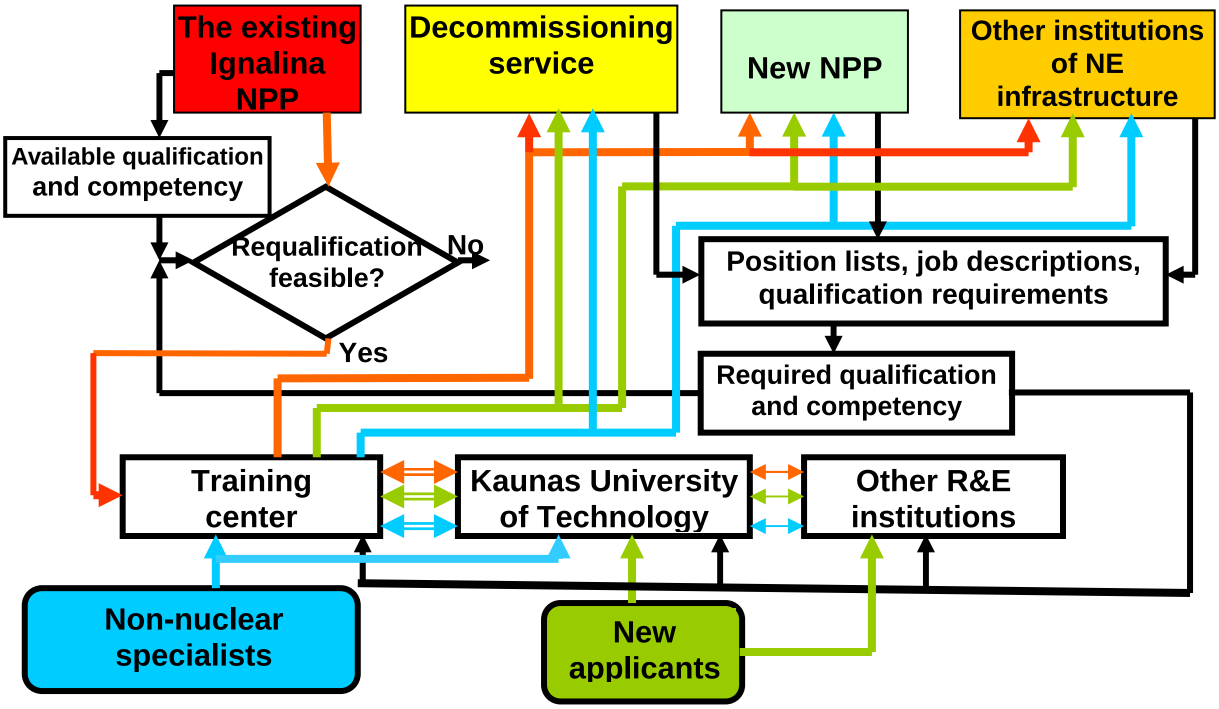

Fig. 1. Possible staffing routes of a new NPP and entire Lithuanian nuclear infrastructure

4. Methodology of the new NE study programs' curriculum development

Up to 2004 the traditional teacher-centred method of designing curriculum was used at Kaunas University of Technology. This approach is focused on the teacher's input and on the learning results assessment in terms of how well the students absorbed the material taught. Course descriptors referred mainly to the content of the course that would be covered in lectures. Such terms as aims and objectives were extensively utilized to describe modules, programs, qualifications, etc., and emphasized teaching hours, subject content and resource counting.

While developing new NE study programmes the student centred learning outcomes approach was used [3]. This approach clearly places the student at the centre of the learning process, and the emphasis moves from the teaching content to the learning outcomes, which focus attention on statements of what students learn. This approach recognizes that much learning takes place outside the classroom and includes the idea that students should be actively involved in the planning and management of their own learning.

Going by this way primarily the desired learning outcomes of the nuclear engineering study programmes were identified. The available documents and guides [4, 5] were taken into consideration and used as reference points. There were written down extensive descriptions of the learning outcomes for both the first and second level NE study programmes. The outcomes of the each study program were differentiated in terms of the following:

- Knowledge;
- Intellectual abilities;
- Practical abilities;
- Transferable abilities.

On the second stage of this process the learning outcomes of the specific modules comprising each programme were defined. It was done on the basis of the interconnection links between the learning outcomes of study programmes and study modules which were portrayed in a tabular matrix diagram. In result the list and content of modules required to achieve the desired learning outcomes were identified. The extended descriptions of the study modules were prepared, indicating the teaching and learning methods to be applied in the learning process in order to enable students to achieve the desired outcomes.

At the final stage the selected modules were comprised into blocks of general subjects, core subjects and special subjects of nuclear engineering and optional subjects according the Lithuanian General Regulations for Technological Sciences (Engineering) [6]. For the further implementation of the learning outcomes concept the following steps are foreseen in the near future:

- Differentiation between generic and subject-specific outcomes in the descriptions of study programmes;
- More precise descriptions of criteria and methods for the assessment of the learning outcomes of all study modules;
- Revision of the learning outcomes' correspondence to the threshold standards of learning.

5. Peculiarities of the developed nuclear engineering study programs

The knowledge and skills necessary to purchase or design the relevant equipment, properly construct, licence, operate, maintain a nuclear power plant and comply with normative regulations are spread across most scientific and engineering disciplines. In addition to fundamental scientific and technical education, nuclear workers typically require several years of specialized training in safety, security and radiation protection, and in the design and operation of the specific technology chosen for deployment.

'Characteristics of learning outcomes at the first (bachelor) level include:

- the acquisition of a systematic and coherent body of knowledge, the underlying principles and concepts of nuclear engineering, and the associated communication and problem-solving skills;
- development of the academic skills and attributes necessary to undertake research, comprehend and evaluate new information, concepts and evidence from a range of sources;
- development of the ability to review, consolidate, extend and apply the knowledge and techniques learnt, including in a professional context;
- a foundation for self-directed and lifelong learning; and
- interpersonal and teamwork skills appropriate to employment and/or further study.

Using these desired learning outcomes as inputs, the specific content of nuclear engineering study program was developed (Tab. 1). Although the primary focus of the four-year bachelor of nuclear engineering program is nuclear power plant engineering, the curriculum is sufficiently broad-based that graduates will be well qualified for careers in many applications of nuclear technology and energy related fields. The first two years of study provide students with a solid foundation in the fundamentals of mathematics and sciences, with years three and four concentrating on the core engineering sciences and specific nuclear engineering courses.

Tab 1: Structure of the first level (bachelor of nuclear engineering) study program

Block of modules	Extent	
	In credits	Relatively
General subjects	11	0.07
Core engineering subjects	91	0.57
Special nuclear engineering subjects	50	0.31
Optional (freely chosen) subjects	8	0.05
In total	160	1.00

A graduate of a Master's of nuclear engineering degree program should be able to:

- provide appropriate evidence of advanced knowledge about main theoretical and applied topics in the nuclear engineering field;
- demonstrate a high order of skill in analysis, critical evaluation and/or professional application through the planning and execution of project work or a piece of scholarship or research; and
- demonstrate creativity and flexibility in the application of knowledge and skills to new situations, to solve complex problems and to think rigorously and independently.'

The two-year Master's of NE study program includes four blocks of modules with total extent 80 credits. The block of theoretical studies covers 7 modules (26 credits, 32,5 % of total); block of special nuclear engineering subjects covers 5 modules (18 credits, 22,5 % of total). 10 % of the Master's study program (8 credits) are devoted for electives and 35% (28 credits) – for research.

6. Conclusions

The learning outcomes approach was employed as an effective tool for development of new Bachelor’s and Master’s of nuclear engineering study programmes. Hereby designed programme’s curriculum seems to be corresponding to main institutional, national and international regulations and reference guides. The ensuring of adequate interconnections among learning outcomes, teaching & learning methods and results’ assessment is most relevant for the quality assurance of the developed study programmes.

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THE ROLE OF UNIVERSITIES FOR THE RENAISSANCE OF NUCLEAR ENERGY IN SPAIN

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ABSTRACT

In the next two years the education at universities in Spain will be changed according to the European Space Education system, adapting the programs to a new model. In this sense and due to the construction of new NPPs in the world and in Europe, we need to consider in our programs new methodologies and advanced tools to generate new engineers with advanced knowledge. There is a good chance to coordinate the high education between universities, research centres and industry in order to create in Spain an appropriate knowledge able to attack the generation changes in human resources and the substitution of NPPs in the next coming years. In this work will be presented several ideas, schemes and actions to build the nuclear knowledge and critical mass in human resources in Spain.

1. Introduction

Spain has eight nuclear reactors operating. Six units are pressurised water reactors (PWR) and two are boiling wáter reactors (BWR), having at present a total generating capacity of 7728 MWe. The electricity generated by the nuclear capacity represented in 2007 the 20% of the total electricity generation. Spanish nuclear reactors continue to perform very efficiently, being the average load factor around 90% for over the last 10 years. This trend is also confirmed in 2007, having a load factor of 88,2% and the operating factor of 90,5 %. The nuclear capacity has additionally gained about 586 MWe since 1990 by capacity upgrades implemented in existing nuclear units. These NPP´s in operation avoid the emission of about 40 million tons of CO_2 per year.

Education and training in nuclear subjects has been tradicionally done in many Spanish universities, mainly at polytechnical universities, as in Madrid (UPM), Barcelona (UPC) and Valencia (UPV), at the research centre CIEMAT, and in the nuclear industry as

TECNATOM and Empresarios Agrupados. At present, most of the professionals working in the nuclear sector came from the aforementioned universities.

Although the nuclear sector is very active in Spain, however the current government has expressed its desire to phase out all the nuclear power units in the medium term. For tis reason, there is not a real renaissance of nuclear energy in Spain, as it has been announced in other countries. According to this political decision, nuclear education don´t need additional enhancement, and the renewal of professionals can be maintained with the present education and training programs. However, if a rainessance is planed for the next coming years, it should be necessary to stablish measures to cover new jobs. Then, new Masters and training programs should be urgently implemented in the planning of universities, research centres and industry, creating grants towards the cost of the university education for brilliant students in the next ten years, otherwise it will not be able to create new jobs with lnational human resources.

In this paper there is a view of how the UPM has considered up to now the education and training in the nuclear sector and what new trends should be considered for the coming years, assuming a renaissance of nuclear energy in a global sense, in which Spanish human resources could participate for the progress of the nuclear science.

2. Actual nuclear education at UPM

The UPM offers education programs covering in a high percentage the needs of human resources for the spanish nuclear industry, mainly for the nuclear power plants in operation and also for the rest of the nuclear sector: services, engineering companies, regulator, waste management, fuel fabrication, research and teaching. UPM provides a large list of engineers especialists in mechanic, electrical and electronic, energetic, chemist, and material science between others, with a favourable and deep background. A few porcentage of them are involved later on in NPP´s, engineering companies and in the public nuclear sector.

While the construction of new nuclear power plants may be complicated in the next coming years, the government should ensure a stable and predictable operating and regulatory framework. In this context, the UPM has a clear vision about its relationship with the society, providing a deep education in this way. If the government maintains its position of desiring a nuclear phase-out, it should conduct a quantitative analysis of the impact of a nuclear phase-out on supply security, GHG emissions mitigation and electricity prices. Such an analysis should also include the costs and benefits of extending the operating lives and increasing the capacity of nuclear plants. The result of such an analysis should ensure: a high level of safety in the operation of NPP´s, the storage of spent fuel, the disposal of low- and intermediate-level nuclear wastes, to build and operate the final disposal facility for high-level radioactive wastes, and the decommissioning of the nuclear power plants. For all these programs the government should enhance the education of young engineers for renewal positions, having as main goal that the nuclear energy is one of the energies for the future share of electricity that don´t produce GHG emission. UPM is promoting this goal as a real chance for the new titulations.

Mobility of both students and professors is one of the most importants added value to the universities and it will contribute to the coming years to increase potentially the Masters offered in competence with other universities. Every year more than 2000 students of UPM are following courses in other european universities, under the Erasmus umbrella and a similar number of foreign students are involved in different courses at UPM. In the last four years this mobility has increased with other continents as America and Asia. Due to this, UPM belives that countries with a renaissance of nuclear programs need a large number of engineers covering different fields, even with nuclear knowledge.Then the Nuclear Engineering Department of UPM offers two Master programs to cover this gap, now in spanish language and it will offered in english in the next years.

A first Master is offered in Nuclear Science and Engineering, which is a vital and exciting field, covering several facets: physics, chemistry, medicine, and engineering. This Master pretends to provide tangible benefits for the future of the spanish society and it is open to the rest of the world. Only a more broadly educated society can hope to deal effectively with a wide range of important scientific topics, including medicine and energy policy. Every year about 15 students are involved in this Master.

The offer of this Masters at UPM is estrategic for the future because consists on establish subjects that help facilitate: a first work in the nuclear energy sector or in nuclear science, and also permits the transition of early-career scientists into forefront research activities and educational opportunities. This Master is offered by the Nuclear Engineering Department and by the Institute of Nuclear Fusion. Postgraduated students have to follow two courses of 60 ECTS each, and this Master has obtained the Quality Award given by the National Agency of Quality and Acreditation (ANECA), depending of the Government. This is the unique Nuclear Engineering Department in Spain having this award. This Master gives also the opportunity to obtain the PhD in Nuclear Science and Engineering for those students that afterwards present and defend their Thesis in this field.

A branch of this Master is the Erasmus Mundus in Nuclear Fusion together to CIEMAT, and other spanish and european universities. This doctoral program has also the Quality Award. One of the adventages of obtaining this award is the possibility to invite every year to foreign professors for teaching in some of the subjects, with public funds.

A second Master is offered in collaboration with TECNATOM, and it is focused to Technologies for Electrical Power Plants. This is a 60 ECTS Master covering all technologies of electric generation. Nuclear generation is one of the main modules, in which students study basic subjects in nuclear physics, nuclear technology, nuclear safety and radiation protection and also dedicate time to work with simulators of NPP´s to know the different phases of the operation. This a good example of collaboration between industry and university. This Master is now in the seven year.

UPM is one of the partners of ENEN from the begining and participates activelly in exchanging students and offering short stages for those whising to dedicate the time to the final thesis.

3. Future nuclear education at UPM

To judge the demand for nuclear engineers in the next years, it is necessary to know that the average age demographics of the current workforce in Spain in the nuclear sector is close to 50 years. For the next 15 years there will be to substitute about 2000 engineers and 4000 technicians. So in case of a renaissance the number will increase by several factors. Several steps might be taken into account by the academic community to realize this goal:

• Shorten the time students spend in the graduation and master programs.

• Become aware of and take advantage of funding opportunities for graduate students in areas of national need.

• Encourage the best and brightest undergraduate students to take advantage of undergraduate research opportunities in nuclear science, then actively recruit these experienced undergraduates to continue their nuclear science studies and research as graduate students.

• Nuclear science faculty should identify new ways to engage graduate students in research early in their graduate careers.

In a near term, professionals in the nuclear sector will be involved in a large number of applications as: medicine, materials, industry and advanced technologies, then the education of professionals should come from the participation in several programs of education, training or research, as:

- Those offered by universities.
- Advanced courses at universities and training providers.
- Research activities done in collaboration through national and international programs.
- Networks of education.
- Summer schools.
- World Nuclear University.

UPM is enhancing the above behaviours focusing in the followings trends:

a. To maintain the high level knowledge in the nuclear science, with the masters above mentioned.
b. To know and implement advanced technologies.
c. To provide professionals in a shorter time, with a high level of knowledge.
d. To improve our master courses offering in foreign languages for increase the number of nuclear experts.
e. To offer training courses in collaboration with industry and research centres for non nuclear professionals, or advanced courses for nuclear professionals.
f. To participate in research programs as those offered by FP7.

4. Conclusions

The nuclear industry in Spain offers services and products that largely cover the needs of its nuclear power plant operators. Yet the current government has publicly expressed its willingness to phase out nuclear energy at least in the mid-term. The regulatory uncertainties caused by the government decisión should be minimised. It should also be borne in mind that a nuclear phase-out could have significant implications for Spain's future energy security and climate mitigation policies. It is essential for the government to develop an reliable estimate of short-, mid- and long-term consequences of the phase-out, including the consequences for nuclear science education at universities.

Nuclear industry demands professionals with a high education and with a broad knowledge, mainly in the nuclear topics, and also in others areas as: mechanics, chemistry, electricity and materials, which are very close matters to the nuclear science. The formation of new professionals takes a long time to universities and industry. Then it is very important to have a planification for the next twenty years to attract good students by means attractive government grants and mobility programs.

Future education in the nuclear sector requires to know advanced technologies, that should be provided by universities, and in a second phase by training proceses in collaboration with the industry. UPM provides both professionals for working in the nuclear sector just after the graduation in Master courses, and also provide appropiate tools for research to cover areas of interest for industry and future reactors in fission and fusión. Nuclear education and training should have an added value for the future, and UPM is enhancing this qualified education in close collaboration with industry, research centres around the world.

THE IMMOBILISATION SCIENCE LABORATORY - BUILDING ON PAST SUCCESS AND DEVELOPING FOR THE FUTURE

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Abstract

The Immobilisation Science Laboratory (ISL) was inaugurated within the Department of Engineering Materials at the University of Sheffield in August 2001 as the third of BNFL's four research alliances with leading UK universities. Its remit was to become a world leading centre in the science and application of waste immobilisation technology. Additional benefits were the generation of a secure skills and a knowledge base in the field of waste immobilisation that was of value to BNFL and the creation of added value to both parties through the mechanism of a university-industry collaboration. In the subsequent seven years there have been many changes to the UK nuclear industry and the ISL has adapted and developed its original remit to answer the new challenges.

Introduction

Throughout the 1970s and 1980s there was a continual decline in funding for nuclear fission research and development in the UK, possibly due to the negative publicity from the incidents at Three Mile Island in the USA and Chernobyl in the Soviet Union, now Ukraine. Historically three organisations had formed the backbone of the nuclear fission skillsbase in the UK - British Nuclear Fuels Ltd (BNFL), United Kingdom Atomic Energy Authority (UKAEA) and the Central Electricity Generating Board. With the closer of many of their laboratories throughout the 1980s and 1990s the manpower had reduced from over 8500 in 1980 to just 2000 in the year 2000. By the late 1990s BNFL decided that investment was necessary to reverse this decline. To facilitate a renaissance in UK nuclear fission research, four University Research Alliances (URAs) were established by competitive tender. Initial core funding of £2M was awarded to each of the URAs, namely -

- Centre for Radiochemistry Research, University of Manchester -1999
- Institute for Particle Science and Technology, University of Leeds - 2000
- Immobilisation Science Laboratory, University of Sheffield - 2001
- Materials Performance Centre, UMIST - 2002

Establishment of the ISL

A centre for waste immobilisation technology was awarded to the Department of Engineering Materials at The University of Sheffield in 2001 and Professor Bill Lee appointed as its first Director. Dr John Roberts was appointed Manager in February 2002 and the centre named the Immobilisation Science Laboratory, reflecting the main thrust of the ISL, to understand the underlying science involved in the immobilisation of radioactive waste. Key to the success of the ISL was the decision to utilise the majority of the £2M award for the appoint of seven new staff; two five year post-doctoral research assistants, Dr Neil Hyatt and Dr

Joanne Hill and five academic appointments. The Department of Engineering Materials at The University of Sheffield is a 5*A rated department and has a long history of research in ceramics, cements and glasses. The world's first Department of Glass Technology was established in Sheffield in 1917. The expertise of existing staff made a significant contribution to the award of the URA to Sheffield and the new academic appointments were made in research areas to compliment and enhance the expertise already present in the Department. Along with Professor Lee (ceramics) the original academic staff of the ISL comprised Professor Peter James (glasses), Professor John Sharp (cements) Professor Fergus Gibb (geological disposal of radioactive wastes) and Dr Russell Hand (glasses). The five new appointments where

- Dr Michael Ojovan - high temperature immobilisation methods and non-destructive testing of nuclear materials
- Dr Neil Milestone - cement chemistry and formulation of new cementing systems
- Dr Karl Travis - modelling over all length scales
- Dr Günter Muobus - electron spectroscopy and mapping of structure at all lengths
- Dr Hajime Kinoshita - handling of actinide materials plus high temperature synthesis and analysis of ceramics.

Professors James and Sharp have retired and Dr Neil Hyatt was appointed as a lecturer bringing the number of ISL core academic staff to nine. Associate ISL academic staff are Dr John Parker (glasses) and Professor John Harding (modelling). The ISL have also appointed Professor Neil Chapman as Visiting Professor. As well as his role as Chairman of the School of Underground Waste Storage and Disposal, Professor Chapman has many years experience as a consultant to the worldwide nuclear waste industry. The ISL currently has six post doctoral research assistants and ten postgraduate students who along with undergraduate project students brings the total number of ISL staff to approximately forty. Three Nexia Solutions staff (formerly BNFL R&T) have been appointed in a visiting capacity, Drs Ewan Madrell and Scott Owens as Visiting Lecturers and Ed Butcher as Visiting Researcher.

Development and External Collaboration

With a team established, the ISL partook in a series of visits to centres of excellence around the world to learn from best practice. These included

- Vitreous State Laboratory, Catholic University of America, Washington DC, USA
- Pacific Northwest National Laboratory, Washington State, USA
- Savannah River Site, South Carolina, USA
- CEA Laboratories in Saclay and Cadarache, France
- SCK•CEN, Mol, Belgium
- SKB Facilities including the Åspo Hard Rock Laboratory, Sweden
- Grimsel Test Site Switzerland
- Institute for Transuranium Elements, Germany.

Collaborations have continued with ISL students and postdocs spending time at these facilities and bringing new experimental techniques back to the ISL. A recent ISL postgraduate student Andrew Connelly has moved from the ISL to a research position with the CEA in Cadarache, further cementing ISL-CEA ties while Claire Utton is working at the Tokyo Institute of Technology. Overall the ISL has been very successful in training postdocs and postgraduate students that have gained employment in the nuclear industry. Of the ten postgraduates that have already obtained their PhD at the ISL, six have entered the nuclear industry with companies such as Nexia Solutions and AMEC. Another successful initiative was the establishment of an International Advisory Panel. The panel visited on a yearly basis as the ISL was being established and consisted of Ian Pegg - VSL:CUA, Etienne Vernaz - CEA, Pierre Van Iseghem - SCK•CEN, Karen Scrivener - EPFL, Pete McGrail - PNNL and Fred Glasser - University of Aberdeen

The ISL has also developed links based on a hub and spokes model with other universities in the UK. The four URAs have always worked closely together through joint supervision of students and collaboration on research projects, both research council and industry funded. The ISL have also developed close ties with Imperial College London, Queen's University Belfast and the Universities of Warwick, Reading and Birmingham. With industry funding through the URAs being so successful research council funding started to re-appear for nuclear fission funding with the ISL having a central role in many of the developments. The Nuclear Technology Education Consortium was established and co-ordinated by the Dalton Nuclear Centre at The University of Manchester as a short-fat modular system for delivery of postgraduate taught courses for Continual Professional Development all the way through to M.Sc. Qualifications. With initial funding from the Engineering and Physical Sciences Research Council (EPSRC) the ISL provide a core module (Processing, Storage and Disposal of Radioactive Waste) of the Decommissioning Stream. This course has so far being given in the last three years as a direct lecture theatre taught course. For the academic year 2008-09 it will also be available as a distance learning course, one of the first NTEC courses to be converted.

Two other major initiatives aimed at PhD level training and also funded by the EPSRC are the Keeping the Nuclear Option Open (KNOO) research programme and the Nuclear Engineering Doctorate. Whereas the KNOO provides a traditional method of PhD training with students based at universities, Engineering Doctorate programmes are run in collaboration with industry with the student based with the industrial partner and visiting the university partner for technical taught courses and supervision, as well as MBA-type courses over a four year period. By including this management aspect of the course it is envisaged that Eng Doc students will eventually gain employment as leaders in industry at the end of their four years. The ISL also has a supportive role is the Sustainable Nuclear Energy project led by the University of Manchester that researches the social and economic aspects of a future UK nuclear fission programme.

Through collaboration with European institutions it was natural that the ISL should participate in EU Framework funded projects. So far we have been successful in obtaining funding under Framework VI from the NF-Pro integrated projects and ACTINET network of excellence. The ISL is hopeful of continuing this success under Framework VII.

When the ISL was established, one of its objectives was to use the initial core funding as leverage to obtain further funding not only from public funding as described above but also from industries associated with nuclear energy. This was seen to be a key objective to ensure the success of the ISL beyond the initial five year period funded by BNFL. However, during this five year period many changes took place in the UK nuclear industry, not least of which was the separation of BNFL into separate companies and the establishment of the Nuclear Decommissioning Authority. As a result the core funding of the ISL was transferred to the NDA. In its initial phase the ISL collaborated with BNFL, UKAEA, AWE and Nirex on long term projects but was also able to work closely with BNFL Business Groups based at Sellafield on short term projects of direct relevance to the site.

A key success of the ISL has been the establishment of the Radioactive Waste Immobilisation Network (RWIN). Initially funded by the EPSRC, RWIN has so far had eight successful meetings covering the whole range of immobilisation technologies and with a membership of over 350 has continued the meetings with delegates now paying a registration fee for each meeting. The main goal of RWIN is to encourage and facilitate communication between the different sections of the UK nuclear waste industry. Government agencies, regulators, industrialists and academics all give presentations on their current work in an environment that fosters collaborative solutions to the many challenges highlighted. Several overseas speakers have also been invited to provide updates on their own national programmes. In tandem with RWIN the ISL has also established an outreach programme aimed at school children. This enables the communication of actual facts about the nuclear waste industry and is a valued contribution to both scientific and environmental aspects of the curriculum.

Research Portfolio

The success of the ISL is ultimately determined by the success of its research which is divided into the following general areas:

- Vitrification and nuclear waste glasses
- A toolbox of cement types for encapsulation
- Ceramic Immobilisation for actinide wastes
- Nanoscale Characterisation
- Non Destructive Testing
- Materials Modeliing
- Deep Geological Disposal.

To enable this research to be undertaken the ISL has access to a range of world class test facilities including

- Scanning Electron Microscopy
- Transmission Electron Microscopy
- X-ray Diffraction
- Isothermal Calorimetry
- Hydrothermal Leach Testing
- Thermal Analysis

Research in vitrification and nuclear waste glasses is focussed on investigating the relationship between wasteform production, processing, composition, structure and materials properties. New glasses are being developed to handle high halide containing wastes which are not compatible with the existing glass formulations. Using X-ray absorption spectroscopy can determine the oxidation state and co-ordination environment of key waste elements such as molybdenum. The corrosion mechanism and durability of simulants in vitrified products is also studied with an emphasis on near-field interactions. A mechanism for breakdown of the vitrified product by water has been developed.

For ILW the ISL is currently developing a toolbox of bespoke cement types for particular wastes. Research into the encapsulation of ILW originally concentrated on the waste/matrix interactions in order to estimate the long term durability. Many potentially detrimental interactions with legacy wastes have been identified such as corrosion of aluminium and uranium in cement or the reactions of zeolitic absorbents and dessicants. By developing different types of cements that use partial substitution of OPC or completely new formulations that are not based on OPC, these problems can be avoided producing a much more durable wasteform.

The ISL's ceramic immobilisation work is focussed on developing a formulation for immobilisation of PuO_2 which may be declared a waste in the UK. Research at the ISL uses Ce and U as Pu surrogates but collaboration with the Centre for Radiochemistry Research URA and the Institute for Transuranium Elements enables the use of active ^{239}Pu bearing samples. Immobilised radionuclides are stored in the immobilisation matrix via an atom by atom solid solution. The details of the atomic accommodation such as the structural units need to be identified and models of structure developed.

By using advanced electron microscopy in conjunction with complementary x-ray spectroscopy, magnetic resonance and Mossbauer Spectroscopy the ISL is conducting research into how radionuclides are held within structures. For example the use of specialised elemental mapping techniques allows the mapping of heavy elements against a light element background.

In the area of non-destructive testing the ISL has successfully developed acoustic emission as a means of monitoring nuclear wasteforms. A validated procedure for interpretation of acoustic signals from laboratory scale simulant cementitious wasteforms has been established with the procedure now ready for full scale deployment.

Most countries in the world are considering underground engineered barrier systems at a depth of 500 - 1000 m for the final disposal of their radioactive waste. The ISL is developing an innovative system of deep borehole disposal that would place the waste in a borehole with a diameter of 60 - 80 cm at a depth of greater than 4 km. One of the key aspects of this type of disposal is that it depends on geology rather than engineering to isolate the waste from the biosphere. Laboratory based tests have proved the viability of such a system which is now at the developmental stage for full scale deployment.

The Future

The establishment of the NDA in April 2005 has created many changes in the nuclear industry in the UK, some of which have affected the ISL. The NDA now owns the liability for all the civil nuclear licensed sites in the UK. The R&T division of BNFL renamed Nexia Solutions have managed the university contracts on behalf of the NDA. Management of NDA-University contracts has recently been put out to tender but the ISL is still working closely with Nexia Solutions as a preferred partner on many of the other tender actions issued by the NDA for work. The UK Magnox stations previously operated by the British Nuclear Group are now clustered together into two Site Licence Companies, Magnox North and Magnox South. As they enter a decommissioning phase the ISL will broaden its focus from Sellafield site challenges to include projects that are specific to these sites. A contract has recently been signed for work to support the decommissioning of Hinkley Point A. In parallel to these initiatives the EPSRC has issued a call for proposals specifically in the area of radioactive waste management. In response, it is hoped that the ISL can provide appropriate training and develop new research projects.

With the UK government issuing statements on the need for new build in the UK, with possibilities of exceeding the current 20% nuclear fission contribution to the electrical grid, it is envisaged that the research and training provided by the ISL will be required for many years to come.

REUSING LEGACY SIMULATION CODES FOR EDUCATION IN DISTRIBUTED SIMULATION ENVIRONMENTS

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ABSTRACT

This paper describes the use of DiSiF (Disitributed Simulation Framework) in the context of education and training in the domain of nuclear sciences. It gives an overview of the underlying framework architecture and focuses on the advantages of DiSiF in reusing and preserving existing knowledge stored in legacy simulation codes. Therefore an example is given that shows how a complex workflow is designed with Graphplan [9] and Kepler [8] using the aspect oriented modelling paradigm. It also covers how new knowledge can be created by deploying these legacy simulation codes using the role-based access and view control for academic education and training.

1 Introduction

In the domain of nuclear sciences, many simulation systems have been developed over the past decades. A lot of effort, knowledge, and experience have been put into place for developing and validating these codes. At the time the codes were developed there were technical limitations, therefore handling them successfully requires a lot of experience and learning time. To overcome this obstacle, and to preserve the knowledge contained in these codes, an architecture based on modern software technologies is required. Therefore the Institute of Nuclear Energy and Energy Systems (IKE) is developing a distributed simulation framework (DiSiF), which makes it easy even for non-programmers to integrate those legacy codes into applications and to provide a new infrastructure in which these codes can be used.

The architecture of DiSiF is based on the separation of concerns paradigm [1] and employs web services and grid computing as implementation technologies. DiSiF also includes the possibility of extended user and access control using the role-based view control (RBVC) model. This role-based access and view control supports an easy adaptation for different aspects of education and training without disregarding the mandatory security needs for the domain of nuclear sciences.

Besides the extended learning effort for understanding the mostly complex input of the codes, the user performs the simulation workflow manually or by manually operated batch processing. DiSiF offers actor based workflow modelling using Kepler which is an extensible system for the design and execution of scientific workflows. This allows non-programmers to model and design workflows without needing to know any programming languages. Once a workflow has been designed by experts using legacy simulation codes they can be used for education and training in different contexts.

2 The System Architecture of DiSiF

The system architecture of DiSiF is divided in two parts (see figure 1): *i. the Client Component (DiSiF-CLI)* and *ii. the Simulation Component (DiSiF-SIM)*. DiSiF-SIM offers secured web service interfaces for DiSiF-CLI. The system architecture defines rules for this interface as follows:

1. DiSiF-SIM fully trusts a DiSiF-CLI that uses the secured web service interface.
2. DiSiF-SIM makes neither authentication nor authorization of users.

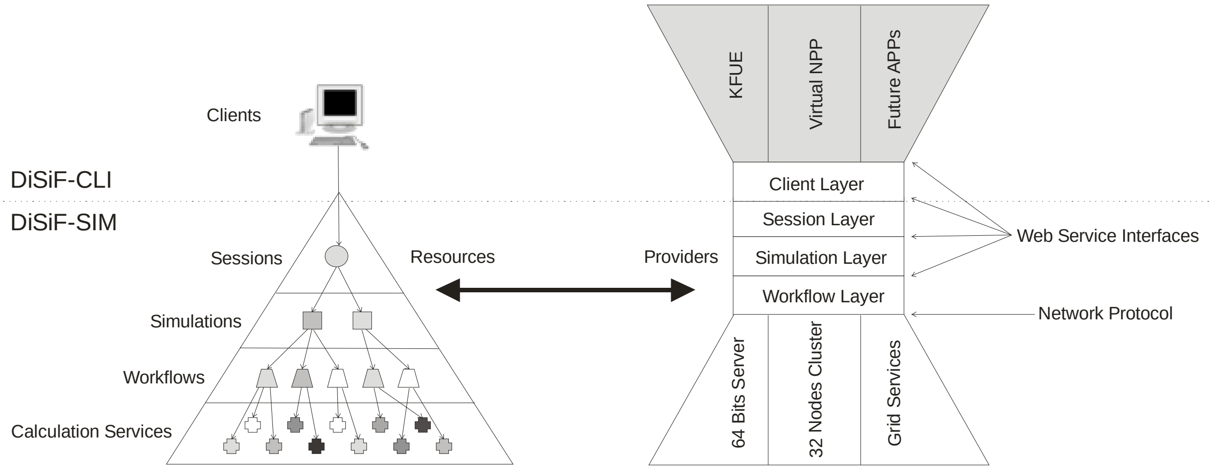


Fig. 1 The hourglass architecture of DiSiF

DiSiF-CLI. The standard implementation of the DiSiF-CLI middleware is a Java Servlet that implements the RBVC user and access control model which extends the role-based access control (RBAC) reference model. RBAC was introduced in 1992 by Ferraiolo and Kuhn [2]. In 2004 RBAC was standardized by ANSI [3] [4]. The ANSI Core RBAC model includes sets of the basic RBAC elements called users (USERS), roles (ROLES), sessions (SESSIONS), and permissions (PRMS). The latter consists of permitted operations (OPS) on objects (OBS). If a role has a specific permission assigned and a user is assigned to this role, he is allowed to perform the operation on the object. In this context the term role represents duties in an organization where users and permissions are assigned to (many-to-many relations).

RBVC extends the RBAC in a way that roles are also used for view control duties. Therefore an extended control model, based on RBAC, was developed, which offers characteristic views on common simulation tool functions. The resulting model is called role-based view control (RBVC) [5]. Fig. 2 shows the view extension made for the new RBVC model. The term view in this context is used for a special shape of a function and includes the behaviour of the presentation and the controller of the application. As a result views can offer optimized functions for the duties in a special role. The figure also shows the standardized role hierarchy (RH) which is a many-to-many relation between roles. In difference to the ANSI RBAC model the inheritance of the RBVC can be controlled by role types. The novelty of this approach is the possibility to use more than one role hierarchy scheme at the same time depending on the role type. This offers more flexibility in using the RBVC model for self administrated and integrating systems.

The standard client is a web browser which communicates with the Java Servlet via Asynchronous JavaScript and XML (AJAX) [6]. This approach allows better graphical user interfaces using AJAX technologies to compensate the benefits given by normal applications compared to normal web applications. But generally the system is not limited to a web browser. The support of other clients is possible but it depends on the specific client if the middleware has to be adapted or changed.

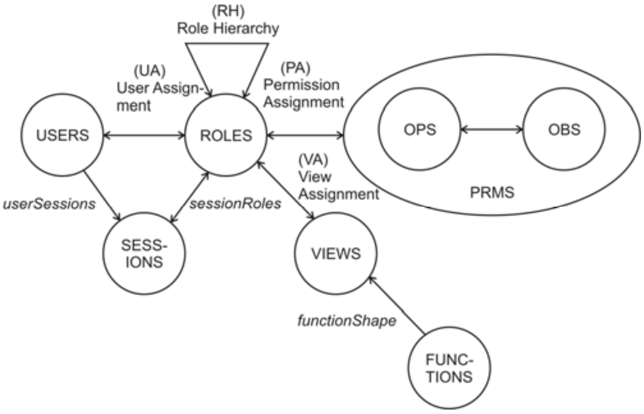


Fig. 2: View extension of the role-based view control model [5]

DiSiF-SIM. The classic simulation scenario in nuclear engineering is the one where a user has to perform a simulation in order to obtain certain results that can be used for further work. The entire simulation is used as a simulation tool or resource by this user, who, most of the time, is unaware of the inherent algorithms and technicalities that make the simulation possible. The user employs the simulation resource and must make a decision based solely on the result of the complete underlying chain of operations. The simulation is composed of one or several workflows which play the role of algorithmic resources for the simulation. Finally, every workflow is composed of computational operations, that can be executed in parallel mode or sequentially and finally provide a result. In DiSiF these computational operations are regarded as the workflow's resources. We called this a hierarchy of autonomous resources and represented it as a layered pyramid (see figure 1). The relations between hierarchical autonomous resources have the following properties: *i. Resources can exchange information with their neighbour's only (i.e. upper, lower, and same level layer);*
ii. A resource from layer n is the owner of the resources it has instantiated at layer n-1;
iii. Information can only be exchanged between a resource and its owner or a resource and it's owned resources.

Figure 1 also shows the layered hourglass software architecture supporting the abstract resource oriented model. Layered software models have been proven to be very efficient in the fields of networking and communication but also in almost all other software development fields, including embedded software or the n-tier model. Each layer corresponds to a resource provider and can run on different machines. Objects that are instantiated at different levels in the stack are the actual resources.

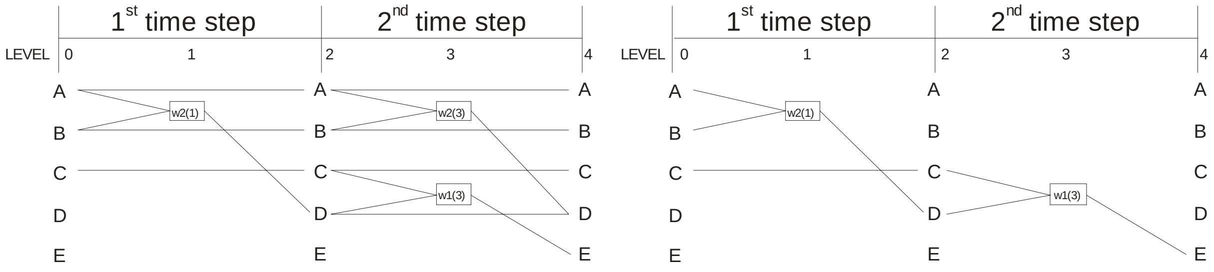
3 Designing Workflows

Workflows are the key components of any simulation system, regardless of whether they are employed in education and training, research or industry. They provide consistency and reliability for the entire system and therefore good workflows should always be a major design goal of any simulation system. Unfortunately in the field of nuclear engineering there is a huge gap between today's software techniques and how workflows are actually assembled by scientists, students and professionals. A typical computer code for the domain of nuclear sciences is composed of scattered computational modules (CMs), usually implemented using the Fortran programming language communicating with each other through input and output files. There are two major issues here:

1. If somebody wishes to make an actual computation which involves more than one such CM there appears the natural need of a workflow and currently this is done by hand, i.e. the user has to manually run the modules one by one in a specific order.
2. The input/output files consumed/produced by the CMs are subject to compatibility restrictions, e.g. the output parameters of module 1 must be among the input parameters of module 2.

Overcoming these issues takes an enormous amount of time for each experiment that one has to undertake. Our approach of designing workflows is based on the actor oriented modelling (AOM) paradigm [8] and a Kepler based implementation. The paradigm states that workflows are composed of actors with different functions that are supervised by a director. The director dictates the way in which actors interact and synchronizes their communication. The actors communicate through input and output ports which are interconnected through relations (see figure 4). The action of an actor is fired when all input conditions are satisfied, i.e. all mandatory input parameters are provided through the input ports. After the actor finishes the action it outputs the results through the output ports and the next actor(s) that are in relation with it can be fired.

Before proceeding to the actual implementation of the workflow, an execution and concurrency plan for the workflow has to be developed. Primarily the plan describes the firing order of the actors and the parameter dependencies but it also provides an overview of all possible interconnection schemes, given a set of CMs (actors) and their associated input and output parameters and variables (actor parameters and ports).



(a) (b)

Fig. 3 – A Graphplan based workflow planning example

Figure 1 shows an example of a workflow plan [10] using the Graphplan formalism [9]. Graphplanning is done in two steps. The first step is called the *expantion step* (figure 3.a) and the second one the *backward search step* (figure 3.b). The parameter sets A, B, and C are available right from the start (level 0), whereas D and E are computed by the two involved modules, w1 and w2. During the first time step, the module action w2(1) is performed and parameter D is output so that at level 2 the prerequisites for module w1 are satisfied. In time step 2 both modules can perform their actions because the required input parameters are available. Module w1 produces the output E which, for this example could be the result of the workflow. Through backwards searching the actual workflow is identified and we can proceed to the Kepler implementation.

The workflow implementation consists of wrapping up the CMs into actor classes and then designing the actual workflow in Kepler. A Kepler actor is a Java class with specialized methods, e.g. *initialize, fire, prefire*, etc., that are called by the workflow engine at different points in time. These classes can be added to Kepler's actor library for future use. Then the job of the workflow designer is to interconnect the actors such that the resulting workflow respects the plan. Furthermore, the execution of the workflow must take place in a specific domain of computation [8] which must also be chosen by the workflow designer. Figure 2 shows an example workflow used in the ABR system [7]. Each computational module is represented by an actor. The model controls the information flow and synchronizes the firing of the different actors, thus, allowing automatic parallel or sequential execution of different branches of the workflow. The SDF (Synchronous Data Flow) director fires the open end actors, i.e. it creates the required number of tokens in order to execute the workflow. The synchronizer actor waits for all the branches to complete. When an actor is fired, the corresponding CM is executed as an operating system process or a Condor [11] grid job.

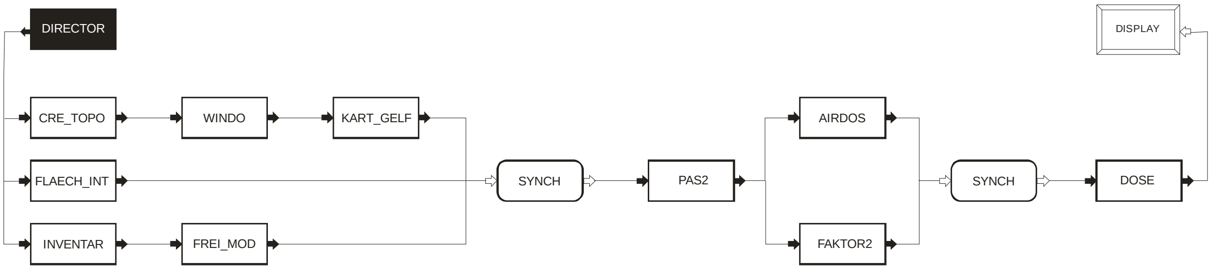


Fig. 4 – The ABR workflow

Kepler workflows can be run from Vergil (Kepler's GUI) or from another Java application by employing and controlling the workflow manager (WM) object. The WM is the same one used by Vergil and it is this feature of Kepler that allows us to define the following two main use case categories: *i. Experimental / educational use* – a researcher / student develops or modifies a workflow using Vergil and the actors in the Kepler library for testing a new concept or *ii. Production use* – the workflow is embedded inside a more complex simulation system like, for example the ABR system.

4 Conclusions

We have presented a method of integrating legacy computer codes into modern software architecture and also showed how to build and use workflows in different contexts. This is an important achievement for the domain of nuclear sciences where researchers, students and professionals must spend much time manually interconnecting scattered computer codes in order to develop a workflow. The presented architecture is secured, scalable and reliable.

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