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Rue de la Loi 57
1040 Brussels, Belgium
Phone + 32 2 505 30 54
Fax +32 2 502 39 02
E-mail ens@euronuclear.org
Internet www.euronuclear.org
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Workshop 1:
Education & Training and Knowledge Management / Cases

PRESERVATION AND MANAGEMENT OF NUCLEAR KNOWLEDGE ON WWER REACTOR PRESSURE VESSELS

V. SLUGEN, M. MIKLOŠ
Slovak University of Technology, 81219 Bratislava, Slovakia

L. DEBARBERIS, A. ZEMAN
EC JRC Institute of Energy, 1755 Petten, Netherlands

ABSTRACT

Activities connected to the nuclear knowledge preservation are ongoing in the EC-JRC Institute of Energy with the intention to collect all available information about reactor pressure vessels of WWER type reactors as well as to analyze and summarize the most important items and issues. This activity is in line of the European Community FP6 projects PERFECT (Prediction of irradiation damage effects on reactor components) and mainly COVERS (Coordinated action on WWER safety) in which all WWER operating countries also take part. Actually, the electronic database was created and is accessible for young or expired researchers in this area. The access is recommended via ODIN (Online Data and Information Network) https://odin.jrc.nl/doma. After registration you can enter the WWER DoMa-db: "Database of references for knowledge management and Preservation on WWER reactor pressure vessel". For the access to confidential information you have to ask an indicated administrator.

The nuclear knowledge management is realized not only via database creation or education process during undergraduate (Bc.), graduate (MSc.) and postgraduate (PhD.) study but also via specialised training courses in a frame of continuous education system, research activities and projects, workshops seminars, ect. For illustration of the actual status and possibilities, the Slovak nuclear knowledge model is used. Unfortunately, decrease of number of employees in nuclear and "human ageing"of experts seems to be a serious problem not only on world but also in Slovakia.

1. Introduction

In the last decade, preservation and optimal nuclear knowledge management are becoming a rising challenge worldwide. Many papers and experts talks at different conferences stressed attention on stagnating or decreasing expertise connecting to decreased numbers of graduates, professors or research workers. [1-3]. Several networks were created in the Europe in frame of the 5^{th} and 6^{th} Euratom Framework Programme accented international collaboration in training and education physics (EUPEN, STEPS) or in nuclear power engineering (ENEN, NEPTUNO) [4-6].

From a huge amount of activities which are in favor nuclear knowledge preservation, we describe our approach based on the database collection of all available information about material behavior of different types of reactors, accenting the WWER ones. We are sure that this knowledge will be essential in the future for proper evaluation of plants life as well as for their lifetime extension. Base on this knowledge, the development of new materials for Generation IV reactors will be easier. Unfortunately, experts in this field are old (with exception of you, of course) and their age is almost close to or even within retirement and thus any preservation and use of their knowledge and experience is becoming more and more difficult or nearly impossible in few years.

2. Database creation

For the project, more than twenty precise selected specialists, mainly from WWER operating countries, have been asked to help with the collection of such mostly rare publications. It is clear that a large number of publications, since the very beginning of the research studies and from the first years of reactors operation, were published in Russian as well as in other national languages (Czech, Slovak, Hungarian, Finish etc.). This makes the situation complicated for most of foreign experts, and today,

also for most of WWER reactor operators in individual countries. A large number of publications was prepared also in other languages and were sent not only to international, but also to some national journals as well as presented in many national conferences/workshops etc. proceedings which are now very complicated to find from abroad.
Authors have been asked via national experts for their full lists of publications dealing with material properties of WWER reactor pressure vessels, and as a first step, it is the intention to concentrate on studies and results related to the irradiation damage and testing for these type of steels as this practically determines reactor pressure vessel lifetime and it is the reason of most vessel problems. As a second step, full texts of the relevant publications have to been required when not be possible to find them in standard libraries. The material and further knowledge has been discussed in the leading group in JRC-Petten and of course, this database of the bibliographies (supported by full text of all included publications with abstracts in English and in electronic format) will be served and will be available to all authors immediately, thus it will also help the authors for current work and studies. Further, these materials will serve as a basis for elaboration of a state-of-the-art report on radiation damage in WWER reactor pressure vessels steels that will be prepared with an active participation of all active authors. The structure and content of the reports will be prepared in the workshop where the participating authors will be invited.

3. Summarization of previous projects

In the field of reactor pressure vessel (RPV) embrittlement, a generational gap is slowly appearing with regard to in depth knowledge of materials behaviour and related neutron embrittlement issues. This is due mainly to the fact that the experts who took part in the design, construction and commissioning of the nuclear reactors are now approaching retirement, if not already retired, and/or changed job for different reasons. In addition, for the Russian design RPVs a significant fragmentation of the knowledge took place with the dissolution of the USSR and the dislocation of the various WWERs into several Member States; including: Hungary, Slovakia, Check Republic, Bulgaria and Ukraine. Significant knowledge on WWER-440 is also available in Finland and of course in Russia. In the previous decades, many of national experts were involved into following international projects.
SAFELIFE - action is the JRC Action dedicated to issues of PLIM (Plant Lifetime Management) of ageing nuclear power plants [7]. Several networks [8], partnership projects and expert groups are operated by JRC on the various PLIM disciplines; among others the major European Networks AMES, NESC, ENIQ, NET, SENUF and AMALIA (see Figure 1). Networks is a key element for the JRC aiming at harmonisation and best practice development amongst the Member States.
In particular the European Network AMES is dedicated to the study of radiation embrittlement of the reactor pressure vessels with the strongest connection to the present initiative. Within the frame of the SAFELIFE - action of JRC, and with NRI as a key partner, a new initiative in the area of knowledge management has been planned and launched at the end of 2004.

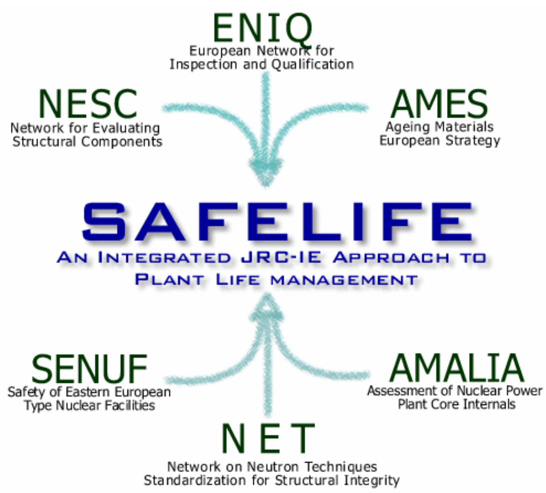

Fig. 1. Major European Networks operated by JRC on PLIM

The initiative of JRC –IE in co-operation with NRI is now concentrating mainly to the very first step of knowledge management: knowledge preservation. This step is now of particular importance when it is urgent to make available as much as possible the scatter knowledge in the various WWER countries. The issues of languages is also considered, since in the Member States besides Russian in the early times and English more recent, national languages were used too as they are used today. The approach followed in those cases is the short translation of the main conclusions and important facts arising from the collected documents.
The initiative is part of the JRC-IE SAFELIFE action and it is the first proto-type example of practical deployment of effective knowledge management in nuclear safety for the particular case of RPV embrittlement.

The general scope of the project can be summarized as follows:

- Collect all paper in original language from the WWER countries; in particular papers which never reached the international circuit. The potential languages that will be encountered are those of the WWER countries: Russia, CZ, Hungary, Ukraine, Bulgaria, Slovakia. More recent papers are mainly in English.
- Prepare PDF files of original.
- Prepare a short English summary with key data & conclusions.
- Organize a documentation data-base.
- Design a method to manage such knowledge including: retrieval by keywords, tracing of authors, additional information, etc.

The project and the database created in frame of this project contributed also directly to COVERS (Coordinated Action on WWER Safety).

4. Development and preliminary results

A first call with a letter (in English and Russian) of intent has been issued at the beginning of 2005 to approximately 20 leading prospective experts identified in the various countries. The identification was done by direct knowledge, amongst the members of the AMES European Network, the IGRMD community and the IAEA Experts.
A series of Workshops was performed with the experts. Assuming that the number of identified experts is a representative sample, their percentage distribution is given in Fig. 2.
The response to the call was unanimously enthusiastically received and the first collection round yielded a good number of papers and documents on the targeted subjects. Besides few papers which could have been anyhow found in the open literature, a large number of ‘original’ or ‘rare‘ documents are now already available.
In Fig. 3, the first round’s collected papers, the estimated available numbers and the expected final numbers are shown. The collection of originals will continue in the period of tree years and extra stimulation methods will be used including the workshops. From a first screening of the content we can draw some statistic of the detailed issues appearing from the collection, see Fig. 4.

5. Follow-up

The selected approach, as given in Figure 5, foresees the finalization of the first round of collection from the pre-defined list of pre-identified experts. The papers are screened and systematically filed in a dedicated documentation d-base. A series of Workshops will support the analysis of the material and the identification of further need and requirement for further collections. A few iterations should be sufficient to reach a reasonable inventory of information.

6. Preservation of nuclear knowledge via education in Slovakia

In the Central-European region, there exists a very extensive and also effective international collaboration in nuclear industry and education. Similarly good situation is also among universities and technical high schools in this area. Actually, the Slovak University of Technology in Bratislava has established contacts with many universities abroad in the area of utilization of research and training reactors. One of good examples of international collaboration is ENEN – European Nuclear Education Network Association which resulted in a formation of “Eugene Wigner Training Courses on Reactor Physics Experiments” running in the last 2 years as a mutual effort of the Budapest University of Technology and Economics (Budapest, Hungary), Czech Technical University (Prague, Czech Republic), University of Technology (Vienna, Austria), and Slovak University of Technology in Bratislava (Bratislava, Slovakia). In total 53 participants from different European countries as Austria, Belgium, Bulgaria, Czech Republic, Finland, Italy, Israel, Romania, Slovakia, Slovenia, Sweden and Switzerland took part at these international training courses so far. In the frame of these courses, students of nuclear engineering visited three different experimental facilities located at the course organisers' institutes and carried out experimental laboratory practices.

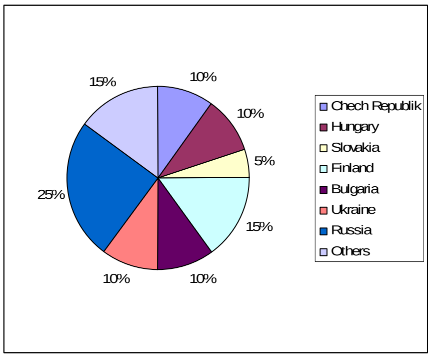

Fig. 2. Experts distribution.

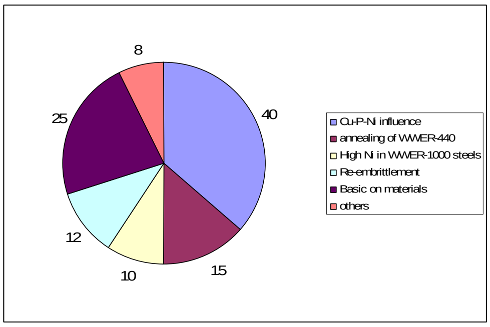

Fig. 4. Distribution of papers per detailed subject.

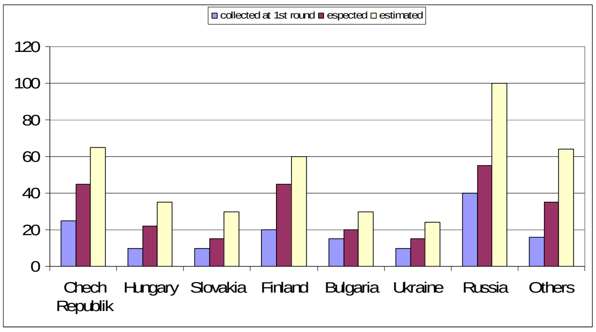

Fig. 3 Distribution of papers and documents.

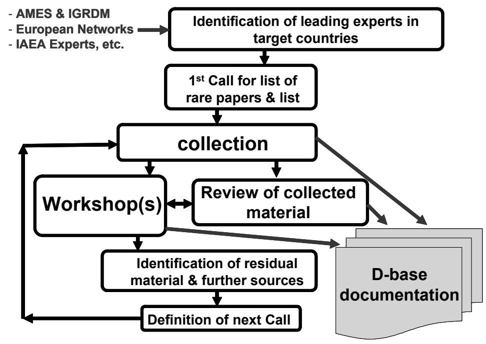

Fig. 5. Methodology.

The high level nuclear education is very important also due to permanent increasing of nuclear experts age. To replace some of them are not easy. Fig.6 shows the number of graduates in the area of nuclear power engineering and nuclear material science in the last 20 years.

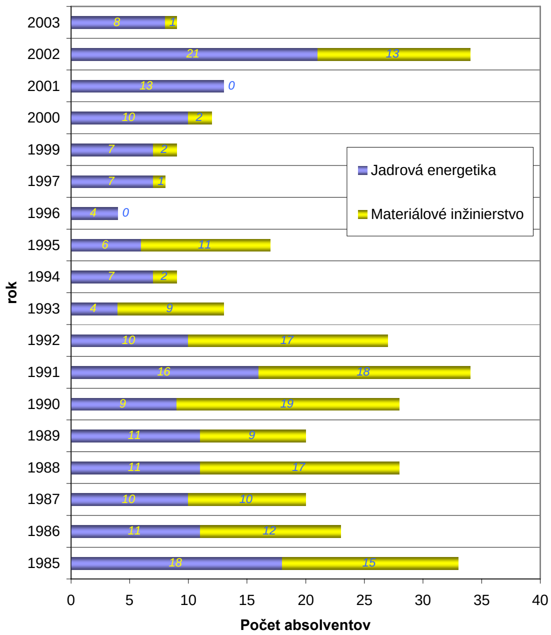

Fig. 6. Number of graduates in the last 20 years.

6. Conclusions

The JRC-IE effort towards Preservation and Knowledge Management in the specific field of RPV embrittlement is a very important tasks and it is discussed in this paper. The effort is carried out in co-operation with the Nuclear Research Institute Rez. The challenge to collect all available information about the behavior of WWER reactors is tackled with a systematic approach; as required in this phase of the plants life. In fact, the information available is for a significant extent available with experts in the specialised field which are close to or even within retirement, so the preservation and use of their knowledge and experience is becoming more and more difficult or nearly impossible in few years. The documentation d-base has been stored and serves as appropriate to suit the requirement of the key projects SAFELIFE, COVERS, PERFECT, etc. Created database was put on the ODIN portal which is provide by European Commission Joint Research Centre (JRC) Petten to the European energy research community. It contains engineering database, document management sites and other information related to European research in the area of nuclear and conventional energy.

The results of the project is accessible (via https://odin.jrc.nl/doma) and useable also for young specialists of the new generation for PWR or WWER plants in all countries since they would be able to be acquainted not only with current views and knowledge but also with its history and background, etc. Further, these materials can serve as a basis for elaboration of a state-of-the-art report on radiation damage in WWER reactor pressure vessels steels that will be prepared with an active participation of all active authors.

University can contribute not only to the education but also to attract students to nuclear field, which is a base also for the safety culture at NPP as well as essential need for accepting nuclear industry by the public. Readers at the university (professors, assistants, etc.) can stimulate students for nuclear physics or at least they can relieve them of distress from nuclear issues. The first contact is very important. University enables an optimal selection of students. The option for "nuclear education" is completely free and independent. The problem is that the amount of students taking these lectures is low. Proper education at the university is a source of knowledge and attitudes for the whole life. Theoretical and practical experiences, professional approach and consistency are very important also from the safety culture point of view. University lectures and seminars are basically opened for public and this academic field can be made better use of in public relations. It is an investment mainly to young generation. During discussions with students, teachers can form their professional orientation according to their abilities and needs. Good teacher encourages also the growth of student and shapes his personality. Graduated students have to learn to take responsibility for their decisions and their academic level of education.

Acknowledgement

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PHYSICS AND ENGINEERING OF NUCLEAR REACTORS AT THE *ECOLE NATIONALE SUPÉRIEURE DE PHYSIQUE DE GRENOBLE* OF THE *INSTITUT NATIONAL POLYTECHNIQUE DE GRENOBLE*

E. MERLE-LUCOTTE, R. BRISSOT
ENSPG-INPG/LPSC-CNRS
53, avenue des Martyrs, F-38026 Grenoble Cedex - France

ABSTRACT

If the use of fossil fuels is to be limited to curtail greenhouse gas emissions, fission nuclear energy is, along with new renewable energies, one of the primary energy sources able to respond significantly to the increasing worldwide demand. In this context, it is necessary to design and evaluate new generations of nuclear reactors as defined by the Gen IV International Forum. The Energy and Nuclear Engineering (GEN) curriculum of the *Ecole Nationale Supérieure de Physique de Grenoble* (ENSPG), one of the nine engineering schools of the Grenoble Institute of Technology (INPG), includes a balanced blend of basic courses in energy, nuclear and thermal hydraulic engineering, together with the corresponding engineering sciences to cover the technological aspects. The objective is to train engineers who shall master not only nuclear engineering for the production of electricity but, more broadly, energy and nuclear technologies and their various application fields.

1. Introduction

Nuclear reactors currently generate nearly one fourth of the electricity in the world, and nuclear technologies have spread into many other industrial areas: instrumentation, medicine, the food-processing industry, materials, etc. The worldwide demand for primary energy is increasing; solutions have to be sought and the level to which these solutions are adapted to the stakes have to be examined. Not many options are available if use of fossil fuels is to be limited to curtail greenhouse gas emissions. Fission nuclear energy is, along with new renewable energies and, in the longer term, fusion energy, one of the primary energy sources able to respond significantly to the demand [1]. In this context, it is necessary:

- To ensure transfer of competences between generations
- To design and evaluate new types of nuclear reactors as defined by the Gen IV International Forum [2]

Such research and development rests on a solid knowledge in physics, on technical innovations, and on efficient numerical and modeling tools allowing the management of these complex systems. The Energy and Nuclear Engineering (GEN) curriculum is one of the six specialty options of *Ecole Nationale Supérieure de Physique de Grenoble* (ENSPG), one of the nine engineering schools of the *Institut National Polytechnique de Grenoble* (INPG).

In this paper, after a brief presentation of the *Institut National Polytechnique de Grenoble* or Grenoble Institute of Technology (INPG), we will introduce the ENSPG. We will then detail the Energy and Nuclear Engineering curriculum, the most complete in France for engineers in the nuclear field. More precisely, three curricula are offered by ENSPG in the nuclear field: the Energy and Nuclear Engineering curriculum itself, a specialized training module in safety and risk management, and a research Masters' in the Physics of Energetics.

2. Grenoble Institute of Technology (INPG)

The Grenoble Institute of Technology (INPG) is one of four universities in Grenoble. The Engineering Schools of the Grenoble Institute of Technology train engineers in key industrial domains. Students are admitted two years after their high school graduation via a competitive entrance exam to the *Grandes Ecoles*, via University degrees, or an in-house Preparatory Course at Grenoble, Nancy and Toulouse Institutes of Technology. They can go on to do a Research Masters' Program and later a PhD, in one of 10 Masters' Programs and 8 Doctoral Schools.

Students graduate after three years of studies in one of the nine "*Grandes Ecoles*" or engineering schools which make up INPG:

- *Physique fondamentale et appliquée, et génie nucléaire* / Fundamental and Applied Physics and Nuclear Engineering (ENSPG)
- *Électronique et technologies de l'information* / Electronics and Information Technologies (ENSERG)
- *Energie et traitement de l'information* / Energy and Information Processing (ENSIEG)
- *Fluides, mécanique et environnement* / Fluids, Mechanics and Environment (ENSHMG)
- *Génie industriel* / Industrial Engineering (ENSGI)
- *Industries papetières et graphiques* / Papermaking and Printing Industries (EFPG)
- *Informatique et mathématiques appliqués* / Information Technologies and Applied Mathematics (ENSIMAG)
- *Matériaux, électrochimie, génie des procédés /* Materials, Electrochemistry, Process Engineering (ENSEEG)
- *Systèmes industriels embarqués* / Embedded Industrial Systems (ESISAR)

INPG is characterized by the following key figures:

- 5,200 students of which 20 % are foreigners
- 11 Engineering Degree Courses from which 1,150 engineers graduate every year
- 1 Masters' and Doctorate School College from which 180 PhDs graduate every year
- 40,000 alumni working worldwide
- 1 Professional Development Department
- 38 laboratories among which 3 are of international standard
- 1 private subsidiary for industrial valorisation, INPG Enterprise SA
- 1,100 teaching and research fellows
- 114 million euros budget

Several aspects of the organization or operation of INPG may appear exotic to a non-French reader. The engineering schools making up the INPG are actually "*Grandes Ecoles*". As for all French "*Grandes Ecoles*", where most of France's top leaders are trained, each school is characterised by a rather small size (under 400 students at ENSPG), and a very selective admission procedure. Students normally are admitted to a school after a competitive examination (*Concours d'Entrée*) which takes place after two years of intensive university-level studies. It is therefore essential to remember that the three years of studies at our engineering schools correspond to the third, fourth and fifth year of university (*post-baccalauréat*) studies.

We will now concentrate on the school of 'Fundamental and Applied Physics and Nuclear Engineering' or ENSPG.

3. Ecole Nationale Supérieure de Physique de Grenoble (ENSPG)

ENSPG stands for *Ecole Nationale Supérieure de Physique de Grenoble*, in other words Grenoble's Engineering School for Physics. ENSPG trains engineers and research physicists who master the various technologies originating from physics, and can make them evolve. It works at developing the students' creativity, and the human qualities they will need as leaders. Over 130 students graduate each year.

More so than other engineering schools, because of its topics and its environment, ENSPG is also strongly involved in graduate studies, leading to the PhD (*Doctorat*), normally obtained after three years of research work, with some courses, following completion of a research masters' degree.

Foreign students are of course welcome at ENSPG. These students can graduate from ENSPG under one of two conditions:

- If these students come from one of the universities with which ENSPG has a double-degree agreement (at the time being: Universität Karlsruhe and Politecnico di Torino), and choose, with their supervisor's agreement, to take the double degree scheme. These students will then obtain both their home University's and INPG's degrees.
- By applying for admission as a regular student at either of the two stages where it can be done: for admission into first year (normally after a 2-year or 3-year university curriculum), or for admission into second year (after a 4-year university curriculum). Admissions are decided on the basis of the student's records.

3.1 Organisation of the Education at ENSPG

The school's main objective is to train physics engineers with both a sound basic training in physics and competence in engineering sciences, economics and social sciences, mastering several foreign languages. The common-core syllabus, corresponding to the three first semesters, aims at this general education. More specialised training, corresponding to one of six specialty options, is given in the following three semesters of the three years of studies at ENSPG.

3.1.1 The common-core curriculum

The common-core syllabus covers the first three semesters or 1325 hours. They include personal work in the form of projects, and cover three main objectives:

- Basic education in the School's general specialty, the properties of matter and their theoretical models, with mathematics as a tool, during 450 hours (34% of the curriculum). Physics of matter is dealt with through lectures in basic physics (quantum and statistical physics, optics, solid state physics, semiconductors and thermodynamics, nuclear physics) and in material sciences (magnetic properties, crystallography, and physics of materials). This academic training is completed by an experimental approach thanks to practical work and a first year group project.
- Sound notions of basic engineering sciences (electronics, automatic control, signal processing, mechanical design, computer science, mathematics and numerical methods) covering 550 hours (41%), aimed at facilitating interdisciplinary exchange with specialists of other fields.
- Throughout the three years, 25% of the time (around 325 hours) is devoted to languages (English and a second foreign language), economics and management, to an introduction to geopolitics, and to sport.

3.1.2 Specialty training: the six specialty options

The student chooses one of the six specialty options. They cover two semesters of courses, followed by the final project. These curricula provide specialised training in areas chosen on the basis of existing or future industrial possibilities, and of Grenoble's technical and scientific environment. The six specialty options (in decreasing number of students) offered by ENSPG are:

- **"Energy and nuclear engineering"** (or 'GEN' standing for Génie Energétique et Nucléaire in French) covers the various aspects of energetics with a particular accent on nuclear technologies.
- **"Functional materials and nanophysics"** deals with materials with magnetic, superconducting, semiconducting... properties, and their applications, especially at the nanoscopic level.
- **"Physical instrumentation"** centres on the design and the technologies of instrumental devices.
- **"Instrumentation for biotechnologies"** centres on the physical and biological processes involved in the instrumentation used in life sciences.
- **"Structural materials"** centres on the preparation and modelling of materials with emphasis on their mechanical properties.
- **"Physics of electronic and opto-electronic devices"** covers microelectronics, optics, optoelectronics and associated technologies.

In section 4, we will focus on the first option, the “Energy and nuclear engineering” or GEN curriculum.

3.1.3 The third year: Special training modules and research masters

The third, final year at ENSPG (fifth year of university studies) is devoted to developing competence in the specialisation field chosen. It includes considerable flexibility, and can to a large extent be tuned to the student’s plans for the beginning of his or her professional career. Thus, the courses in the third year include, apart from a kernel specific to each specialty option, a large choice of “specialised complements” which allow in-depth study of a discipline, or an opening to other fields. Two main options are offered.

1. students intending to complement their training through a PhD will normally follow, in parallel with their final year, a research masters’ (graduate course) as a prerequisite for doctoral work. The research masters’ associated to the nuclear specialty option and chosen by around 30% of the nuclear students is the Masters’ in the Physics of Energetics described in section 4.3.
2. Students can also choose one of two modules: “Project Management and Quality” or “Safety Engineering and Risk Management” to complement their last year of studies. The module “Project management and quality” gives the students some training for jobs like product engineer, project engineer, business engineer, quality engineer. The aim of the module “Safety engineering and risk management” is to give engineering students some basic knowledge in the field of safety (nuclear or chemical safety). This becomes mandatory in positions involving responsibilities as department or laboratory manager. This INPG teaching module, directly linked to the GEN option, will be detailed in section 4.2.

An additional module concerning “Accelerator Physics and Technologies”, an international course organized with a strong participation from the European Particle Physics Center, CERN, is open to students coming either from the nuclear engineering option or from the instrumentation option. As this training module leads mainly to PhD theses, students are encouraged to follow it though a research masters’ like the Masters’ in the Physics of Energetics described in section 4.3.

3.1.4 The training periods

After the first year, students can take a summer job in a company or a research laboratory, allowing them to discover their future work environment. At the end of the second year, students have to perform an internship of at least two months, normally in industry in France or internationally. At the end of the third and last year of studies, they have to complete a six month final project, involving an actual engineering or research work.

The second year internship and the final project lead to written reports and oral presentations.

3.2 Business Opportunities

From 1989 to 2001, ENSPG has awarded more than 1800 degrees. 60% of graduating students decided to begin their professional career straight away. The others preferred to add to the training received in the school either a doctorate (30% of the graduates) or another specialisation (5% of the engineers chose another scientific speciality, very often abroad; 5% chose to obtain a degree in economics or management).

The standard profile for an ENSPG alumnus a few years after graduation is a Research and Development job in a high technology field corresponding to the School’s lines, either in Paris or in the Rhône-Alpes region. But there are many variations, ranging from Theoretical Physics to Marketing and Communication. In a survey of the jobs found after ENSPG by our engineering students, we found:

- 71% in the research and development field
- 13% as production, quality and security engineer
- 10 % in computing
- 6 % as business engineers and in marketing

The main field of opportunities for our engineers is the energetic area, and more precisely research and development in nuclear energy (34% of them), and also the area of ‘physics and materials’ and ‘instrumentation’ (23% each) and finally microelectronics and optoelectronics (20%).

4. Energy and Nuclear Education

4.1 The ‘Energy and Nuclear Engineering’ (GEN) Stream

Power production has been revolutionised for some thirty years by the increasing role played by nuclear energy, particularly in France where some 75% of the electricity is of nuclear origin. In the same way, nuclear technologies have spread into many other industrial areas: instrumentation, medicine, the food-processing industry, materials...
Nuclear energy cannot be separated from the energetic problems involved in the transportation of energy and in the transformation of heat into electricity. Therefore, energetics is also a huge application field.
Our objective is to train engineers who will master not only nuclear engineering for the production of electricity, but more broadly energy and nuclear technologies and their various application fields.
The curriculum “Energy and nuclear engineering” of ENSPG is original, and it is the only one in France that trains engineers in the nuclear field.

This one and a half year specialized training includes a balanced blend of basic courses in energy, nuclear and thermal hydraulic engineering, together with the corresponding technologies engineering sciences to cover the technological aspects. It is based on the solid background in physics acquired during the first year and a half of the common-core syllabus of our engineering school. The details of the courses are indicated in table 1.

SECOND YEAR COURSES: 340 hours	THIRD YEAR COURSES: 350 hours
Energy and Nuclear Physics: 175 hours - Advanced Nuclear Physics - Neutronics and Reactor Physics - Fluid Mechanics - Radiation-matter Interactions - Radiation Detection - Advanced quantum Physics	**Nuclear Engineering: 75 hours** - Reactor Kinetics - Nuclear fuel cycle and wastes management - Nuclear Metallurgy - Nuclear Reactor Simulations
Computing sciences: 20 hours	**Energy Engineering: 115 hours** - Thermal hydraulics - Thermal Radiation - Simulation in thermal hydraulics - Electrochemical conversion
Practicals: 80 hours - Physics Lab - Practice of numerical methods - Practice of computers in process measurement	**Practicals: 65 hours**
	Optional Lectures: 75 hours Among the lectures of the research master in Physics of Energetics, materials and foreign languages
Foreign Languages and Sports: 45 hours	**Foreign Languages: 20 hours**

Tab 1: Courses of the Energy and Nuclear Engineering Stream

Amongst the graduates, roughly 30% decide to add a PhD to the education received in the school, while 60% of them decide to launch their professional career straight after the 3-years education as engineers. Most of these join the design and invention department of major companies working in the field of nuclear power generation, like AREVA and EdF as far as France is concerned; a significant part of our alumni are working worldwide, mainly in nuclear industries. They carry out technical studies, develop calculation tools and methods, prepare next generation equipments, plants and technologies, or improve the performance of water reactors.
Another major field of employment, nuclear safety, is growing very fast: nuclear safety is of paramount importance and this requirement underpins the organization and operation of nuclear

groups. As operating safety engineer, they ensure that safety and occupational safety criteria are met. They also work in radiation protection, radiological monitoring and risk assessment.

4.2 Safety Engineering and Risk Management

People are less willing to accept risks whether they are high scale risks (public safety related to nuclear, chemical or transportation activities) or more restricted risks (electrical failure, explosion...) or even natural risks. In his or her job, every engineer, as laboratory, section or firm manager, will have to take into account the existence of risks and will thus have to acquire some basic knowledge about safety.

The aim of the "Safety engineering and risk management" module is to give engineering students, as a complement to their specialty field, basic knowledge about safety. Various approaches are developed: risk analysis, concepts related to operating safety (failure trees...), structure reliability, risk identification and evaluation, regulation elements, insurance, crisis management… The course essentially concerns two fields of application: the nuclear and industrial chemistry risks.
This INPG module, though driven by ENSPG, also concerns two others engineering schools: the Materials, Electrochemistry, Process Engineering School (ENSEEG) and the Industrial Engineering School (ENSGI). The curriculum is thus organised so that students of all specialty options of the three engineering schools concerned can follow the whole module.

The 140 hours of lectures, delivered over seven weeks during the third year, deal with risk analysis methods (reliability diagrams, failure analysis, functional analysis, event trees, state diagrams, ergonomic approach), systems reliability, operation safety, technological risk, nuclear safety and radioprotection, risks of the industrial chemistry, impact of regulatory and insurance considerations, risk and crisis management…. These lectures are completed by practical studies on real cases during the last week of the module. Lectures are given mainly by industrial teachers from the French nuclear and chemical industries.

4.3 Master of Science Degree: Physics of Energetics

The Master Degree is the first stage of the doctoral study scheme. Students who complete a Masters' Degree at the same time as their ENSPG engineer degree can thus directly embark on the preparation of a doctorate, which generally lasts three years. In France, the organisation of graduate studies is based on graduate schools (*Ecoles Doctorales*). *Université Joseph Fourier*, the Grenoble University of Science, operates the Graduate School in Physics in cooperation with INPG. Physics for Energetics is one of the specialties of this Graduate School in Physics, a specialty driven by INPG. More precisely, the specialty 'Physics of Energetics', a research oriented masters' degree, is operated jointly with INSTN, the training subsidiary of the French Atomic Energy Commission, and with the Science University of Grenoble.

Each Graduate School runs a number of Masters' Degrees, graduate courses which span a year but can be taken in parallel with the final year of ENSPG. They consist of a semester of courses, followed by four to six months of full-time research in an academic or industrial laboratory.
The first semester is organized in three different options, all three related by a physics approach:

- 'Nuclear Energy' option, corresponding to the research aspects of nuclear energy, enlarged by two lectures on energy to be chosen in the two other options of the master
- 'Physics of Transfers' option, covering the fields of thermal hydraulics, heat transfers and exchanges, two phase flow
- 'Materials for Energy' option, composed of lectures on solar energy, electrochemical conversion and energy storage (fuel cell), cryophysics, micro fluidics, physics of phase change

More detailed information can be found in reference [3].

Students from the Energy and Nuclear Engineering stream of ENSPG can prepare this Masters' through a special training scheme including:

- a set of compulsory courses validated for the school and the masters' (see list above)
- a set of specialized courses, specific to the school, in the continuity of the 4th semester

It leads to positions in the nuclear industry, in public or private research or development laboratories involved in energy problems, and in engineering companies.

5. Acknowledgments

We are very thankful to Ms. Elise Huffer for her help during the translation of this paper.

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NUCLEAR ENGINEERING EDUCATION: PIONEERING ACTIVITIES IN SAFETY, DECOMMISSIONING AND NEW-BUILD

M.J. JOYCE
Engineering Department, Lancaster University
LA1 4YR Lancaster – United Kingdom

R.J. AVES
Devonport Royal Dockyard Ltd., Devonport Royal Dockyard, Plymouth PL1 4SG

ABSTRACT

The current professional nuclear engineering requirements of many academic training/education initiatives are immensely demanding, with many nuclear engineering organisations requiring broad syllabi of the highest quality whilst requiring the minimum time away from the workplace by their employees for the purpose of study. This is a very difficult balance to achieve, requiring flexibility on behalf of both the education provider and the industry-based recipient of the taught provision if teaching quality and commercial interests are both to be borne in mind. In this paper we report on an immensely innovative and successful relationship between a research-led University and a major nuclear engineering organisation that has pioneered an approach to nuclear education to meet this balance of needs. This relationship has resulted in over 70 Master's level graduands in nuclear safety, including the professional chartership of numerous nuclear engineers and has also been instrumental in the launch of the first undergraduate course in Nuclear Engineering in the UK for 20 years.

1. Introduction

In the late 1990's, in the United Kingdom, nuclear education and training was widely regarded to have reached its lowest ebb, as a result of a moribund civil nuclear industry and the paucity of public sector funding initiatives to substantiate new nuclear educational initiatives. This unsustainable situation was identified and recorded in a number of surveys [1,2,3,4,5] from a number of expert groups from 2000 through to 2003. This situation was characterized at the time by the entire lack of a dedicated nuclear engineering first degree and acute difficulties in sustaining postgraduate activities.

Somewhat independently of these activities a very productive relationship formed between the Department of Engineering at Lancaster University in the UK and the Devonport Royal Dockyard (DRDL), Plymouth UK in 1999. This collaboration across the academic-industrial divide and across 500 kilometres has resulted in significant innovation in nuclear education and industry-based training, including:

- Education approved by the engineering institutions, enabling routes to chartership for students from a broad selection of engineering backgrounds and experiences.
- Accredited prior experiential learning, providing a variety of routes to postgraduate Higher Education (HE) for employees without a traditional higher-education portfolio.
- Industry-based training local to the sponsoring company's location.
- Postgraduate education that marries the needs of the employer with the teaching and learning requirements of the HE provider.
- A welcome blurring of the traditional roles of academia and industry, with students learning from each other and from industrial role models who contribute directly to the taught provision.

2. Course provision

2.1 Safety Engineering Masters

Lancaster and DRDL first established their relationship with the Safety Engineering MSc in 2000. This course's aim was to tackle an important development that occurred in the late twentieth century associated with the complex mixture of engineering sub-disciplines that constitute many engineering systems. For these systems, the division between mechanical and electronic aspects of such a system is often difficult to discern. In particular, it is often difficult for the non-specialist engineer to identify the interdependencies of mechatronic engineering systems. Moreover, the inclusion of embedded intelligence in otherwise traditional mechanical systems, such as fluid valves, introduces a subsequent interface between software and electronic hardware. Hence, a system for which risk may have once been adequately assessed by a single engineer, may now require input from several experts.

Many professional engineers have an undergraduate degree as their training foundation from which they continue to draw on throughout their careers, to a greater or lesser extent. The relentless growth of technology has, and continues to result in the supporting syllabi of this essential preparation being increasingly wide. It is, in part, a reflection of this that in the UK four-year MEng degrees have become the standard professional requirement for engineering chartership in the UK. Indeed, there is often greater pressure on undergraduate engineering schemes of study than, for example, Physics, since the lack of a dedicated secondary-school subject restricts the extent to which established aspects of the syllabus can be incorporated into the secondary-level education syllabus; the capacity for flow-down to schools is limited. This is especially relevant to softer aspects of engineering training. Thus there remains a constant requirement for both the old and new at undergraduate level.

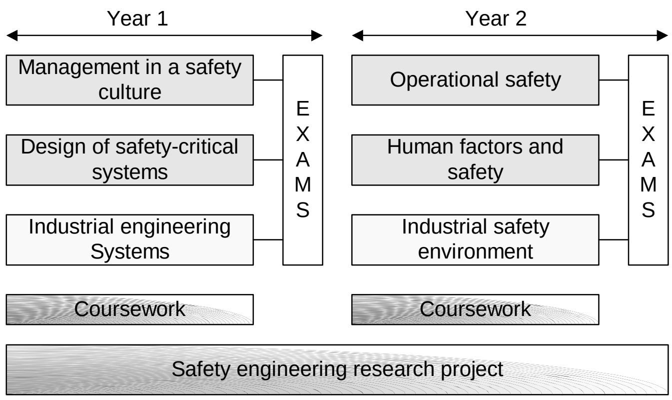

Figure 1: Schematic of Safety Engineering MSc scheme

A significant effect of this competition for space in the tertiary syllabus is that professional safety aspects are paid relatively little attention at present. This is despite the clear relevance of safety to important softer skills, such as engineering management, economics, engineering in society, sustainability and environmental issues of engineering. Furthermore, adequate substantiation often requires rigorous application of the most important engineering principles, and can draw on profound numerate ability in many cases. Indeed, the safety audit of a given engineering system can provide extensive exemplary material for the engineer early in their career.

In response to this training shortfall, industry has established in-house training procedures that often constitute part of the professional engineering industrial graduate training programme. However, unless the individual concerned is likely to realise a position dedicated to safety, the depth and breadth of this training rarely extends beyond operational concerns designed to empower the *individual* against *individual* risk. Even for the case where safety is likely to take a higher profile of an individual career, the training rarely extends beyond the specialist immediate needs of the industry concerned, thus neglecting the broader-based needs of the engineer's professional development and direct transferability of training.

2.2 Decommissioning and Environmental Clean-up Masters

In April 2005, the Nuclear Decommissioning Authority (NDA) was formed with the mission to deal with the UK's nuclear legacy facilities to time and cost, safely and with respect for the environment. This goal is ambitious and requires that training and education provision in nuclear topics is expanded and broadened. To appeal to this requirement, Lancaster designed and launched a postgraduate scheme in October 2004 which anticipated the postgraduate needs of engineers working in or aspiring to work in the decommissioning sector. This course built upon our experience with the Safety Engineering MSc. and followed a similar format in order to balance the needs of the workplace and the individual student.

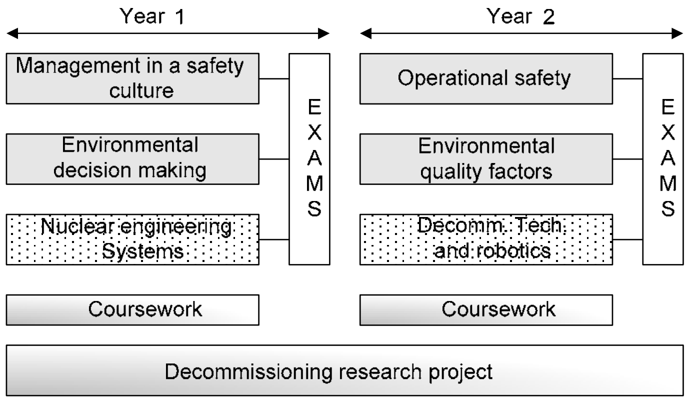

Figure 2: Schematic of Decommissioning and Environmental Clean-up MSc scheme

The Decommissioning MSc was designed in correspondence with the UK Government's White Paper 'Managing the Nuclear Legacy' [6], which highlights issues regarding Project Management, Safety and Environmental Restoration. This course shares modules with the Safety Engineering MSc., since this enables students to share their experience with students with a broader safety background. The course collaborates with the Department of Environmental Science at Lancaster, which provides expertise relating to Environmental Quality Standards, also drawing on regulator expertise. The Westlakes Research Institute, in West Cumbria near the Sellafield site, provides complementary expertise in Environmental Decision Making within the essential context of the nearby nuclear reprocessing complex. This course has proved very popular, drawing students from British Nuclear Group and Nexia Solutions, amongst others.

3. Industry-based projects

A key benefit of the industry-based Masters courses described in this paper has been the opportunity for students to pursue an extended scheme of individual study on a topic of joint interest to themselves and their sponsoring employer. Representative examples of such studies include:

- Quantitative aspects of the 'As low as reasonably practicable' (ALARP) concept,
- A review of safety issues associated with the application of nuclear power in transport,
- An investigation of cultural analysis to improve the interaction between design, safety and operations.

In some cases, these studies have stimulated further interest in the students associated with these projects to do further research, potentially via part-time PhD study. Very importantly, these projects have enabled students to establish themselves within their companies as resident experts in the topics they have studied as part of their projects.

4. Peer review and awards

As an indication of the success of the industry-academe collaboration described in this paper the team delivering the course and the graduates from the course have received related peer-driven awards, including:

- British nuclear Energy Society (BNES) Young Generation Network (YGN) Achievement Award (2007)
- UK Nomination for the Jan Runermark Award (2006)
- Institute of Physics Award for Best Practice for Professional Development (2006),
- BNES Masters' project prize (Lancaster) (2006),
- Royal Academy of Engineering Teaching Prize (2005),
- The Jack Martin Prize for excellence in Radiation Protection (2004),
- Lancaster University Staff Prize (2004).

Although both of the Masters courses described in this paper were established without any prior funding, the Decommissioning and Environmental Clean-up course has subsequently attracted funding from the Engineering and Physical Sciences Research Council (EPSRC), as part of a Collaborative Training Account (CTA). This has enabled dedicated facilities to be established at Lancaster including what is possibly the UK's only mock contaminated cell for laboratory-based remote characterization with a Brokk remote manipulation platform. As a measure of the course's success, it has also attracted a number of scholarships from the NDA as an incentive to Small and Medium-sized Enterprises (SMEs).

5. Future directions

Recently, modules from these degree schemes have been used as part of the Nuclear Technology Education Consortium (NTEC), which brings together further provision of this type across a broader range of syllabi. Lancaster is currently building on its experience in nuclear education at the postgraduate level through the launch of an undergraduate degree in Nuclear Engineering. This course is designed as a four-year Masters of Engineering (MEng) degree and will began in October 2006. This course has already attracted sponsorship from the Institution of Nuclear Engineers (INucE), and has already generated a great deal of interest from graduate employers in the nuclear sector and prospective students alike.

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CHERNE – DEVELOPING A NETWORK TO ENHANCE COOPERATION FOR HIGHER EDUCATION ON RADIOLOGICAL AND NUCLEAR ENGINEERING

F. TONDEUR
Institut Supérieur Industriel de Bruxelles, HE Spaak,
150 rue Royale, B1000 Brussels - Belgium

J. RÓDENAS
Secretary of the CHERNE Network
Departamento de Ingeniería Química y Nuclear, Universidad Politécnica de Valencia
Camino de Vera 14, E-46022 Valencia - Spain

On behalf of the CHERNE Network

ABSTRACT

In the last two decades, the educational capacity of many European Institutions of Higher Education in the field of Radiological and Nuclear Engineering has decreased, because of the conjunction of less interest among students, academic and political authorities. An increasing cooperation at the international level on the educational efforts in radiological and nuclear science and engineering 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 as well as equipment sharing between its partners. Typical activities organized within the network include workshops, intensive courses, seminars and conferences. Student and professor exchanges necessary for these activities are organised when possible in the framework of the ERASMUS program. In this paper, the CHERNE network and its main objectives will be presented and an account of the activities developed since its foundation, or foreseen in the near future, will be given.

1. Introduction

The educational capacity of many European Institutions of Higher Education in the field of Radiological and Nuclear Engineering has decreased in the last two decades, in parallel with the decrease of interest for this domain among students as well as among academic and political authorities. Furthermore, financial restrictions have made it more difficult to maintain and develop facilities, equipment and academic staff needed for practical training of students.

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.

In this situation, an increasing cooperation at the international level on the educational efforts in radiological and nuclear science and engineering is considered presently as the only viable solution. 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.

In particular, 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 as well as equipment sharing between its partners. Typical activities organized within the network include workshops, intensive courses, seminars and conferences on radiation protection and nuclear

measurement, radiochemistry, safety analysis, etc. Student and professor exchanges necessary for these activities are organised when possible in the framework of the ERASMUS program.
In this paper, the CHERNE network and its main objectives will be presented and an account of the activities developed since its foundation, or foreseen in the near future, will be given.

2. The CHERNE network

2.1 Members of the network in 2007

The network was created in 2005, involving now 12 European Institutions and one from United States. The list of members in alphabetic order of cities is the following:

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

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]. The IP "PAN: Practical Approach to Nuclear techniques" was first organised in 2002 in Prague, with the participation of CVUT, DIQN-UPV and ISIB. XIOS and UAS Aachen joined the two next editions, held in Prague (2003) and Mol-Brussels (2004). A second IP (SPERANSA, Stimulation of Practical Expertise in RAdiological and Nuclear SAfety) was first held in Prague in 2005, with no European grant, by the same partners. This project 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 was initiated with the constitution of the CHERNE network in 2005 during a workshop organised 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 an 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 include seminars, courses, intensive courses, and research collaborations.

Seminar:

- Simulation of detector calibration using MCNP, by Prof. J. Ródenas (UPV) at ISIB, 2005.
- Neutron Detection and Measurement, by Prof. U. Scherer (UAS Aachen) at U. Bologna, 2007.

Workshops and Conferences:

- Annual workshop of the CHERNE network, Valencia (2005) [2], Valencia (2006) [6], and Prague (2007) [7].
- Participation in ETRAP 2005 [1].
- Participation in the First EUTERP Platform Workshop [8].

Courses:

- Gamma spectrometry: simulation, deconvolution, applications, by Prof. J. Kluson (CVUT) at ISIB, 2005.
- X-Ray Photon Spectroscopy Calculations, by Prof. J. Fernández (Bologna) at ISIB, 2007.
- Introduction to plasma physics, by Prof. D. Mostacci (Bologna) at ISIB, 2005 , 2007.
- Protection against natural radiation, by Prof. F. Tondeur (ISIB) at U. Bologna, 2005 , 2007.
- Participation of Prof. F. Tondeur (ISIB), Prof. E. Zio (Milano) and Prof. J. Fernández (Bologna) in Doctoral courses at UPV, 2004-2007.

Intensive courses:

- Radiation protection and nuclear measurement in non conventional sectors.
  2-week course organised by ISIB Brussels and XIOS Diepenbeek (Belgium), 2007.
- Nuclear Chemistry.
  2-week course organised by UAS Aachen , 2007.
- Low radiation measurements.
  1-week course organised by UAS Aachen, 2007.
- Probabilistic Safety Analysis.
  2-week course organised by UPV and Politecnico di Milano, 2008.

- Radiation protection and nuclear measurement in non conventional sectors (2nd edition) ISIB & XIOS, 2008.
- Nuclear Chemistry (2nd edition) , UAS Aachen, 2008.

This last course is submitted as an Erasmus IP for the academic year 2008-2010. Another Erasmus IP project will be submitted for 2009-2011, coordinated by Politecnico di Milano for a first organisation proposed to ITN Lisbon.

3.3 Some Statistics.

A resume of the collaborations between the CHERNE partners is schematically presented in table 1.

	Poli Milano	**ISIB**	**UPV**	**XIOS**	**Bologna**	**Jülich**	**CVUT**	**Catania**
Poli Milano		IP	EBA, IP	IP		IP	EBA, IP	
ISIB			EBA, IP	IP	EBA	BA, IP	EBA, IP	EBA
UPV	PE, SE	PE, SE		EBA, IP	EBA	EBA, IP	EBA, IP	
XIOS						EBA, IP	EBA, IP	
Bologna		PE, SE	PE			EBA		
Jülich			PE, SE		SE		IP	
CVUT		PE, SE	PE, SE	SE				
Catania								

Table 1: Summary of collaborations between CHERNE members

IP cooperation in one or several intensive programme(s)
EBA Erasmus bilateral agreement
PE professor exchange
SE student exchange.

4. Conclusions

On the basis of an existing collaboration between some institutions, the creation of the 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.
Furthermore, specific activities already developed and those proposed for the future are on the way to enhance the interest of students and academic authorities on Nuclear Engineering and Radiation Protection.
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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POPULARIZING NUCLEAR SCIENCE AND TECHNOLGY TO STUDENTS OF SOME BRAZILIAN HIGH SCHOOLS

W.A. SOARES

Business and Communications Division, Nuclear Technology Development Centre (CDTN/CNEN)
P.O. Box 941. CEP 30123-970 - Belo Horizonte- Minas Gerais - BRAZIL

F. MARETTI JR.

Reactor and Irradiation Division, Nuclear Technology Development Centre (CDTN/CNEN)
P.O. Box 941. CEP 30123-970 - Belo Horizonte- Minas Gerais - BRAZIL

ABSTRACT

This paper intends to present the results of the project “Nuclear energy: itinerant expositions” coordinated by the Nuclear Technology Development Centre (CDTN). Public high school students were the focus of the project. Stimulating such students for subjects, like physics, chemistry, biology, mathematics, history and awakening vocations to science was the main objective. The project consisted of an exposition and a talk motivating the audience to the nuclear theme associating at the same time to the subjects taught at such schools. Searching information on the target public, infrastructure mounting, team training, multimedia material elaboration, interviews with students and teachers by journalists, project evaluation and divulgation were typical project activities. About 40 people of CDTN were directly involved in the project, that reached 30 public schools and about 11,100 students. The project received only high approval as the global evaluation in the returned questionnaires.

1. Introduction

Nuclear energy to the public is always associated with the production of nuclear weapons or nuclear and radiological accidents. Public communication actions done by the Nuclear Technology Development Centre (CDTN) have been contributed to popularize the social and peaceful applications of nuclear. The project “Nuclear energy: itinerant expositions” is one of these actions and had high school students as target public. Stimulating such students for subjects, like physics, chemistry, biology, mathematics, history, etc, awakening vocations to science and technology and also contributing for having citizens able to question their uses were the purpose of the project. The project consisted basically of an introductory talk on fundamentals and applications of the nuclear energy and ionizing radiation followed by a visit on a nuclear stand exposition. The talk had as goal motivating the audience to the nuclear theme and at the same time associating it to subjects taught at such schools.

2. Project methodology

The project required the implementation of six important phases: target public survey, design, team training, execution, evaluation and divulgation.

2.1 Target public survey

In this phase on target public to be reached a list of schools in the metropolitan region of Belo Horizonte-MG was prepared. Some candidate schools were selected and visited in order to know the available space and infrastructure needed to the project. It was important to have an idea of the school ambient and students’ behaviour. It was observed that some schools had large spaces for the talk presentation and other small ones. This last information helped then to define the number of talks to be presented and the number students to be sent each time, to the stand exposition.

2.2 Design

Once defined the selected target public, a letter was addressed to each school formalizing the invitation. In order to keep students quiet during the talk and paying attention to the event, special strategies had to be used in the production of the multimedia material. Short time films and animated images were incorporated into the slides as a way of facilitate the understanding. Small scale models of a nuclear power plant, a research reactor nucleus and a gamma irradiation laboratory were prepared. Coloured gems by gamma rays were used also to compose the stand. Illustrative panels on nuclear theme were prepared to compose the exposition stand making easy the expositor explanations. About 2,000 samples of a CNEN nuclear booklet on the nuclear energy applications were pre-printed and a participation certificate was prepared do be distributed to each school that took part in the project.

2.3 Team training

A workshop on scientific divulgation, conducted by researchers with experience in communication made part of the team training stage. Researchers and technicians of CDTN and members of the communication area from the nuclear institutions and from the science and technology area took part in this workshop. Three previous training for the team directly involved in the work at the exposition stand were also prepared using the multimedia material produced for the project.

2.4 Execution

In general, one day before the execution, two members of project staff moved to the school with all needed infrastructure in order to let it safely, near the space where the exposition would take place. In the beginning of the following day the project coordinator and members of the staff moved again to school to install all equipment in order the talk could start. In parallel the exposition infrastructure was mounted to receive the students after the explanation. A foreseen 45 minutes talk start then with an audience of a order of 500 students, with the coordinator trying to relate science and technology with the school subjects and using images as a source of concepts retention. At the end of this session, a booklet on nuclear energy applications was distributed to each participant. All students moved then to their classrooms. Then a teacher conducted ordered groups of students to the stand, where they could see the exposed material and scale models, receive additional information and talk with the expositors. In general the event started at seven and finished at noon, but sometimes in function of the number of students the event still run in the afternoon. Once finished the event, nuclear energy informative material and a participation certificate were given to the school principal.

2.5 Evaluation

The project evaluation consisted of three approaches: 1) interviews with students and teachers by journalists; 2) evaluation of the project by the schools, at the end of the execution phase; and 3) evaluation of the project by some students three months after the event. The information asked and results related to the second approach are presented in Table 2. The methodology used for the third approach was applied to the last six schools, involving only a sample of students. Items involved in the evaluation and its results are presented in Tables 3 to 4.

2.6 Divulgation

Once each school was visited by the project, news on such event were disseminated internally in the Centre by a weekly mural newspaper and sometime by an electronic bulletin distributed to all workers. The CDTN printed newspaper, for the internal and external public, was also used do bring news on the project. Releases to the media were sent before each visit to the schools and some television networks and newspaper present news on the project.

3. Results

Figures 1 and 2 illustrate exposition scenes.

Figure 1 - Talk in opened gymnasium (Photo: Santiago).

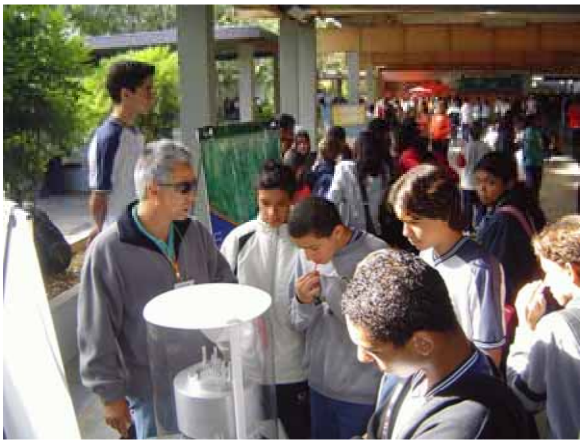

Figure 2 - Exposition of a research nuclear reactor core (Photo: Santiago).

Performance indicators were used in order to quantify all tasks done in the project and also its results. Table 1 shows results of main indicators used for monitoring the project development.

Table 1 – Main indicators used for monitoring the project development.

Indicator name	Measured result
Number of people involved in the project execution	39
Number of different public schools that took part in the project	30
Number of visits of the project to public schools	36
Number of public school classes reached by the project	294
Total number of students from public schools that took part in the project	11,116
Number of talks presented	64
Number of hour of talks presented	48
Number of students and teachers interviewed by journalists	31
Number of news disseminated internally in the mural newspaper	8
Percentage of the Very Good grade in global evaluation (event)	84.8

Figure 3 shows the evolution of the student that received talks on nuclear science and technology given by CDTN. The Nuclear Energy: Itinerant Expositions project results were included and the high impact of the project is prominent.

Thirty eight people of the CDTN were directly involved by the project, working 1,535 hours, corresponding to 192 days of 8 hours or 6.4 months of work. This work duty was done by 9 doctors, 11 masters, 2 graduated, 3 journalists, 8 technician from nuclear area and 2 from the administrative area. The first 18 public schools received the project in its own installations. In 2006, a very important technological and historical nuclear conference took place in Belo Horizonte, on a big convention centre - Minascentro. This event also celebrated the birth century of the pioneer in nuclear energy in Minas Gerais, Francisco de Assis Magalhães Gomes an it was used to reach the goal of presenting the project at one great circulation place. Another 12 public schools took part in the itinerant project there. As free available auditorium was available at the centre, 26 private schools participated in the project, totalizing 1,524 students. In the project evaluation process at the end of each event, 33 questionnaires were filled and returned. Grade for evaluation varied from 1 (Very Bad) do 6 (Very Good). The results are presented in Table 2. The project received 85% of “Very Good” and 15% of “Good”.

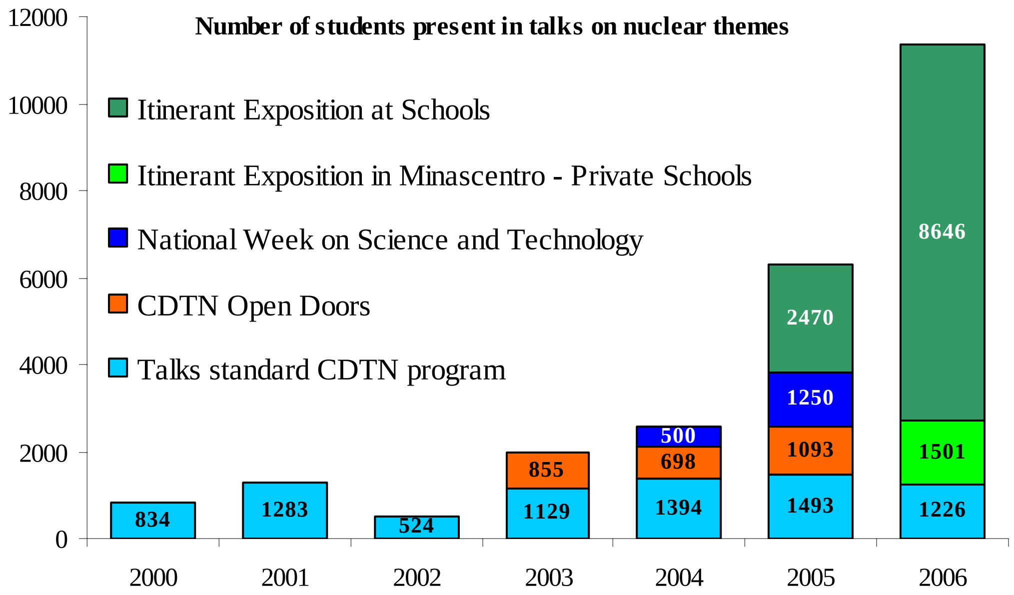

Figure 3 - Evolution of number of students taking part in talks on nuclear technology in CDTN program.

Table 2 – Evaluating the project at the event's end.

Evaluated items	Evaluated themes	NAT	Evaluation (%)		
			Regular	Good	VG
Preliminary contacts	Preparatory contacts	32	3.1	12.5	84.4
Talk	Pedagogical/didactic interest	32	0	21.9	78.1
	Talk content	32	3.	6.3	90.6
	Expositors explaining capacity	31	3,3	29	67.7
	Global evaluation	8	0	0	100
Exposition	Visual impact	33	9.1	21.2	69.
	Pedagogical/didactic interest	33	0	21.2	78.8
	Exposition content	33	3	21.2	75,8
	Expositors explaining capacity	33	6,1	24.2	69.7
	Global evaluation	23	0	13	87
Distributed material	Visual impact	33	3	24.3	72.7
	Pedagogical/didactic interest	33	3	18.2	78.8
	Content	33	0	9.1	90.9
	Global evaluation	24	0	0	100
Global evaluation	Project global evaluation	33	0	15.2	84.8

Notation – **NAT**: Number of answer to each theme. **VG**: Very Good.

Three months after the last event, evaluation of the project results was done based on a sample of 162 students from six public schools. 55% of these students affirm that they were stimulated to study more the subjects presented by the expositors and 93.6% consider important the presented talk and the exposition. Table 3 presents results concerning the feelings of the students when confronted with the nuclear theme.

Table 3 - Feelings of the students hearing about radiation or nuclear area.

Associated image	Answers (%)
Utility and applications that the nuclear area can have	42.6
Atomic weapons and nuclear wars	19.8
Danger to people due to the use of radiations	17.9
Danger to the environment with the use of radiations	8
Science and technology that the students do not yet know	6,2
Not answered	4.9
None of the other options	0.6

The project called attention to the Education Centre for Sciences and Mathematics (CECIMIG) of the Education Faculty of the Federal University of Minas Gerais (UFMG) that invited the coordinator to show the project experience in a specialization course for public state high school teachers, and up to now 500 teachers took part. This experience was also presented to 30 journalism students of the Newton Paiva Institute, in Belo Horizonte.

4. Conclusions

To be at 6 hours in the morning at the schools were challenge faced by the project staff involved in the infrastructure mounting at each event. A negative point in the majority of the cases was a not prior preparation of the students by the teachers in order to take advantage of the event, as for example making the participation as part of a school homework. Only few schools adopted such procedure. Understandable, but negative, in many schools, was the absence of some teachers during the event. Lack of adequate infrastructure for giving talks and for locating the exposition stand was also faced. The foreseen goals to attend 30 schools and also to carry out the project in place of great circulation of people were reached. The project contributed in order that CDTN could fulfil its social and strategic goal to increase the number of public schools reached by the science and technology divulgation program in relation to the number of private schools. The project was a very good opportunity for the researchers and technician of the CDTN learning more on the job training and knowing how to interact directly with society, speaking about the nuclear science and technology with a very questioning public as young students. The multimedia material developed with graphical animation resources, the small scale models of nuclear and radioactive installations and the irradiated foods demonstration created propitious conditions in order the students could clarify its doubts and questionings with the expositors. The project evaluation results indicate that it contributed to awake the interest of the students for school subjects. Designed initially only to high school students the target public was enlarged, pointing out the importance of the project. The merit honour distinction given to the project in the 2006 by the Minas Gerais state government in the Prize “Francisco de Assis Magalhães Gomes” recognizes the project as an important instrument of science and technology divulgation.

Acknowledgments

Thanks to the Minas Gerais government Agency for Support of Research (Fapemig) that sponsored the “Nuclear Energy: Itinerant Expositions” project and also to the Minas Commerce Association (ACMinas) a very important partner in the project. Thanks to all colleagues from the Business and Public Communication Area and from of other sectors of CDTN, who understood the importance of divulging the peaceful applications of the nuclear technology to the students and contributed with their works in this project. Thanks also to the researchers Alfonso Rodrigues de Aquino and Martha Marques Ferreira Vieira, from the Nuclear and Energetic Research Institute (IPEN), for conducting a Workshop on Scientific Divulgation at CDTN in 2005, as part of the team training project.

Workshop 2:
Safeguards and terrorism

FIELD TRIAL OF SAFEGUARDS' SHORT NOTICE RANDOM INSPECTIONS AT THE JUZBADO PLANT

O. ZURRÓN-CIFUENTES, C. ÁLVARO-PÉREZ

Department of Safety, ENUSA Industrias Avanzadas S. A.
Juzbado Nuclear Fuel Fabrication Plant
Ctra. Salamanca-Ledesma, km. 26
37015 Juzbado, Salamanca - Spain

ABSTRACT

During the last decade a number of different issues concerning either illegal traffic or diversion of nuclear material for undeclared activities have been detected by the safeguards agencies throughout the world. These global challenges have led the safeguards agencies to rework their own procedures and objectives. In particular, both the IAEA and the European Commission (EC) have been interacting at the highest level during the last months in order to conclude an agreement on its collaboration protocols, aiming to easy the achievement of their new goals and objectives and increase the effectiveness of the safeguards controls. Within this framework and in line with its transparency policy, ENUSA and the Deputy Direction for Nuclear Energy of the Spanish Ministry of Industry, Tourism and Trade have been working jointly with the IAEA and the EC DG-TREN to implement a six months field trial of a Short Notice Random Inspections' scenario (SNRI) at the Juzbado Nuclear Fuel Fabrication Plant. The implementation procedure of this field trial was agreed upon by all the parties involved in January, 2007 and is the first of its kind within the EU. The lessons learned are intended to be taken into account in the implementation of integrated safeguards in the rest of the EU. This paper shows the details of such SNRI scenario for the Juzbado Fuel Fabrication Plant.

1. Introduction

During the last decade a number of different issues concerning either illegal traffic or diversion of nuclear material for undeclared activities have been detected by the safeguards agencies throughout the world. In some cases, these misled activities were committed by individuals or entities escaping the existing States' controls, but there is a number of examples with the governments themselves being the main actors of such behaviour, so challenging the global consensus on the right way to proceed in order to avoid nuclear weapons' proliferation and assure the development of peaceful uses of nuclear energy worldwide. These global challenges have led the safeguards agencies to rework their own procedures and objectives, realizing that the control should be not only on the nuclear material itself, but also on the parallel tasks needed to be carried out to develop undeclared nuclear programmes or other malicious activities.

As an outcome of such internal revisions, the IAEA issued the Additional Protocols (AP) to the Safeguards Agreements, which have been so far endorsed and implemented by a large number of States, including the European Union. The AP implementation is seen by the IAEA as the first step of a much more ambitious aim called Integrated Safeguards, which is intended to be fully implemented within the EU by the end of 2008. The ongoing revision by the European Commission (EC) of its own safeguards approaches can be seen in this same regard. These so called new approaches have been developed during the last two years by the EC taking into account the different sensibilities of the EU Member States and are intended to be officially issued not far long. Furthermore, both Inspectorates have been interacting at the highest level during the last months in order to conclude an agreement on its collaboration protocols (the so-called partnership approach), aiming to easy the achievement of their new goals and objectives and increase the effectiveness of the safeguards controls.

Within this framework and in line with its transparency policy, ENUSA and the Deputy Direction for Nuclear Energy of the Spanish Ministry of Industry, Tourism and Trade have been working jointly with the IAEA and the EC DG-TREN to implement a six months field trial of a Short Notice Random Inspections' scenario (SNRI) which complies with the safeguards objectives of both inspectorates taking into account the specific constraints of the Juzbado Nuclear Fuel Fabrication Plant. The implementation procedure of this field trial was agreed upon by all the parties involved at the beginning of 2007 and is the first of its kind within the EU. The lessons learned are intended to be taken into account in the implementation of integrated safeguards in the rest of the EU.

The following epigraphs show the details of the above cited SNRI field trial at the Juzbado Plant. Also, an epigraph with the definitions of the main concepts discussed has been included at the end of the paper, with the purpose of easing its comprehension. The basic objective of such inspections is to provide full coverage of the nuclear material involved in domestic transfers through random selection of the timing of the inspections, so that the maximum advance notification to the Juzbado Plant is two hours. From the operator's point of view, the benefit lies in a reduced annual number of inspections, which in the particular case of the Juzbado Plant would vary from a figure of 6-7 inspections per year to 4-5 inspections per year.

2. Notification of inspections

The notification that a SNRI inspection has been triggered will be received at the plant between 9:00 and 9:30 of any of the agreed dates (which basically match with the Juzbado Plant working days). Should a notification is not given during the notification window no SNRI can take place during the rest of that day.

The Party (IAEA or EC) triggering the inspection will submit a fax to the Plant's Control Room, backed up by telephonic confirmation. The fax's template has also been agreed and contains very specific information on the details of the inspection. Later this same day, the Plant's Control Room will receive another fax submitted by the second Party with similar information regarding its participation in the inspection (basically, date and estimated hour of arrival of the inspectors and their names). All the information received at the Plant's Control Room is promptly forwarded to the on-plant organizations responsible to host the inspection, which have to be activated upon reception of the notification.

3. Access to the plant of the inspection team

Once notification of a SNRI has been given, the SNRI must take place. In case of *force majeure* events which could interfere with the inspection, the operator will always grant the inspectors access to the plant and later discuss with them the situation and determine the appropriate course of action.

The inspection team will arrive at the security check-point of the Juzbado Plant almost simultaneously with the reception of the notification and ready to produce positive identification. The inspectors will be admitted at the facility as soon as possible, but not later than two hours from the notification time. When managing the access clearance for the inspection team, the plant's personnel checks that all the inspectors are included in the list of *designated inspectors*, so that their access is granted only if they are in the list and hold a valid identification document.

Then, ENUSA produces the electronic file with the physical inventory listing (EURAPII) and hands it to the inspectors at the beginning of the SNRI. Should the IAEA being the Party triggering the inspection the file is kept under seal until the EC inspectors arrive. Besides of that, the inspection team is provided upon arrival with a hard copy of the updated itemized list of all fuel assemblies at the final stage of the production process. The information contained in such listing has been previously agreed and let the inspectors verify on spot the physical inventory of finished fuel assemblies at the facility.

4. SNRI verification activities

The maximum duration of a SNRI is three working days, its activities being performed during normal Juzbado Plant's working hours (from 8:00 to 17:00). The second inspection day will start in a maximum of 72 hours after the arrival of the inspectors of the Party triggering the SNRI.

Should the EC be the Party triggering the inspection the order of the activities described in epigraphs 4.1 & 4.2 will be swapped in order to give the IAEA team the chance to carry out partial defects verification (PDV) measurements on fuel assemblies in all interim inspections (see below). In this particular case, the EURAPII file will not be sealed.

4.1 Scope of the verification activities on the first inspection day

Upon arrival, the inspectors are immediately led to the production areas to carry out the following activities:

- To establish the fuel assembly inventory, by 100% item counting and comparison with the provided itemized list and any other relevant documents, and by gross defects verification (GDV).
- To randomly select two fuel assemblies for PDV. In case that no new fuel assemblies were produced since the last SNRI, just one the items present in the store will be selected for PDV.

The activities described above are performed only on fuel assemblies and loaded shipping containers physically present at the final stages of inspection, storing or packing and assuming there is neither need to move the containers with a crane nor to open them. Moreover, the containers that have been already enclosed within the maritime transport container or loaded onto the transport platform will not be subjected to verification activities.

Once the verification on the inventory of fuel assemblies is finished, the inspectors are conducted to the pellet loading stations to select one pellet sample which is kept under seal for analysis (DA) during the next PIV.

When all these activities have been conducted, it is understood that the first day of inspection is over.

4.2 Scope of the verification activities on the following inspection days

The second day of inspection is started once the inspection teams from both Parties arrive at the facility. ENUSA personnel checks that this requirement is complied before granting the inspectors the access to the plant. Any event regarding the access of inspectors should be notified to the Spanish competent authority as soon as possible.

ENUSA produces the electronic file with the Inventory Changes Report (ICR) and hands it to the EC inspectors along with the sealed EURAPII file generated on the first inspection day. If needed, a second EURAPII file updated to the second inspection day is also produced.

The activities to be carried out by the inspectors during the second part of the SNRI are the following:

- To generate the sampling plan from the information included in the EURAPII file.
- To select the items containing received powder which were identified in the sampling plan for PDV. Samples of these items may be taken where appropriate and kept under seal to be analyzed during the next PIV.
- To select the rods identified in the sampling plan for both GDV & PDV.
- Book examination of the inventory changes which have occurred since the previous inspection.
- On top of the pellet sample taken during the first day and only in the event of foreign receipt of pellets, these will be verified by DA sampling which will be kept under seal until the next PIV.

- Finally, in case of shipment of material other than fuel assemblies, verification or sealing activities will be agreed on a case by case basis.

All the activities described above will be performed in a maximum of two working days.

5. Information to be provided to the Parties

The inspection procedure above described is established on the basis that ENUSA provides the Parties with timely and accurate information according to agreed formats. Thus, the Parties have the information on the productive activities of the Juzbado Plant needed to fulfil their objectives. Such information is detailed in the following paragraphs:

5.1 Juzbado calendar

By December, 20th each year, ENUSA will submit to the Parties the preliminary version of the Juzbado calendar for the following year. This information will be updated as soon as the calendar becomes official. In case that *force majeure* events which could affect or otherwise limit the inspection activities in a given day, ENUSA will notify the Parties as soon as the event is known.

5.2 Fuel assemblies production forecast

By December, 20th each calendar year, ENUSA will provide the Parties with the fuel assemblies production forecast corresponding to the following year, according to a previously specified format.

5.3 Powder receipts forecast

Before January, 31st each calendar year, ENUSA will submit to the Parties the forecast with the powder receptions for the whole year. Again, this information is provided according to agreed formats.

The forecast cited in §5.2 and §5.3 will be updated weekly if any change occurs or ratified monthly, providing there is no need to include any modification. Should the scope of the revision be important enough, the update will be submitted as soon as the changes are known. All the information will be transmitted in electronic format by encrypted mail with copy to the Spanish authority.

6. Conclusions

This procedure is still in a 6-months trial phase which started on March 1st, 2007. Thus, it is still premature to drawn conclusions on it, both from the point of view of the achievement of the IAEA and EC objectives, and from the operator's standpoint. Nevertheless, it must be said that by the date on which this paper was written, two SNRI have taken place at the Juzbado Plant with satisfactory results for all the parties involved (IAEA, EC, Spanish authority and ENUSA). Some minor issues regarding the exchange of information were identified, as well as it was the need to improve the interface between IAEA and EC for triggering the inspections. These issues will be discussed after finishing the trial period along with any other which could be identified in the near future. The outcome of these discussions will be taken into account for the revision of the procedure, as well as the new modalities of co-operation between IAEA and EC being discussed at high level.

7. Definitions

- **SNRI.** Short Notice Random Inspection.
- **PARTY.** Either the International Atomic Energy Agency (IAEA) or the European Commission Directorate General for Energy and Transport (EC DG-TREN).
- **GDV.** Gross Defects Verification. It stands for assays to roughly determine whether there is or there is not nuclear material in a given item.

- **PDV.** Partial Defects Verification. It stands for assays to determine in detail the safeguards related relevant characteristics of a given item.
- **DA.** Destructive Analysis. It stands for the verification of the safeguards related relevant characteristics of the material using destructive techniques. It is usually performed during the annual PIV. On the opposite, verification activities during interim inspection are carried out by means of NDA (Non-Destructive Analyses) techniques. These are also used during the PIV.
- **PIV.** Physical Inventory Verification. This is a very specific inspection to verify the physical inventory carried out by the Juzbado Plant once a year. It usually lasts one week and its scope is completely out of the SNRI scenario.
- ***Force Majeure.*** Event beyond the control of the operator that prohibits or otherwise limits the inspection activities that could be carried out on a particular day.

ADVANCED SAFEGUARDS FOR THE GLOBAL NUCLEAR ENERGY PARTNERSHIP (GNEP)

S.F. DEMUTH, E.T. DIXON, K.E. THOMAS, R.K. WALLACE
Los Alamos National Laboratory
P.O. Box 1663, Los Alamos, NM 87545 USA

ABSTRACT

World energy demand and greenhouse gases are expected to significantly increase in the near future. Key developing countries have identified nuclear power as a major future energy source. Consequently, the United States and other countries are currently exploring the concept of a Global Nuclear Energy Partnership (GNEP) to address the concerns of nuclear proliferation. Advanced safeguards will be based on new world standards for the prevention of nuclear materials proliferation. Safeguarding nuclear facilities includes inventory accountancy, process monitoring, and containment and surveillance. An effort has been undertaken to prioritize technology development for advanced safeguards accountancy by way of using the Standard Error in the Inventory Difference (SEID) as a basis for cost/benefit analyses. By performing cost/benefit studies, technology development R&D efforts can be prioritized.

1. Introduction

As part of the Global Nuclear Energy Partnership (GNEP) the United States has begun to design a reprocessing and fuel fabrication research and development (R&D) facility to support spent fuel transmutation and power production by way of a fast reactor. The reprocessing and fuel fabrication R&D facility is referred to as the Advanced Fuel Cycle Facility (AFCF) and the reactor is the Advanced Burner Reactor (ABR). The closed fuel cycle supported by the AFCF and ABR will serve two primary purposes (1) reduce the underground waste repository size and engineered barrier requirements, and (2) recycle more proliferation resistant fuel than the existing plutonium mixed oxide (MOX) fuel cycle. Figure 1 represents the AFCF/ABR closed fuel cycle.

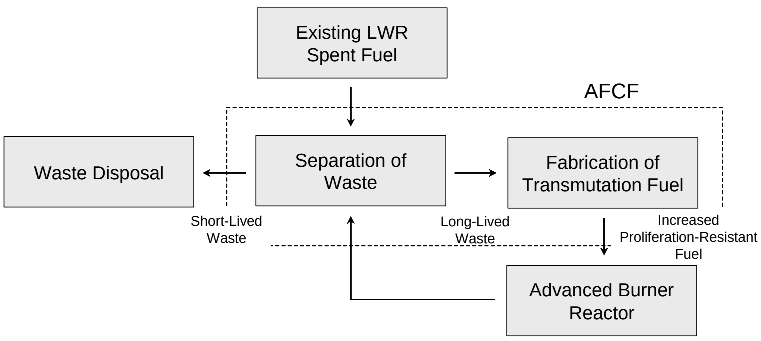

Fig 1: The AFCF and ABR closed fuel cycle

Principal safeguards design components used for nuclear fuel reprocessing and fuel fabrication include inventory accountancy, process monitoring, and containment and surveillance [1]. It is the accountancy component of the safeguards design that this paper is concerned with. Accountancy requirements for nuclear facilities are usually related to diversion detection of a significant quantity of nuclear material. When the statistics of measurement uncertainty are considered, such as detection of a significant quantity of material at high confidence, accountancy goals for large throughput facilities become nearly impossible to achieve. For this reason a cost/benefit methodology for prioritizing advanced safeguards R&D, based on modelling of the Standard Error in the Inventory Difference (SEID), Sigma-MUF (σ_{MUF}) or Sigma-ID (σ_{ID}), is proposed and discussed here [2]. Examples of advanced safeguards for transmutation fuels includes (1) destructive assay (DA) of Pu in the presence of significant actinides such as Np, Cm and Am, (2) accountability of Np, Cm and Cm, and (3) automation of DA to reduce labour cost.

2. Methodology

Extend™ simulation software was used to model UREX reprocessing for demonstration of the cost/benefit methodology [3]. An 800 MTHM/yr facility was used for the baseline simulation with measurement uncertainties based on nominal values for a PUREX type process, as reported by ESARDA [4]. Both interim and annual inventory difference (ID) measurement uncertainties were evaluated. The individual measurement uncertainty is expressed as sigma (σ), which is the square-root of the variance for systematic error, and the square-root of the variance divided by the degrees-of-freedom (i.e. number of measurements) for the random error. The following equation represents an individual measurement uncertainty, based on systematic and random error, for concentration and mass. Measurement uncertainty for the entire process is then represented by Sigma-ID, which is equivalent to the SEID or Sigma-MUF, depending on the regulating or monitoring agency of interest [5].

$$\sigma^2_{\text{total}} \approx \sigma^2_{\text{s,c}} + \sigma^2_{\text{s,m}} + \frac{\left(\sigma^2_{\text{r,c}} + \sigma^2_{\text{r,m}}\right)}{\text{n}}$$

The nominal measurement uncertainties are listed in Table 1 and represent one standard deviation. A representation of the Extend™ based model is shown in Figure 2. Two separate simulations were conducted to demonstrate the cost/benefit methodology. The first simulation relates to the interim inventory difference, which is based on plant operation rather than shutdown, and is dependent on the process inventories. The second simulation relates to the annual inventory difference, is based on plant shutdown and therefore does not depend on process inventory, but rather on feed, product and waste accountability. For international monitoring the interim inventory period is dictated by the IAEA goal of detecting a significant quantity of plutonium with high confidence. An increase in inventory period will produce a cost reduction. The benefit sought for the annual inventory is not dependent on a goal, but rather any reduction in the overall ID measurement uncertainty.

	$\sigma_{s,c}$(%)	$\sigma_{s,m}$(%)	$\sigma_{r,c}$(%)	$\sigma_{r,m}$(%)
Feed	0.2	0.2	0.3	0.3
Product	0.2	0.05	0.2	0.05
Waste	0.2	0.2	0.3	0.45
In-Process tanks	n/a	n/a	0.3	0.45
In-Process solvent extraction	n/a	n/a	0.6	1.0
In-Process conversion	n/a	n/a	0.6	1.0

Tab 1: Systematic and random measurement uncertainties for a PUREX type process

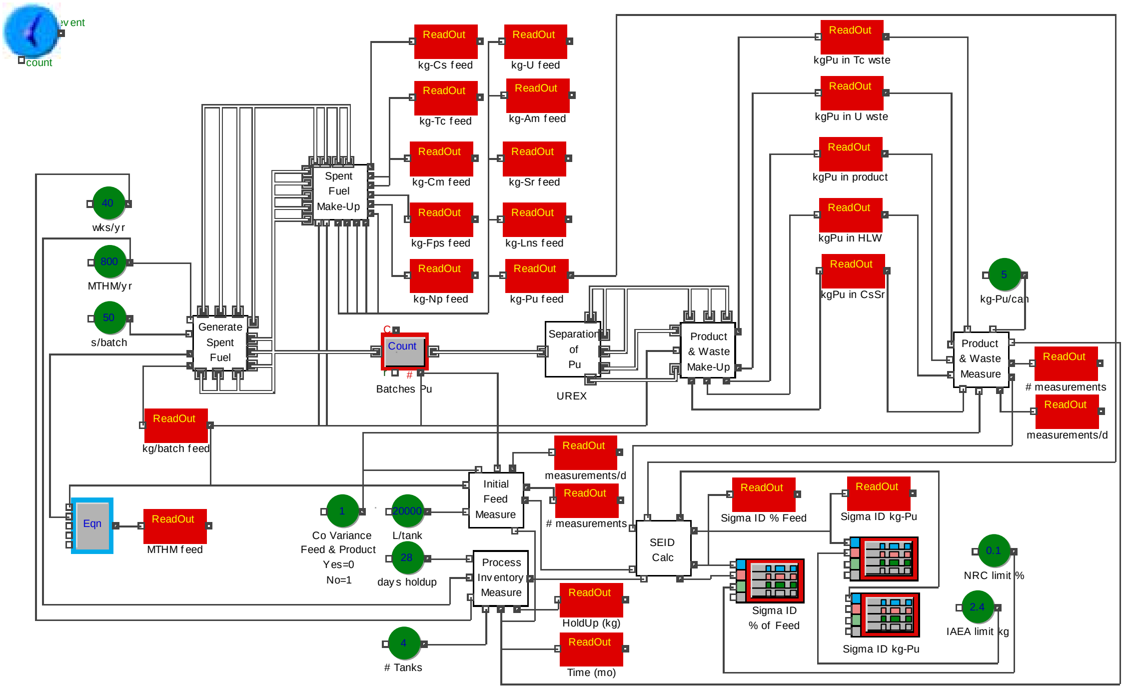

Fig 2: Top layer of Extend™ based UREX model for Sigma-ID calculation

3. Results

3.1 Interim ID

Due to the short interval period, plant shutdown is not practical and therefore the interim inventory is measured during plant operation. For this study, it is assumed approximately 90% of the process inventory exists in four tanks, which is typical for an 800 MTHM/yr plant. Additionally, it is assumed the concentration measurement uncertainty for the four process inventory tanks is similar to the primary accountancy tank as defined by ESARDA, but the mass measurement uncertainty is 50% greater. Typically, primary accountancy tanks are design for more accurate mass measurement than process inventory tanks, were liquid mass is based on level and density. Advanced safeguards evaluated are (1) reducing the concentration measurement uncertainty for process inventory tanks by 1/3 and (2) reducing the mass measurement uncertainty for process inventory tanks by 1/3. The simulation based on nominal uncertainties is shown in Figure 3, and the results of the measurement uncertainty changes are shown in Table 2.

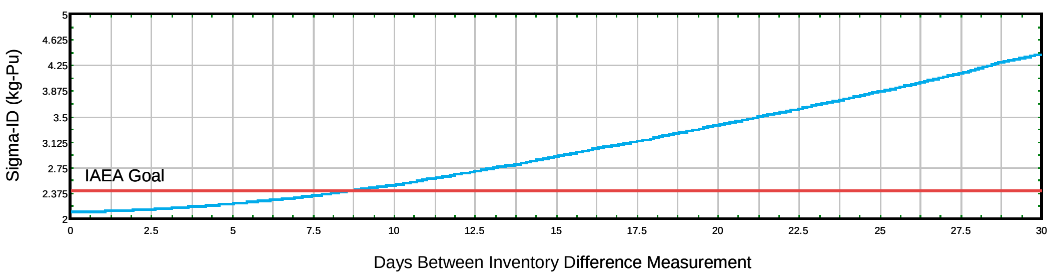

Fig 3: SEID/Sigma-ID for Interim measurement, baseline measurement uncertainties

	$\sigma_{r,c}$(%)	$\sigma_{r,m}$(%)	Days to IAEA Goal
Baseline	0.3	0.45	8
Reduced mass error	0.3	0.3	13
Reduced concentration error	0.2	0.45	11

Tab 2: Effect of measurement uncertainty upon interim inventory period

3.2 Annual ID

The annual inventory difference is measured during plant shutdown. For these conditions, the measurement uncertainty is based on the cumulative error for the feed accountability tank, product cans and waste forms. Sigma-ID for the nominal uncertainty case is shown in Figure 4.

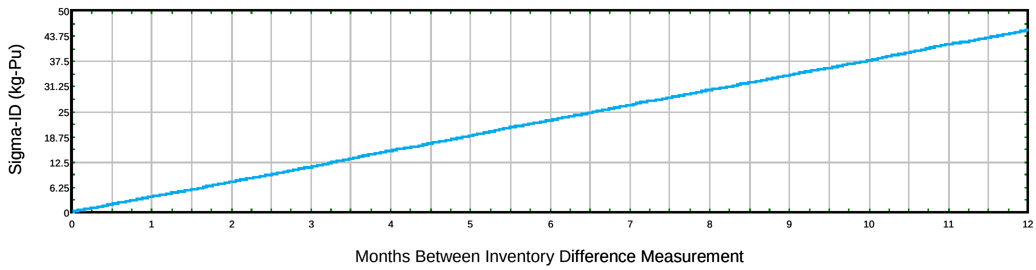

Fig 4: SEID/Sigma-ID for annual measurement, baseline measurement uncertainties

The advanced safeguards evaluated for annual inventory are (1) automated destructive assay (DA) in the laboratory and (2) automated DA in the process cell. For case 1, the random error is reduced by 25% due to automation of analysis, and the systematic is not changed. For case 2, the random error is reduced by 50% due to automation of analysis and sampling, and the systematic is increased by 25% due to increased calibration difficulty. The results of the measurement uncertainty changes are shown in Table 3.

		$\sigma_{s,c}$(%)	$\sigma_{s,m}$(%)	$\sigma_{r,c}$(%)	$\sigma_{r,m}$(%)	σ_{ID}(kg-Pu)
Baseline	Feed	0.2	0.2	0.3	0.3	45
	Product	0.2	0.05	0.2	0.05	
Automate in Laboratory	Feed	0.2	0.2	***0.225***	0.3	44
	Product	0.2	0.05	***0.15***	0.05	
Automate in Process Cell	Feed	***0.25***	0.2	***0.15***	0.3	53
	Product	***0.25***	0.05	***0.1***	0.05	

Tab 3: Effect of measurement uncertainty upon annual inventory period

4. Conclusions

The results of Section 3 can be used to form the basis of a cost/benefit study. Cost changes include (1) the reduced number of interim inventories required (2) decreased labour upon automation, (3) R&D required for advanced instrumentation and (4) implementation of advanced instrumentation. This study is intended to demonstrate only the cost/benefit methodology; whereas, actual costs savings for specific instrumentation is left as a follow-on activity. Quantification of the cost savings for extended interim inventory measurement is more straight-forward than reduced Sigma-ID for the annual inventory.

However, it may be possible to rank new technologies by way of percent reduction in Sigma-ID versus additional cost. Future efforts will need to estimate measurement uncertainties for advanced processes such as UREX, rather than use known PUREX values.

5. Nomenclature

n = number of measurements during the inventory
SEID = cumulative measurement uncertainty for inventory difference at one standard deviation used by the United States Department of Energy
σ_{ID} = cumulative measurement uncertainty for inventory difference at one standard deviation used by the United States Nuclear Regulatory Agency
σ_{MUF} = cumulative measurement uncertainty for inventory difference at one standard deviation used by the IAEA
$\sigma_{s,c}$ = systematic measurement uncertainty for the concentration at one standard deviation
$\sigma_{s,m}$ = systematic measurement uncertainty for the mass at one standard deviation
$\sigma_{r,c}$ = random measurement uncertainty for the concentration at one standard deviation
$\sigma_{r,m}$ = random measurement uncertainty for the mass at one standard deviation

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European Nuclear Society
Rue de la Loi 57
1040 Brussels, Belgium
Telephone +32 2 505 3 50
Fax + 32 2 502 39 02
ens@euronuclear.org
www.euronuclear.org

Layout and Design: Marion Brünglinghaus, ENS