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What is the situation with regard to infrastructure and tools for nuclear education and training?

EDUCATION AND TRAINING PRINCIPLES AND TOOLS FOR NEW NUCLEAR DEVELOPMENT

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ABSTRACT

To develop new nuclear power the decision makers need to consider the long term commitment; the concerns for safety, security, reliability, radiation protection, spent fuel management, radioactive waste management and economics; the need for a solid scientific and technological infrastructure, and the development of a diverse and complete education and training programmes covering all phases in the life of the power plant and directed to all actors concerned: government, regulatory bodies, plant owners, designers and constructors, operators and dismantlers. As a response to these requirements, the IAEA has published two basic documents: *Fundamental Safety Principles* (2006), and the INSAG document *Nuclear Safety Infrastructure for a National Nuclear Power Programme Supported by the IAEA Fundamental Safety Principles* (2008). From the principles and advises in those documents and to cover all education and training needs, a group of 35 experts, members of the IAEA, INSAG and the International Nuclear Industry, have published a book titled *Infrastructure and Methodologies for the Justification of Nuclear Power Programmes* (2012), aimed at providing expert information and self-study on the education and training needs in each one of the phases in the life of the nuclear power plant for all types of affected persons. The book is divided into three parts. Part I covers the scientific, industrial and administrative infrastructure needed to start a new nuclear power programme. Part II, based on the justification principle, analyzes the need for nuclear power; the requirements for safety, security, safeguards, radiation protection and waste management. It also covers the economics of nuclear power, the social and environmental impacts and the current and advanced nuclear technologies. Part III describes the knowledge and training which should be developed to cover each one of the phases in the life of the nuclear power plant: Siting, design and construction, commissioning and commercial operation and dismantling. There are also appendixes covering justification, safety culture, the IAEA training programme, simulator training and the NEA driven Multidesign Evaluation Programme.

1. Introduction

The arrival of the 21st century brought a renovated worldwide interest for nuclear power, the so called *nuclear renaissance.* Many Member States of the International Atomic Energy Agency, IAEA, requested information and advice from the Agency; a large number of new entrant countries and those with long moratoria on new constructions started to announce large new nuclear power programmes. International Organizations such as the IAEA, the Nuclear Energy Agency, NEA; the International Energy Agency, IEA; the World Energy Organization, WEO, and others projected installed nuclear capacity in 2030-2050 in ranges that doubled even quadrupled the current capacity. The March 2011 Fukushima accident arrested the enthusiasm created by the *nuclear renaissance*.

As a consequence of the accident some European countries decided to phase-out nuclear energy from their energy mix, while others have decided to reassess their nuclear energy programmes. Finally, other European countries, notoriously Finland, France and Slovakia have decided to continue with their new builds, while the UK is close to decide on the construction on new nuclear power plants. The European Human Resources Observatory for the Nuclear Energy Sector, EHRO-N, has recently published a document [1] in which a top-down modelling approach is used to estimate the number of nuclear power plants which may be in operation or under construction within the European Union from 2010 to 2050, assuming that the current reactor park and new constructions will include generic third generation reactors of 1400 Mwe and 1000 Mwe for an assumed scenario of 95 to 110 reactors. It is estimated that at the end of the considered period there are needed from 7500 to 10000 nuclear experts and from 50000 to 65000 nuclearized experts. Partime contracts will amount to 70000 to 100000 new jobs. These figures give a first impression on the human resources needed within the European Union.

This document will discuss the education and training requirements which are implicit to the IAEA Safety Fundamentals, make a review of INSAG recommendations and present the contents of an experts´ book on infrastructure and methodologies for nuclear power programmes, considered as a valid tool to cover some of the education and training needs.

2. The IAEA Safety Fundamentals

The IAEA Nuclear Fundamental Safety Principles [2] were endorsed by affected international institutions and published in 2006. The List of Principles is reproduced in table 1.

Table 1. The IAEA Fundamental Safety Principles

Principle 1: Responsibility for safety
The prime responsibility for safety must rest with the person or organization responsible for facilities and activities that give rise to radiation risks.

Principle 2: Role of government
An effective legal and governmental framework for safety, including an independent regulatory body, must be established and sustained.

Principle 3: Leadership and management for safety
Effective leadership and management for safety must be established and sustained in organizations concerned with, and facilities and activities that give rise to, radiation risks.

Principle 4: Justification of facilities and activities
Facilities and activities that give rise to radiation risks must yield an overall benefit.

Principle 5: Optimization of protection
Protection must be optimized to provide the highest level of safety that can reasonably be achieved.

Principle 6: Limitation of risks to individuals
Measures for controlling radiation risks must ensure that no individual bears an unacceptable risk of harm.

Principle 7: Protection of present and future generations
People and the environment, present and future, must be protected against radiation risks.

Principle 8: Prevention of accidents
All practical efforts must be made to prevent and mitigate nuclear or radiation accidents.

Principle 9: Emergency preparedness and response
Arrangements must be made for emergency preparedness and response for nuclear or radiation incidents.

Principle 10: Protective actions to reduce existing or unregulated radiation risks
Protective actions to reduce existing or unregulated radiation risks must be justified and optimized.

All principles have an impact on education and training, under that context only the most relevant ones are discussed.

Principle 1 assigns to the license holder the prime responsibility for safety. It means that the license holder has to be sure that: the site is compatible with the plant; the design is based in proven technology; the construction complies with all quality standards; the commissioning is complete and satisfactory; the operation is safe and reliable in all modes of operation and the plant is kept safe and reliable through established maintenance and oversight procedures. A great deal of knowledge and experience is collectively needed to cover all those responsibilities.

Principle 2 addresses the role of government on promulgating the needed legislation and creating a regulatory body. These responsibilities require that the dedicated legislative branch of government has a good knowledge of the nature of nuclear science and technology, the risks associated to ionizing radiation and the safety and security measures to be taken. Education and training for members of the regulatory body has to be based on a solid knowledge of nuclear science and technology enriched with a deep understanding of the aims and approaches of the regulatory function. These functions includes three basic aims: (1) enacting a complete and satisfactory set of safety and security regulations, (2) verifying compliance with the enacted regulations through a complete and satisfactory system of evaluations, inspections and continuous oversight, (3) enforcing compliance when discovering unacceptable deviations from the regulations. It should be stressed that the regulatory function has to be accomplished without unnecessarily engendering the economic interest of the licensee and with full respect to its responsibility for safety and security.

Principle 3 refers mainly to the license holder. The license holder has to procure and maintain a competent organization based on excellent leadership and management to assure safety culture and reliable operation. Apart for maintaining an integrated management, operation requires well trained nuclear operators and supervisors; highly qualified nuclear experts-core criticality, fuel behaviour, safety analysis, radiation protection, radioactive waste -; nuclearized engineers covering many technologies-thermo hydraulics, electrical, instrumentation and control, materials, procurement, design modifications, and a large number of skills in the mechanical, chemical, electric and electronic areas.

Principle 9 requires that there should be internal to the plant and external programmes to be prepared and act in case of an emergency. Accidents or incidents internal to the plant are under the responsibility of the licence holder, while accidents or incidents with external consequences are covered by the local and national authorities. Regulations require that drills are periodically conducted to test the validity of such emergency plans under the surveillance of the regulatory body. To cope successfully with nuclear emergencies includes many aspects and affects many people and social institutions requiring especial programmes on information, education and training.

3. INSAG view on needed infrastructure, education and training

The International Nuclear Safety Group, INSAG, a group of highly qualified experts in the field of nuclear safety, under the auspices of the IAEA, has analyzed the nuclear safety infrastructure which is needed for a national nuclear safety programme supported by the IAEA Fundamental Safety Principles. From the INSAG report [3] the need for nuclear education and training is easily deduced.

Nuclear education and training for the development and maintenance of new nuclear power programmes has to cover the different phases in the live of the nuclear power plant, consider the many technologies involved in each one of the phases and the specificity of the required knowledge and experience. The phases in the live of a nuclear power plant have been defined by INSAG in the cited report from which an education and training oriented table 2 has been deduced. The table copies the five major steps defined by INSAG, from the pre-decision phase to the end of the life of the plant, slightly modifies the major activities to be performed in each one of the phases and includes the needed infrastructure, education and training.

Table 1. Main phases in the life cycle of a nuclear power plant

PHASE	DURATION (years)	MAJOR ACTIVITIES	NEEDED INFRASTRUCTURE, EDUCATION AND TRAINING
1. Pre-decision	1-3	Develop a nuclear plan Conduct a public consultation Develop basic legislation	A government strong project management organization A comprehensive training programme for leaders
2. Decision	3-7	Develop a detail nuclear programme. Select a technology, a site and a supplier	An independent nuclear regulatory body A specific training programme for regulatory experts.
3. Implementation			
3.a. Site selection and characterization	2-3	Characterize the selected site. Formulate a site licensing authorization	A strong owner project management organization. Competence on earth sciences and man-made external inputs
3.b. Design and construction	5-7	Site preparation and detail plant design. Fill application for construction permit. Construction in accordance with requirements.	A set of siting and design criteria. Licensee and regulatory competence on design and procurement, inspection processes and quality assurance and quality control.
4. Operation			
4.a. Testing and commissioning	1-2	Verify compliance with requirements. Reach first criticality and perform established nuclear tests. Apply for operation permit. Transfer knowledge and responsibility to operating organization.	A set of criteria for safe commissioning. A well trained and sufficient operating personnel. Licensee and regulatory competence for the review and approval of test results and licensing reactor operators. An emergency preparedness and response system.
4.b.Commercial operation	40-60	Operate the plant within safety and reliability requirements. Perform periodic testing and inspection of safety related components, systems and structures. Evaluate malfunctions, incidents and accidents.	A set of criteria for safe and reliable operation. An integrated management organization for safe and reliable operation. Licensee and regulatory competence on equipment maintenance, aging, radiation protection and radioactive waste.
5. End of life			
5.a Decommissioning	5-10	Fill a dismantling plan for approval. Develop a radioactive waste management system.	A set of criteria for plant closure and decommissioning. Dismantling organization and regulatory body need training on specific dismantling activities and waste management
5.b. Long term management of spent fuel	15-100+	Establish and maintain a long term radiological control of spent fuel and high level waste	Define a policy for the management of spent fuel: reprocessing or geological disposal.

The pre-decision phase is a responsibility of the government in synergy with those national or private enterprises generating electricity. It requires a strong management organization composed of well trained persons with knowledge on the basic aspects of nuclear energy, the scientific and technical capabilities of the country, the foreseen human resources and how they can be educated and trained on safety, security, safeguards, radiation protection, waste management and project management.

The decision phase requires the construct of a regulatory body with the capability of establishing a well defined regulatory system to cover the succeeding phases in the life of the power plant. The members of the regulatory body require a specific training to develop regulatory requirements, verify project compliance with the established regulations and to correct and enforce any deviation.

The implementation phase requires a solid management structure within the future plant owner and operator and a complete and satisfactory set of regulatory requirements. Both the licensee and the regulator need to have competence on earth sciences and man-made events for site characterization; experience in design evaluation, construction management, equipment procurement, inspection processes and quality assurance and quality control, during the construction phase.

The operation phase starts with the commissioning activities and continues with commercial operation of the plant. To achieve that, a sufficient number of well trained operators and supervisors are necessary. During the commissioning period they are generally coached by the plant supplier. Once the plant has been transferred to the plant owner the licensee becomes fully responsible for the safe and reliable operation of the plant. Their initial training has to be maintained through continuous training programmes. The operation of the plant includes many and varied technologies needing a strong integrated management system to secure safety, security and reliable operation.

The end of life phase includes two very distinct activities: Dismantling the plant and long time management of the spent fuel. Dismantling is a technology by itself now being developed. It includes cutting big metal radioactive pieces, concrete walls scarification, to remove surface contamination, and demolition, as well as a strict radiation protection system and radioactive waste management. Dismantling is generally performed under the responsibility of national organizations. The funds to dismantle nuclear power plants come from taxes imposed to the plant owner-operator and are collected during the commercial operation of the plant. The national policy on spent fuel is the responsibility of the government. Spent fuel can be considered a waste or a source of energy when recycled to recuperate and reuse the plutonium produced through MOX fuel in current nuclear power plants. The policy to follow has to be determined by the government.

From table 2 it has been possible to deduce table 3 on the needs for education and training. Table 3 makes it clear the large list of specialities and skills that are needed for the development of a nuclear power programme. In general, most of these specialities required some type of university degree, which must be complemented by specific training offered by the suppliers of the power plants. The needed skills during construction and operation require training diplomas from vocational schools and skills academies.

Education and training for members of the regulatory body has to be based on a solid knowledge of nuclear science and technology enriched with a deep understanding of the aims and approaches of the regulatory function. Initial training of regulatory staff is complicated and experience can only be obtained from collaboration with advanced regulators.

Education and training for operating personnel is the responsibility of the licensee. It is conducted by specific organizations, such as Tecnatom in Spain, or by the licensee. In most countries, some of the operators have to be licensed by the regulatory body through a well regulated system. The US Institute for Nuclear Power Operations, INPO, has created a Systematic Approach to Training, SAT, procedure which includes an elaborated training programme accreditation system, which is also followed by Eskom in South Africa and by EDF-Energy in the UK.

Table 3. Needs for education and training to serve nuclear power plants.

PHASE	TRAINING REQUIREMENTS	TRAINING FACILITIES AND TOOLS
1. **Pre-decision**	Nuclear fundamentals needed to acquire technical capabilities, appreciate the international framework and understand nuclear economy.	University courses. IAEA International courses. World Nuclear University. European Nuclear Energy Leadership Academy.
2. **Decision**	Nuclear science and technology, nuclear systems, nuclear safety and security, nuclear regulation.	High level university degrees and specific courses. Specific training courses for nuclear regulators
3. Implementation		
3.a Site selection	Expertise needed on the earth sciences- meteorology, geology, seismology - and on environmental impact of nuclear power plants.	High level university degrees and courses covering earth sciences and environmental impacts (physical, chemical, social and economic)
3.b. Design and construction	Expertise needed on bid invitation and selection, design, construction and assembly of structures, systems and components and quality assurance	High level university degrees and experience in large projects. A large variety of expertise gained in vocational schools and skill academies
4. Operation		
4.a Testing and commissioning	A long specific training on plant operation of a large and sufficient number of reactor desk operators and supervisors, turbine operators, maintenance and radiation protection experts.	A long specific initial training is provided in full scale simulators and human factors training facilities operated by dedicated companies or in plant training resources.
4.b Commercial operation	Increasing expertise in all aspects and modes of operation is maintained. Leadership and management for safety and safety culture are developed and constantly improved. Own and outside operating experience is analyzed and lessons applied.	Initial, for new comers, and continuous training, for all personnel, is provided in full simulators and human factor facilities. On the job and mentor training is also provided to cover all aspects of nuclear plant operation
5. End of life		
5.a Decommissioning	Decommissioning includes technologies for removal of large radioactive components and system, demolition of active structures, separation of active and non active waste and site restoration.	Decommissioning requires experienced managers with university degrees and a large number of technical persons trained in vocational institutions and skill academies.
5.b Management of spent fuel	It is a high level decision requiring a good knowledge of alternatives, their cost and social implications and the international context.	High level university degrees on international policy and regulations, economics, nuclear technology and sociology.

4. The book on infrastructures and methodologies

With the information above a group of experts with training experience, regulatory know-how, international background, from research and academic institutions and nuclear industry organizations, decided to publish a book to cover the science, technology and administration they considered necessary to develop a nuclear power programme. The effort done was completed with the publication in 2012 of a book title *Infrastructure and methodologies for the justification of nuclear power programmes* [4]. The book was published almost a year after the Fukushima Daiichi accident, when most of the book was already written and edited. The text of the book was reviewed, references to the accident were included when considered necessary; it was also estimated that the accident reinforced the need for education and training and that nuclear power development will continue worldwide, although at a lower rate. The list of chapters and authors is included in table 4.

Table 4. List of authors and chapters in the book on infrastructure and methodologies

Chapter 1, A. Alonso, *Overview of infrastructure and methodologies for the justification of nuclear power programmes*
Chapter 2, A. Carnino, *The lifecycle of a nuclear power plant*
Chapter 3, D. F. Torgerson, *The role of government in establishing the framework for nuclear power programmes*
Chapter 4, G. Caruso, *Regulatory requirements and practices in nuclear power plants*
Chapter 5, J. Moares, *Responsibilities of the nuclear operator in nuclear power plants*
Chapter 6, F.J.Sánchez, *The need for human resources in nuclear power programmes*
Chapter 7, S. K. Sharma, *National technical capability development in nuclear power programmes*
Chapter 8, A. Alonso, *Application of the justification principle to nuclear power development*
Chapter 9, S. Bilbao y León et al., *Available and advanced nuclear technologies for nuclear power programmes*
Chapter 10, D.A. Maneley, *Nuclear safety in nuclear power pants*
Chapter 11, A.J. González, *Radiation protection in nuclear power programmes*
Chapter 12, E. Gil López, *Emergency planning in nuclear power programmes*
Chapter 13, M.S. Pellechi, *Non-proliferation safeguards in nuclear power programmes*
Chapter 14, H. Forsström, *Spent fuel and radioactive waste management in nuclear power programmes*
Chapter 15, H.H.Rogner, *The economics of nuclear power, past, present and future aspects*
Chapter 16, F. Bazile, *Social impacts and public perception of nuclear power*
Chapter 17, I. Salter et al., *Environmental impacts and assessment in nuclear power programmes*.
Chapter 18, A. Alonso, *Site selection and evaluation for nuclear power plants*
Chapter 19, A. González, *Bid invitation in nuclear power plant procurement*
Chapter 20, A. Alonso et al, *Licensing for nuclear power plant siting, construction and operation*
Chapter 21, R. Gasca, *Quality assurance during design, construction and operation of nuclear power plants*
Chapter 22, E. Grauf, *Commissioning of nuclear power plants*
Chapter 23, M. Lipar, *Operational safety of nuclear power plants*
Chapter 24, T.S. LaGuardia, *Decommissioning or nuclear power plants*

Appendix 1, W.E.A. Wilson, *The justification test for new nuclear power development: United Kingdom experience*
Appendix 2, A. Carnino, *Nuclear safety culture: management, assessment and improvement of individual behaviour*
Appendix 3, M.J. Moracho Ramirez, *Nuclear installation safety: IAEA training programmes, materials and resources*
Appendix 4, E. Lindauer, Simulator training for nuclear power plant control room personnel
Appendix 5, J. Reig, *Multinational Design Evaluation Programme: multilateral cooperation in nuclear regulation and new reactor design*

4.1 Part 1: Infrastructure on nuclear power programmes

Part 1 of the book is developed in five chapters covering: The lifecycle of a nuclear power programme; the role of government in establishing the framework for nuclear power programmes; regulatory requirements and practices; Responsibilities of the nuclear operator; the need for human resources, and national technical capability development in nuclear power programmes.

The role of government is considered critical for the success of a nuclear programme. The main responsibility of the government is enacting appropriate legislation and the creation of an independent regulatory body. The government is also responsible for education and training, research and development and for complying with the many treaties and international conventions on safety, security, safeguards, waste management and third party liability. The regulatory functions require an intense and specific education and training programmes, but initial experience can only be obtained in countries with a well established nuclear power programmes.

The license holder should be aware of his prime responsibility for safety, but the operation of a nuclear power plant engages hundreds of persons with diverse knowledge and skills, which have to be organized into a cohesive workforce and with a clear collective vision on what the team has to achieve. This requires and effective and successful leadership. Successful leaders do not only need knowledge and have experience, their manners, honesty, integrity and the quality of engendering respect and trust are even more important.

The need for human resources and how individuals should be educated and trained is a key chapter of the book. It addresses the human resource requirements of nuclear stakeholders, the specialities to be covered in each phase in the life of the power plant, the level of education and training required by nuclear professionals, nuclearized engineers, technicians and craftsmen and the national and international programmes and facilities to cope with the foreseen challenges.

The chapter on the national technical capability development stresses the need for developing national scientific and technical capabilities to respond to the initial and long term requirements demanded by a nuclear power plant. The chapter recommends orientation training for those people participating in the early decision and the development of a well trained technical core group to ensure the maximum national participation in siting, construction an operation.

4.2 Part II: Justification of nuclear power programmes

Justification of nuclear facilities and activities is the fourth principle in the 10 IAEA Fundamental Safety Principles. It establishes that "*facilities and activities that give rise to radiation risks must yield a general benefit*". The principle compares the economic, social and environmental benefits of a nuclear development with the associated risk. When the benefits outweigh risk the proposed nuclear development is considered justified. Although these two terms are easily identified its quantification and comparison is a difficult task including many uncertainties and different opinions. Chapter 8 defines and develops the terms in the justification equation, including nuclear risks and detriments of nuclear energy. Chapter 9 is an account of the available and advanced nuclear technologies.

Means and procedures to quantify risks are included in chapter 10 on nuclear safety. The chapter introduces the early deterministic approach to nuclear safety and the most recent probabilistic methodology and the risk-informed decision-making process. Radiation protection is the science related to the health effects of ionizing radiation. An extended chapter 11 contains the scientific bases and standards used on protecting workers and the public. Emergency preparedness and response is the last barrier available to mitigate the consequences of radioactive releases. Chapter 12 includes references on the international conventions of Early Notification of a Nuclear Accident (1986) and on Assistance in the Case of a Nuclear Event (1986) established after the Chernobyl accident. Non-proliferation of nuclear devices is an international concern; chapter 13 on nuclear safeguards considers the

Non-proliferation Treaty and the international safeguards developing by the IAEA to ensure non-proliferation.

Radioactive waste and spent fuel need to be managed, first during the operation of the plant and later on during extended periods of time. Chapter 14 includes an account on the policies and strategies for the management of both. The management of spent nuclear fuel is of particular interest as it can be classified as a waste or be declared as a useful resource of energy.

The singularities of nuclear power economics are considered in depth in chapter 15. It is well known that the initial investment is high but operation is cheap. The chapter discussed the current and future economics of nuclear power its risks and uncertainties.

Chapters 16 and 17 consider the social and environmental impacts of nuclear power respectively. Methodologies have been developed to quantify the national and local social benefits of nuclear power, but the methods are elusive and generally not accepted by social groups. The polls clearly indicate that there is a link between the social nuclear education level and acceptance of nuclear power. Environmental impact is well regulated at the international and national level. The radiological impact is considered very small and acceptable, while there is some concern on some physical impacts, mainly the heat discharged to the environment to comply with the second principle of thermodynamics.

4.3 Part III: Development of nuclear power programmes

Part III includes seven chapters including information of training interest. It includes chapters on site selection, bid invitation, licensing, quality assurance, commissioning and operational safety and decommissioning. Once decision has taken, the next steps are site selection and characterization and preparation of a bid invitation specification, BIS. Site selection, chapter 18 is based on the compatibility of the site characteristics with the design of the plant. The BIS depends on the desired type of contract and should end with the signature of a contract. The chapter describes in detail the intention and contents of the different documents in the BIS.

Licensing is based on the applicant submitting to the regulatory body a set of well defined documents and the regulatory body verifying compliance with the previously establish regulations and requirements. The process may last several years and end with the granting or denying the licence. Chapter 20 describes the general process; it also includes an Appendix describing the peculiarities of the licensing system in the United Kingdom an in Germany.

One of the most relevant activities is quality assurance. Chapter 21 describes the quality assurance criteria and processes during design, construction, commissioning and operation. It also covers the assessment of the quality assurance programme through independent peer reviews and self-assessments.

Commissioning is a short –one to two years – but crucial phase in the life of a nuclear power plant, as it serves to verify that the plant has been designed and constructed as required in the contract and within the safety requirements establish by the regulator. It also serves to test the performance and qualification of the operating personnel. The chapter describes the relevant applicable codes and standards, the different commissioning stages – preoperational, subcritical test and first criticality, low and power tests and final acceptation power test.

Commercial operation is the productive longest phase in the life of the nuclear power plant. Based on the IAEA requirements for nuclear power plant operation, chapter 23 describes the management organization and puts emphasis on the initial and continuous training and qualification of the operating personnel–management and supervisory personnel, control room operators and shift supervisors, field operators, maintenance personnel, technical support and general employee. Of specific interest is the training organization and training facilities, as considered in the IAEA standards.

Decommissioning will considerably grow in the future as old plants are reaching the end of their useful lives; nevertheless experience is accumulating in the dismantling of the early prototypes and demonstration facilities. Chapter 24 includes a brief history of decommissioning development, cost estimates, decommissioning technologies, research activities and the management of decommissioning waste.

4.4 Part IV: The Appendixes

The book includes five appendixes covering: 1. The United Kingdom experience in a test conducted to apply the justification principle to new nuclear builds. 2. The concept of nuclear safety culture, how it can be measured and the benefits it may provide. 3. The IAEA training programmes, the four quadrants competencies for regulators and SARCoN Guidelines. 4. Simulator training with recommendations on who should received a full-scale simulator training, operating scenarios, competences to be acquired, best ways to train in simulators and simulator requirements. 5. The NEA driven Multinational Design Evaluation Programme, MDEP, is a valid intent to achieve international harmonization in design codes, standards and safety goals; enhance multilateral cooperation within existing regulatory frameworks and facilitate licensing reviews of new reactors.

5. References

[1] F. Roelofs and U. von Estorff, *Top-down workforce demand extrapolation from energy scenarios*, European Commission Joint Research Centre, Institute for Energy and Transport, JRC81666, EUR 26008 EN, Luxembourg Publications Office of European Union, 2013.

[2] European Atomic Energy Community, Food and Agriculture Organization, International Atomic Energy Agency, International Labour Organization, International Maritime Organization, OECD Nuclear Energy Agency, Pan American Health Organization, United Nations Environmental Programme; World Health Organization, *Fundamental Safety Principles*, IAEA Safety Standards Series Nº. SF-1, IAEA, Vienna, 2006.

[3] INSAG, *Nuclear Safety Infrastructure for a National Nuclear Power Programme Supported by the IAEA Fundamental Safety Principles*, INSAG-22, IAEA, Vienna, 2008.

[4] A. Alonso, Editor, *Infrastructure and methodologies for the justification of nuclear power programmes*, Woodhead Publishing, Oxford, Cambridge, Philadelphia, New Delhi, 2012.

THE FUKUSHIMA ACCIDENT IMPACT ON SIMULATION TRAINING TOOLS

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ABSTRACT

As what happened with the TMI and Chernobyl events, it is expected the Fukushima accident will drive to significant changes in the simulation training tools.

The importance of analyzing and understanding the plant behavior under severe accident conditions is growing, leading to motivating the reinforcement of training on severe accident phenomenology and emergency management.

Full scope training simulators are one of the primary tools the plants have available to address their training needs, however few simulators in the world possess severe accident capabilities, mostly because the control room is not normally the right place to handle severe accident sequences (e.g. extended SBOs). Likewise international standards haven't yet required this feature.

Technical Support Center (TSC) members, and other emergency center staff, need specific training since they may not have the necessary skills to understand and operate, in depth, their plant evolutions in case of a major accident.

After careful analysis on the available solutions Tecnatom decided one year ago to start a project aimed at extending the use of simulators to the emergency center staff for training purposes in emergency drills. The project has addressed the following major points:

- To extend the simulation scope of available classroom simulators by integrating a severe accident module that has been developed based on MAAP4, code (MAAP technology is owned by EPRI: Electric Power Research Institute and used by the Spanish NPPs for PSA analysis).
- Integration of the severe accident module with a PWR full scope training simulator operated by Tecnatom. Simulation continuity has been guaranteed between normal operation and accident conditions.
- On-line switch between real time and faster than real time execution.
- Stimulation of emergency support tools. The Technical support Center staff will receive the information in the same manner they would receive it in case of a real accident sequence.

The project successfully finished last year with an implementation plan that is currently under analysis.

1. Introduction

As a consequence of the accident that took place at Fukushima, there has been an increase in the importance of reinforcing the training in severe accident management in nuclear power plants. Full scope training simulators are one of the primary tools the plants have available to address these new training needs.

From the point of view of severe accident simulation, the technology is fairly mature and available, with several previous experiences about the use of severe accident codes with training purposes. However, severe accident scenarios are hardly used in training.

On the other hand, Technical Support Center (TSC) members and other emergency centers staff need specific training and do not have the necessary skills to understand and operate, in depth, their plant evolutions in case of major accident.

At Tecnatom we work on different activity areas related to nuclear safety, including simulation technology, control rooms design and modernization, plant operation support, plant staff training and safety management. This experience provides Tecnatom with a multidisciplinary point of view as well as a general approach to safe operation of a NPP and an effective response in the event of an accident.

The conclusion is that reinforcing severe accident management training is one of the challenges that NPPs have to face in the near future and severe accident simulation technology needs a new angle in order to be really useful.

2. Background

Back in 2005, Tecnatom developed a methodology for the design and integration of severe accident simulation models in training simulator environments. This methodology was applied and validated by developing a severe accident simulation model, based on the MAAP code (MAAP is a technology owned by EPRI: Electric Power Research Institute, Inc.) and by implementing it in a full scope training simulator.

3. Project Design Criteria

Project design criteria taken into consideration were:

- The control room simulator may not always be the most appropriate environment, for instance to train on severe accident phenomenology
- Plant staff, other than operation crew, is not qualified to operate the NPP from the control room
- Accident scenarios duration exceeds usual training sessions´ time
- There are no specific support tools connected to simulators for nuclear emergency training purposes

These considerations led to the conclusion that there is a need to integrate simulation technology supporting severe accident phenomenology within the specific training necessities of plants and Technical Support Center staff.

4. Project Scope Main Features

In the light of all of these considerations, Tecnatom embarked on a project aimed at extending the use of simulators to the emergency centers staff for training purposes in emergency drills. The project consisted of implementing new features in available training simulators, enabling its use in emergency centers. Amongst others, the project addressed the following major points:

- Extension of the simulation scope of available classroom simulators by integrating a severe accident module, based on the code MAAP4 (technology used by the Spanish NPP for PSA studies)

- Integration of a severe accident module in a PWR training simulator operated by Tecnatom. Simulation continuity has been guaranteed between normal operation and accident condition
- On-line switch between real time and faster than real time execution. This feature allows fitting a severe accident sequence within a training session timeframe by speeding up the simulation while the information is not relevant.
- Duplication of the most important classroom simulator displays in case of emergency. That way, the displays may show either the instrument values, so the staff will receive the information in the same manner they would receive it in case of real emergency, or the physical values calculated by the model, associated with the instruments, which is of great help to understand the accident progression
- Stimulation of the emergency support tools SACAT-GGAS, developed by Tecnatom.
- Possibility of different type of training configurations, oriented to different type of training sessions. For instance, sessions only with control room operation crew, only with TSC members or mixed sessions, and a phenomenology training configuration, showing the physical values in the displays.

5. Emergency support tools stimulation

5.1 SACAT – Technical Support Center Support System

Tecnatom has developed several computer-based tools for emergency training and management, named SACAT, running at the Technical Support Centers.

SACAT includes different modules and displays which show the main operating parameters, radiation monitors and external radiological impact estimates due to all possible leakage pathways.

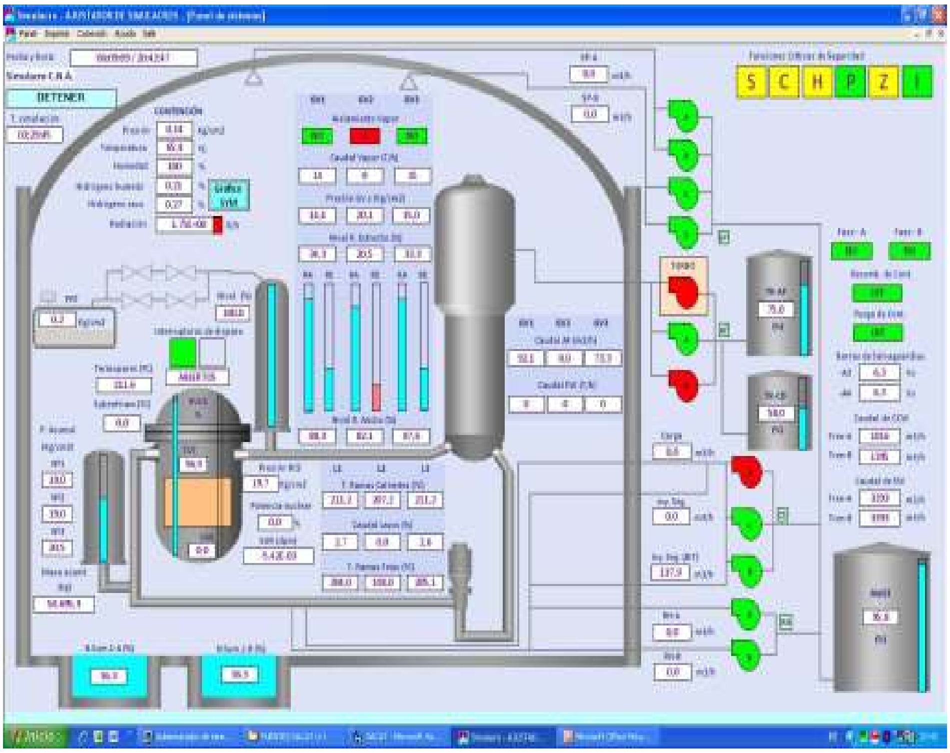
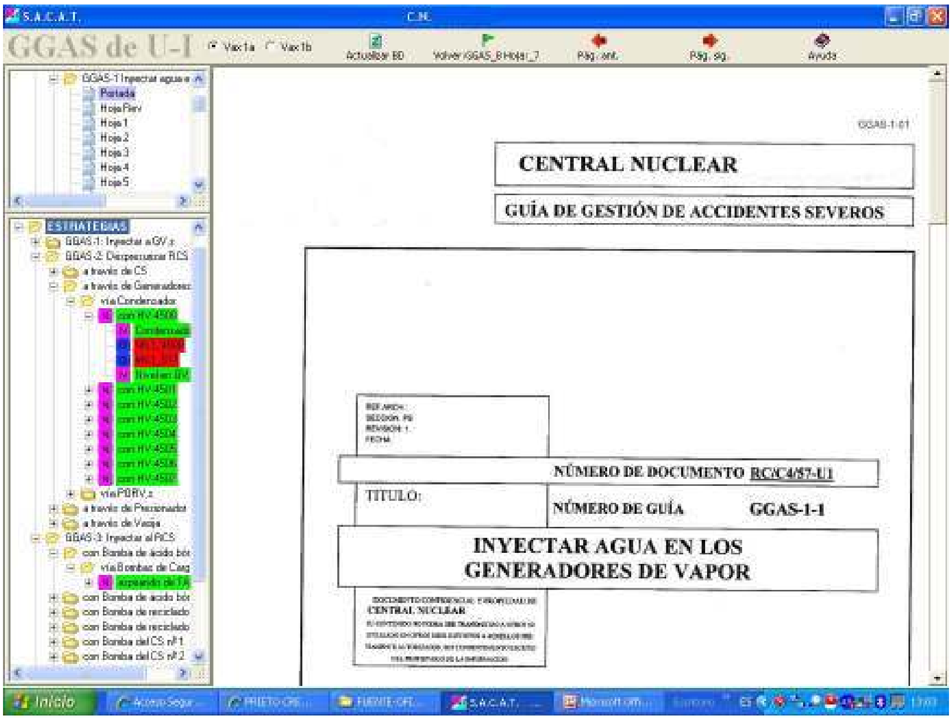


Fig 1. SACAT: main operation display

5.2 SACAT-SAMG: Severe Accident Management Guidelines

The second tool, SACAT-SAMG, is a computerized module of the Severe Accident Management Guidelines, customized for every Spanish NPP. It consists of a general display with the available guides, allowing consulting tables and providing computational aids during the follow up of a specific guide, as well as checking the state and availability of equipments, systems and strategies.



CENTRAL NUCLEAR

GUÍA DE GESTIÓN DE ACCIDENTES SEVEROS

NÚMERO DE DOCUMENTO RC/C4/57-U1

TITULO:

NÚMERO DE GUÍA GGAS-1-1

INYECTAR AGUA EN LOS GENERADORES DE VAPOR

CENTRAL NUCLEAR

Fig 2. SAMG computerized module

The stimulation of the emergency support tools by the simulator supports the training of the Technical Support Center members, allowing the follow-up of the accident through these tools and helping in the decision making process, since they provide the most relevant data and information about the most important parameters as well as the SAMG strategies available at every moment. Furthermore, it allows the TSC members to be trained with the same tools they use in case of real emergency.

6. Different training configurations

Amongst the different training configurations:

- Session with operation crew alone, to train on their own Control Room Severe Accident Management Guidelines
- Session with TSC members alone, to train on their Severe Accident Management Guidelines
- Session with TSC members and operation crew coordinated under the same scenario, making possible for them to develop team skills in emergency situations
- Phenomenology training session, following the data calculated by the severe accident module and therefore the accident progression

7. Simulator validation

One of the most important phases of the project is the validation. In this case three different validation processes were required.

The first step was to validate the online switch between real time and faster than real time. In order to do that, some sequences were executed at different simulation speeds. For instance, the SCRAM sequence was executed at real time and 5, 20 and 60 times faster than real time, obtaining the exact same results:

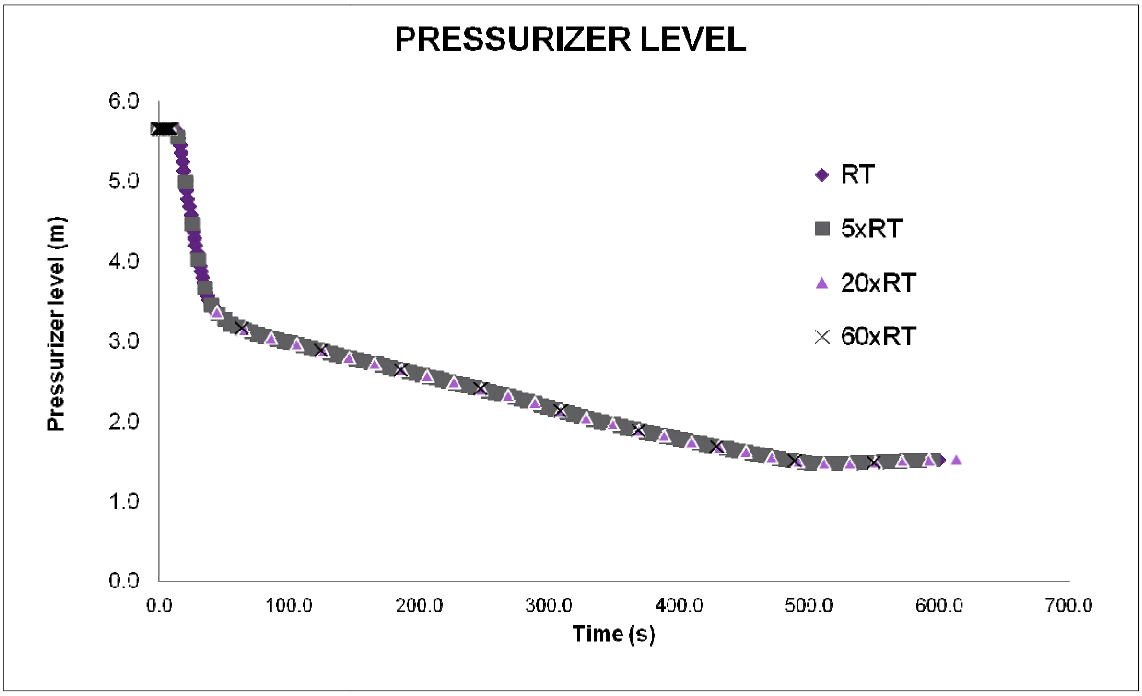


Fig 3. Time switch validation. Pressurizer level in SCRAM sequence

As a second step, the integration of the severe accident module in the classroom simulator was validated, checking that all the variables were correctly exchanged. This validation was carried out according to the ANSI/ANS-3.5 standard, which sets the functional requirements for full-scope nuclear power plant control room simulators for use in operator training and examination. Ten sequences were executed and the main operation parameters compared between the simulator before and after the integration of the severe accident module. For example, for the sequence of loss of feedwater, the following results were obtained, finding that both performances were qualitatively identical:

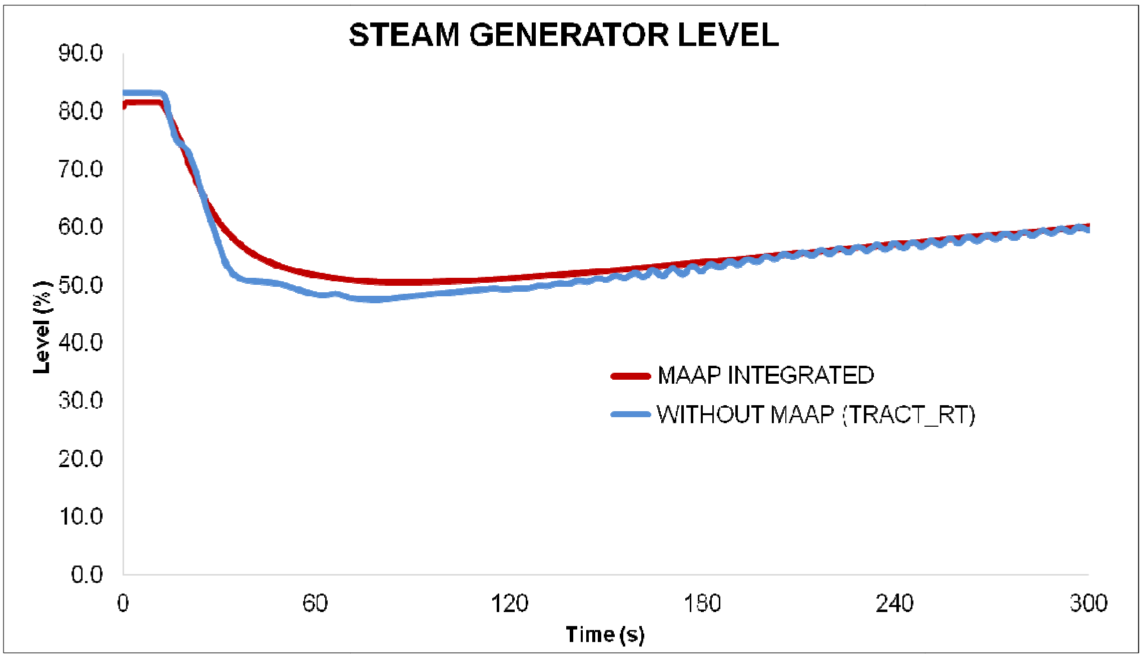


Fig 4. Integration validation. SG level in loss of feedwater sequence

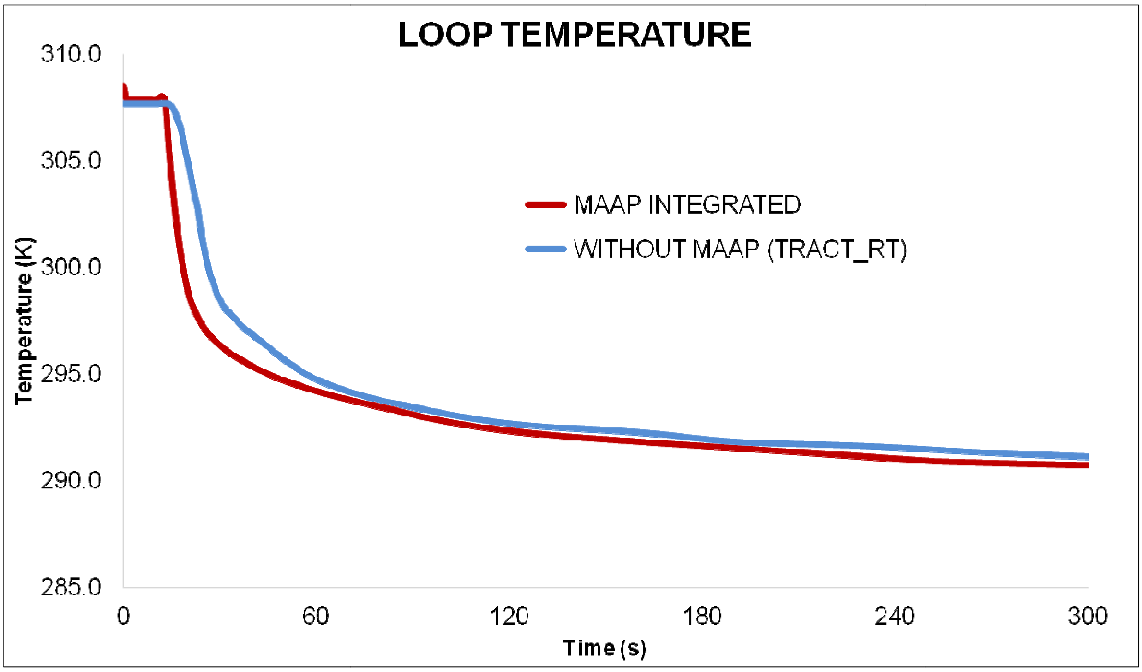


Fig 5. Integration validation. Loop temperature in loss of feedwater sequence

Finally, the simulator severe accident performance was validated. For this purpose, a series of severe accident sequences were executed, such as a prolonged Station Black Out, loss-of-coolant accident (LOCA) with failure of LPSI pumps or total loss of feed water accident with failure of HPSI pumps. These sequences were run following the Emergency Operation Procedures and the Severe Accident Management Guidelines with experts in severe accident phenomenology. For instance, some of the results for the LOCA sequence with failure of the Low Pressure Injection System and later recovery of these pumps are the following:

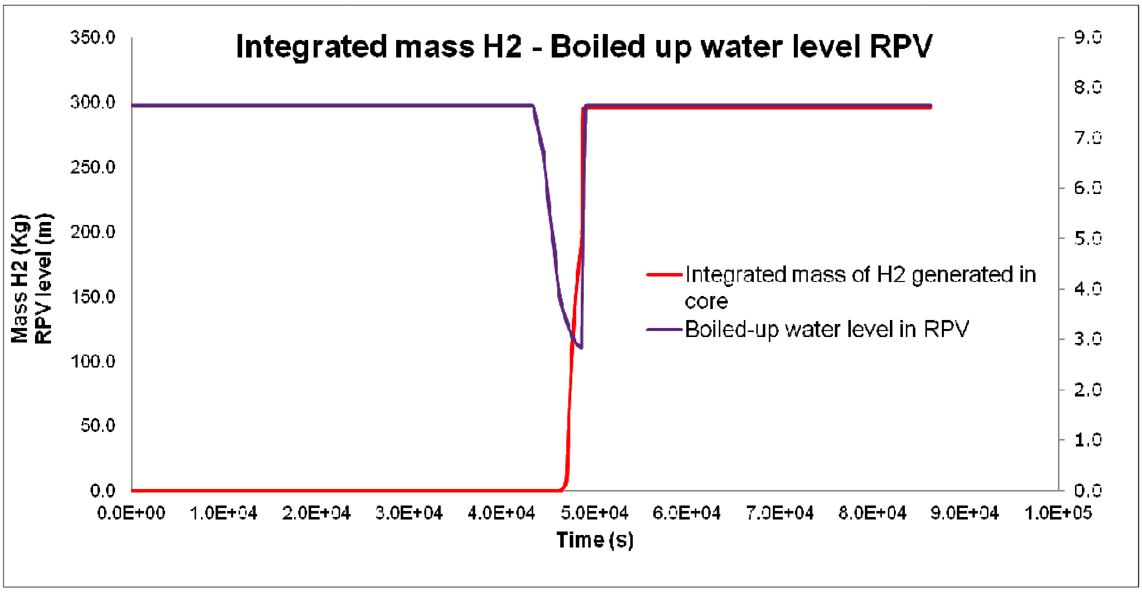


Fig 6. Severe accident performance validation. LOCA sequence

8. Conclusions

Although severe accident simulation is an available technology, a new approach is requested in order to get the most out of the training in severe accidents management.

As identified in this paper, the new features implemented within the full scope simulators domain make them efficient tools for such important points as the definition, assessment and training in severe accident management as well as the deep understanding of its complex phenomenology.

MULTIMEDIA TOOL FOR WWER TRAINING

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ABSTRACT

The Institute for Energy and Transport of the Joint Research Centre (JRC) of the European Commission, jointly with the International Atomic Energy Agency (IAEA), have developed an innovative multimedia knowledge package which is based on systematically collected and consolidated knowledge of top-experts in WWER (i.e. the Russian version of a pressurised water reactor) Reactor Pressure Vessel (RPV) Embrittlement and is meant to support training in the field.

The tool is addressed to nuclear engineers and researcher who need to be trained on WWER RPV Embrittlement issues. The modules provide very compact knowledge; an expert is recorded while giving a lecture (usually composed of 10-20 topic related questions answered) and his speech is subtitled. The presentation is powered with eye-catching animations that make simpler the learning process and that attract the user attention. At the end of each lecture the trainee can test his understanding on the topic with a multiple-choice questionnaire and receives a score based on his performance. A powerful search engine is built in the package to ensure the easy navigation across all Modules in, text, video and sound.

These multimedia modules are designed as an on-line resource and include the possibility to easily share and discuss on social medias (i.e. twitter, Facebook, etc.) the selected presentation/slide.

The package is completed and programmed in HTML 5 language to allow high flexibility and make the content browsable also on tablets and phones. For classroom training an offline version can be generated.

1 Introduction

1.1 Methodology

The Institute for Energy and Transport of the European Commission Joint Research Centre has developed a methodology for consolidation of nuclear knowledge [1].

The method, shown in Fig.1, relies on the mobilisation of all identified leading experts in the European Union (EU) or beyond, re-evaluating old knowledge and consolidating what is necessary to create training and education material for new generations of nuclear engineers, researchers and experts.

These experts are asked to provide the papers in their possession related to a specific nuclear expert field. Furthermore, they are asked to identify still more key-experts in that area.

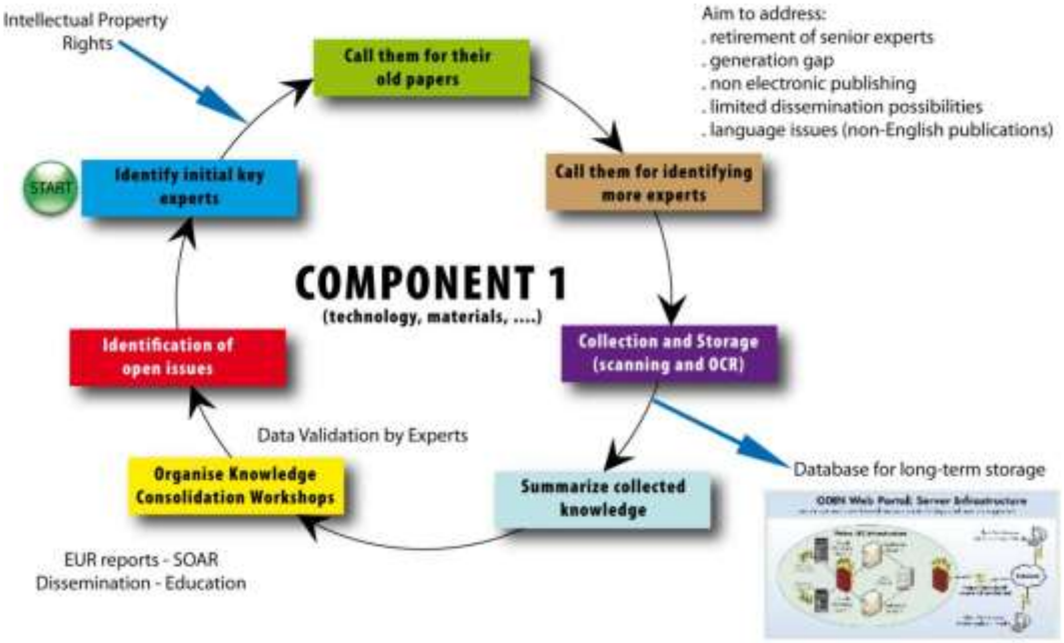

Fig. 1 Nuclear Knowledge Preservation Circle

All papers are collected centrally and stored in a protected database DoMa, which is a document database located within ODIN (http://odin.jrc.ec.europa.eu), managed by the Institute for Energy and Transport. The papers are stored in pdf format and additionally have information about the title, authors, keywords and abstracts stored separately in MS Word for an easy search function implementation.

After the identification of some possible reviewers amongst the expert group, the subject is subdivided in subfields, in order to reduce the heavy work of review, summary and preliminary consolidation.

When the reviewers have finished their work, they prepare a summary report for their subfield, which is then sent to all experts participating to the upcoming consolidation workshop. At the workshop the reviewers present their summary and conclusions on the subfield reviewed, which is afterwards discussed among the experts. The task of the chairman is to lead the experts to an as agreed as possible consolidation of the knowledge in each particular subfield. Finally, recommendations are made at the end of the workshop, which lead to further consolidation efforts in certain subfields or to a final consolidation document in others.

An additionally very important item in the consolidation process is the identification of commonly agreed (consolidated) open issues in the subfields. They complement the final goal of a State-of-the-Art report in the specific expert area.

1.2 Knowledge preservation of WWER Reactor Pressure Vessel Embrittlement

WWER (acronym of Water Water Energetic Reactor) is a type of Nuclear Reactor designed in Russia and similar by construction to a Pressurized-Water-Reactor (PWR) more common in the western countries. Approximately 50 WWER reactors are still in operation worldwide and 20 of them are located in European Union member states [2].

There is a huge amount of information and knowledge in WWER Reactor Pressure Vessel (RPV) embrittlement available, either published or easily available, but there are also publications that are difficult to trace. Especially those at risk of being dispersed or lost due to a series of factors, including:

- retirement of Senior Experts who were present at the time when most WWER Nuclear Power Plants were designed and put into operation,
- generational gap (due to years of decline in new constructions, only a limited number of people started their career in that area)
- non-electronic publishing in the past
- limited dissemination possibilities
- language (many non-English publications from Eastern countries)

Therefore, the Institute for Energy and Transport has decided, jointly with some key experts, to perform a pilot study using the previously described methodology for consolidation of WWER RPV embrittlement knowledge.

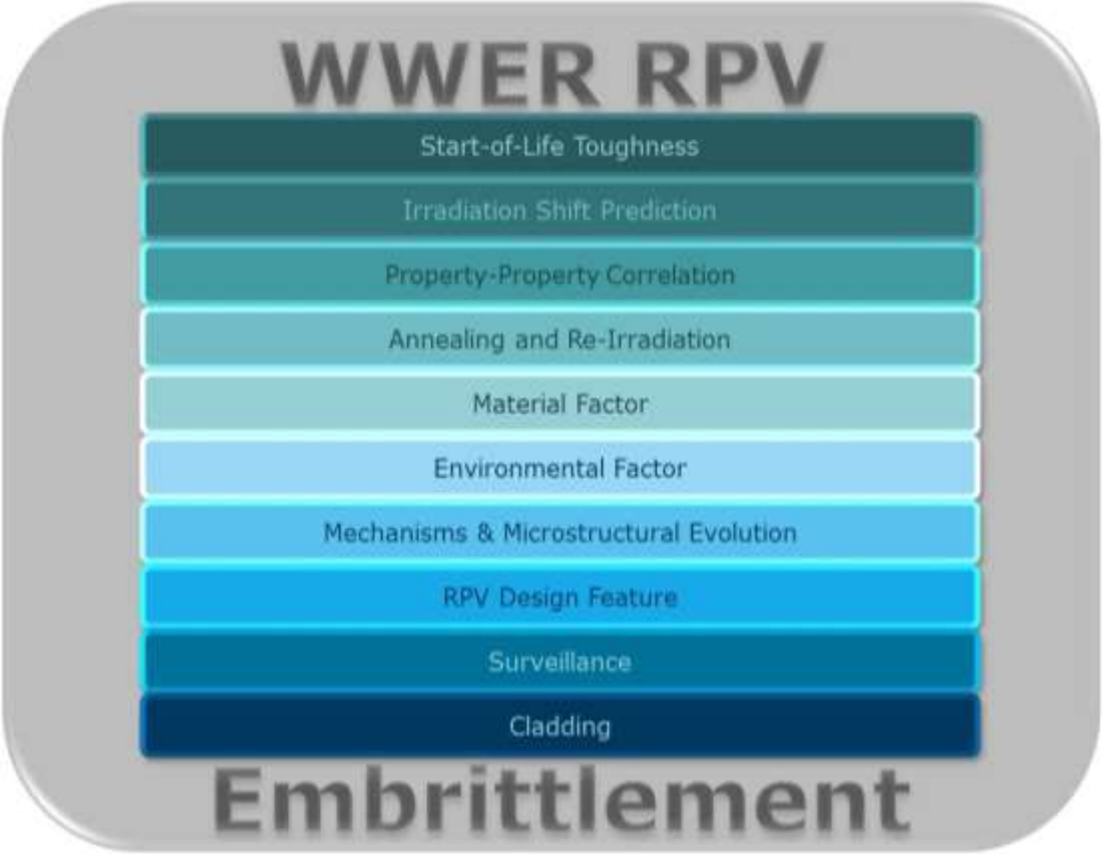

Fig. 2 Subdivision of WWER RPV Embrittlement Expert Fields

It has to be mentioned that the last State-of-the-Art document was produced in 1981 by Alekseenko, Amaev, Gorynin and Nikolaev [3, 4], which needs upgrading.
In a brainstorming session at the beginning, the predefined fields of expertise in WWER RPV Embrittlement were discussed and defined as described in fig. 2

1.3 Conclusions on the Methodology

It is evident that this pilot-project alone cannot solve a structural shortage of nuclear experts and vice versa, that initiating such a pilot-project cannot prevent the experts from retiring with their specialist knowledge. The key problem is the effect of these developments: a shortage of human resources qualified to do the work to be done. This shortage causes difficulties everywhere in the field and it will make it even more difficult to collect the knowledge of the retiring experts in a complete and systematic way.

The above described methodology applied to the knowledge of WWER RPV embrittlement has proven to be a step in the right direction. The experts themselves, mostly active in the field from the beginning of the nuclear area, are proud of their work. They contributed in a very idealistic and positive way to this first circle of knowledge consolidation. Some even did the reviewing work in their spare time at home. The atmosphere during the discussions of the proposed consolidated conclusions per subfield was relaxed and constructive, as were the discussions on the consolidated open issues per subfield. The outcome was preserved in several summary records (to be found at http://capture.jrc.ec.europa.eu). It was interesting to notice that the experts were agreeing on their consolidated conclusions and open issues on the basis of a limited number of papers per subfield. It was clear that the complete (tacit) knowledge and experience of the experts were taken into consideration when making such a judgement, not only the knowledge by reviewing the limited amount of papers. This may be a very powerful tool in order to save time in the consolidation process.

A further advantage of this consolidation methodology is that the summary reports of the subfields can be published openly, pointing to all reference papers, but not violating intellectual property rights (IPR). A wide dissemination to the interested public is guaranteed free of charge and to the benefit of engineers, experts and researchers who constitute the identified target group of this exercise and who needs to be trained in RPV issues.

Fig. 3 Process Scheme from Knowledge Consolidation to dissemination

It seems promising to continue applying this consolidation methodology to other fields of possible nuclear knowledge loss. This could be done not only for materials, but also for technologies, components, systems, etc.

Therefore, in summary, the first pilot study on WWER RPV Embrittlement is being carried out with some encouraging preliminary results:

- The consolidation methodology proves to be efficient
- The participation of the experts to the consolidation is excellent
- Unified keywords are essential to trace the information needed
- The consolidated summaries per expert sub-field give a good general overview on results, open issues and key references without violating IPRs

2 Multimedia Project

2.1 Basis

As described before, the EC-JRC recognised the importance of WWER reactors knowledge preservation. The next step after the consolidation process would be a wide distribution of the gained knowledge to the target group. Therefore an initiative on “Preserving WWER RPV Embrittlement Knowledge using Multi Media Technologies” has been launched. To ensure the best quality of the final product, which is the Multi Media Training Course on WWER RPV Embrittlement, EC-JRC asked the International Atomic Energy Agency (IAEA) for cooperation. This initiative is part of the Practical Arrangement signed between the IAEA the EC- JRC where a closer cooperation in the development of Multi Media Material for Nuclear Knowledge Dissemination and Education is indicated. For a visual impression of the process Figure 3 is a good illustration.

2.2 Execution and Technical Details

Starting from March 2010, video recordings of key experts were conducted at different locations, main papers and documents were reviewed, materials from key conferences were preserved and multiple-choice tests to evaluate students' understanding were created. After a first pilot module the others follow shortly and by today 10 modules were successfully completed, one for each of the 10 expert fields identified in Fig. 2.

WWER Reactor Pressure Vessel Embrittlement
Multimedia training course

There is a huge amount of information and knowledge in WWER Reactor Pressure Vessel (RPV) embrittlement available, either published or easily available, but also publications difficult to trace. Especially those were at risk of being dispersed or lost due to a series of factors, including:

- Retirement
- Generational gap
- Non electronic publishing in the past
- Limited dissimenation possibilities
- Language (many non-English publications from Eastern Europe countries)

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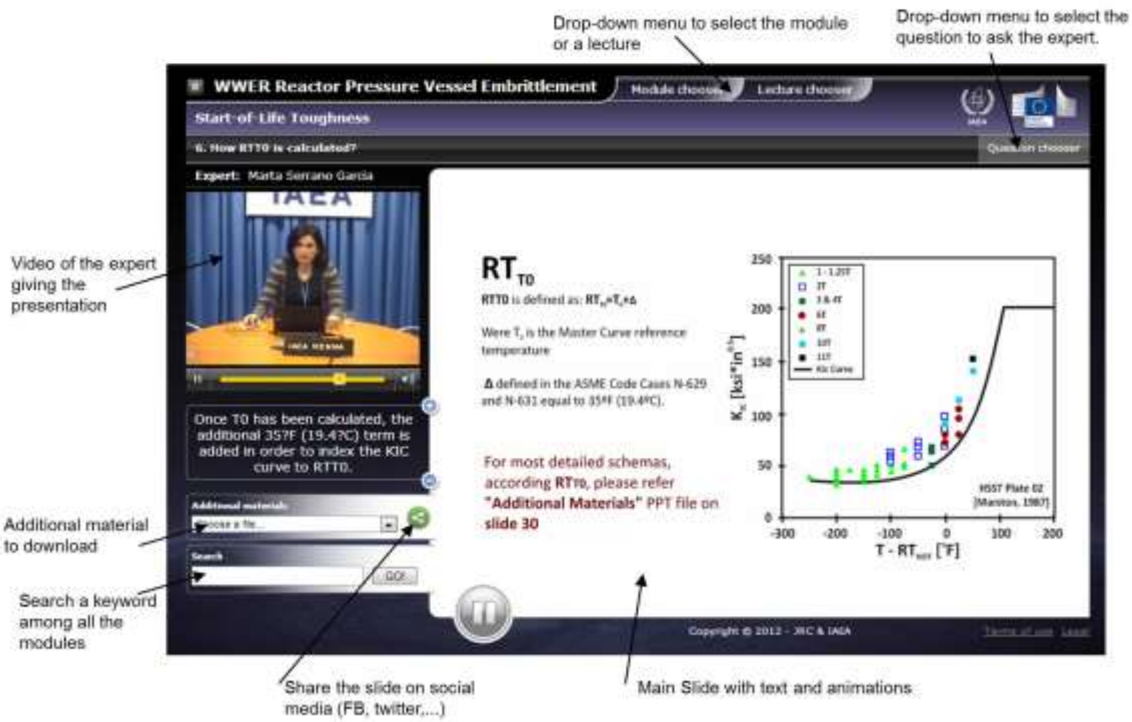
Fig. 4 Entrance screen of the Multimedia Course on WWER RPV Embrittlement

The entrance page, shown in Fig.4, allows an easy selection of the modules and the beginning of the multimedia experience.
The tool offers a modern interface with a rational disposition of all the offered features: the window is divided in several frames as shown in Fig.5. The knowledge presented is compact and easy to assimilate: an expert is recorded while giving a lecture (usually composed of 10-20 topic related FAQs and is subtitled); slides are appealing and have eye-catching animations to attract the user's interest. The interface presents the following characteristics:

- Big central animated presentation slide
- Three drop-down menus to select either one of the 10 modules, a lecture recorded during a workshop or a variety of questions asked to the expert.
- Video of the expert recorded while giving the presentation
- Subtitles of the presenter's talk for better understanding
- Additional material (papers, book chapters, presentations, etc.) on the topic easily downloadable through a drop-down menu
- Social-button: allows to share the selected slide on social media such as Facebook, Twitter, Google+, Digg-it
- Multiple choice test at the and of each module to check the user's learning process



Once T0 has been calculated, the additional 35?F (19.4?C) term is added in order to index the KIC curve to RTT0.

RT_{T0}

RTT0 is defined as: $RT_{T0}=T_0+\Delta$

Were T_0 is the Master Curve reference temperature

Δ defined in the ASME Code Cases N-629 and N-631 equal to 35ºF (19.4ºC).

For most detailed schemas, according **RT_{T0}**, please refer **"Additional Materials"** PPT file on **slide 30**

Fig. 5 Example of a Multimedia Course page

From a technical point of view the tool is modern and innovative under certain perspective in fact presents the following features:

- The tool was completely developed in HTML5, making it browsable on PC/laptops and on mobile devices as well (tablets, phones…) regardless of the screen size or of the operative system running on the device
- The tool can be hosted either on Windows or Linux server with PHP support
- For classroom training or location without internet access, an off-line version can be recorded on a DVD
- The platform is modular and scalable, allowing to add different modules or to use it for other knowledge-preservation projects
- Results of the multiple-choice tests can be stored and a completion certificate can be printed at the end of the ten modules.

3 Summary

The encoding was finished and the platform was incorporated on the CAPTURE website in autumn 2013 and can be used in its online form free of charge at the following web-url: http://capture.jrc.ec.europa.eu/wwer, an off-line version can be requested to the authors of this publication.

The tool has been used already during a classroom pilot training course in connection with the CORONA project (financed by the 7th framework programme of the European Commission http://projectcorona.eu/): participants had at their disposal a multimedia Pc with Internet connection and this allowed the trainer to tailor the course on the individual needs of each of the 16 participants, directing them to the modules of major interest for their background/requirements.

The platform in this form proved to be easy to use and scalable to different needs and can become a powerful tool for future knowledge preservation tools.

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[4] Radiation Damage of Steel for Reactor Pressure Vessels, N. Alekseenko, A. Amaev, I. Grynin, V. Nikolaev, ISBN 0-89448-564-4, 282 pages, ANS publication, USA (1997)

CURRICULUM DEVELOPMENT FOR A MODULAR SHORT COURSE ON RADIATION EFFECTS IN ELECTRONICS

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ABSTRACT

At the senior undergraduate and graduate levels, course catalogues of many University nuclear programs and departments fail to cover the breadth of specialties that are now standard in nuclear science and engineering. This is largely a result of many typically small faculty sizes and the ever expanding overlap of nuclear science with other disciplines. In this regard, distance learning and online courses have been invaluable in filling in the gaps in course material. Furthermore, such courses are geared for a student audience and are designed to be easily assimilated and cover fundamental concepts. We have prepared an online course sponsored by the US Nuclear Regulatory Commission, which is aimed at teaching students the fundamentals of radiation effects in electronic materials. The course consists of a series of five modular video lectures, ranging between 15-20 min long, that cover topics from basic nuclear interactions and materials science to defect evolution models and semiconductor physics. Accompanying these lectures are a series of video labs intended to help supplement the students' newly developed theoretical knowledge with demonstrations of the various phenomena discussed in the lecture modules. The labs also help introduce the experimentally inclined to the basic tools and techniques used in experimental radiation engineering.

1. Introduction

University courses teaching core topics and delivered in a classroom setting are an indispensable ingredient in a student's academic upbringing. Given the faculty size of many nuclear science and engineering programs and the priority of teaching core fundamentals, however, it is often difficult to provide a broad coverage of specialized material pertaining to particular sub-fields. While many individuals in academia will typically only specialize in a single sub-field it is generally a benefit to a student's resume and career to be literate in a number of different areas. Students at the graduate level may gain experience in such areas through research conducted with their faculty advisors expert in those areas but as academic expertise is highly localized at particular universities, only students at those universities will have direct exposure to it.

Self-study is another tool to help students become literate in sub-fields not covered by their normal course offerings. However, there is little educational infrastructure to support self-study. Students taking this approach must show considerable determination and follow through to absorb the more difficult concepts without the aid of a professor, course instructor or TA. A recent phenomenon of open courseware published by public and private Universities in the United States has facilitated free and open self-study in the general public. The most developed open courseware, however, is primarily available only for core undergraduate classes. Furthermore, the open courseware for advanced classes or classes covering special topics is a byproduct of what is, first and foremost, meant to be material delivered in a classroom setting.

Short modular video lectures are a useful tool in self-study because they are not tethered to a classroom, they are designed to encapsulate all of the information covered in the course, and by being short, and they can be completed by a moderately motivated student who might have other scholastic or time commitments to balance. In a similar vein, the short video module is a convenient way to deliver continuing education material for individuals in industry or academic staff positions who have many job responsibilities and little time or inclination to complete a full course.

We have constructed a series of modular video lectures to teach students the basics of radiation effects in electronic materials. The topic is multidisciplinary in nature and incorporates aspects of nuclear engineering, materials science and solid state physics. Students who are interested in radiation detector design, electronics for space or nuclear reactor applications, accelerator engineering, and microelectronics will find that the material covered is a valuable supplement to their knowledge. It is assumed that the student has a familiarity with basic terms like neutron, atom, electron, crystal etc. and that he or she has taken math classes up to and including differential equations. The course material is appropriate for upper level undergraduate students in the natural sciences and engineering or students starting graduate school.

2. Course Structure

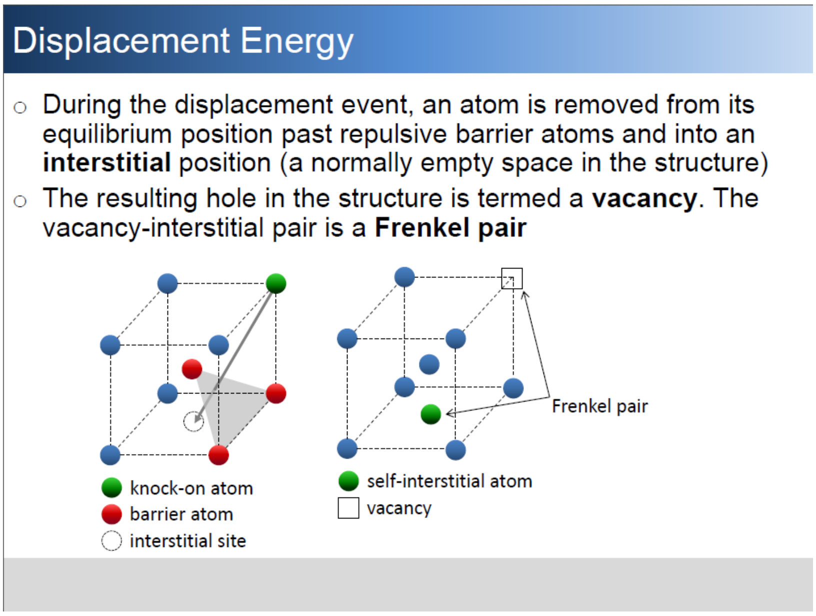
The course consists of the following 7 modular video lectures:

1. Nuclear interactions and interatomic potentials
2. Stopping power and the damage cascade
3. Defects and damage evolution
4. Electronic properties
5. Radiation effects on electronic properties
6. Introduction to scanning electron microscopy
7. Irradiation by beams and radioactive sources: uses in materials science

Each lecture of the first five modules is about 15-30 min in length and covers a different topic related to radiation damage in electronic materials. The lectures are modular in the sense that information is encapsulated as much as possible within a particular lecture. In this way, a student who wishes to review a concept only has to review one of the modules instead of the whole series. Additionally an individual with good familiarity in one area might choose to only use selected modules. For example, someone familiar with solid state physics could choose to skip module 4 while someone familiar with radiation effects could choose to skip modules 1, 2 and 3. However, in general, it is assumed that the student will want to work through all seven modules in order as the information builds to a rounded survey of the subject matter.

The material, being fairly technical in its nature, must necessarily be dense in order to fit within the 15-30 min format. However, an advantage of having short, on-line lectures is that the student may pause the lectures as they see fit or review them additional times if necessary. The material is not comprehensive as it only takes a cursory look at some basic concepts within a large body of knowledge. Therefore, some recommendations for textbooks and review articles are provided within the first module which will aid the student in any subsequent literature research that they wish to pursue.

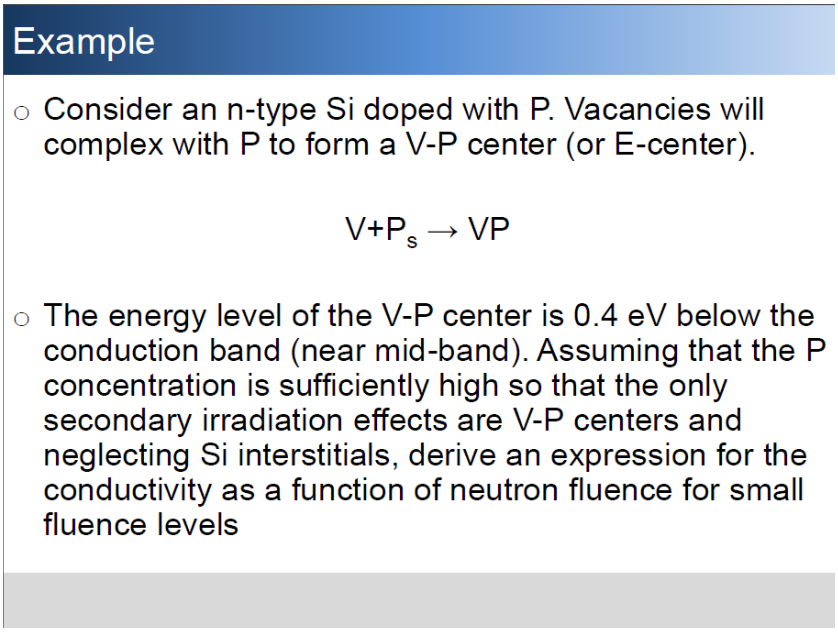
The content of the video comprises a series of presentation slides with text, equations, and figures on them and an audio track with the instructor narrating. An example of a slide is shown in figure 1. The narration closely follows the text on the slide so as to conform to both auditory dominant and visual dominant learning styles. Several example problems are provided in the modules in cases where it helps to show how various mathematical formulae and concepts are united in a practical way. Figures 2, 3 and 4 are slides presenting an example problem and its solution. It is necessary that the example problems are made with enough assumptions that the solutions are fairly simple. In this way the student can better understand the gist of the solution and not get distracted by algebraic manipulations. For more in-depth and challenging practice using the concepts and theory, each lecture is accompanied by a problem set. Some students find that problem solving exercises helps them to cement their knowledge. The problem sets are provided as a resource should they want the additional challenge.



Displacement Energy

- During the displacement event, an atom is removed from its equilibrium position past repulsive barrier atoms and into an **interstitial** position (a normally empty space in the structure)
- The resulting hole in the structure is termed a **vacancy**. The vacancy-interstitial pair is a **Frenkel pair**

Figure 1: An example slide from a lecture module



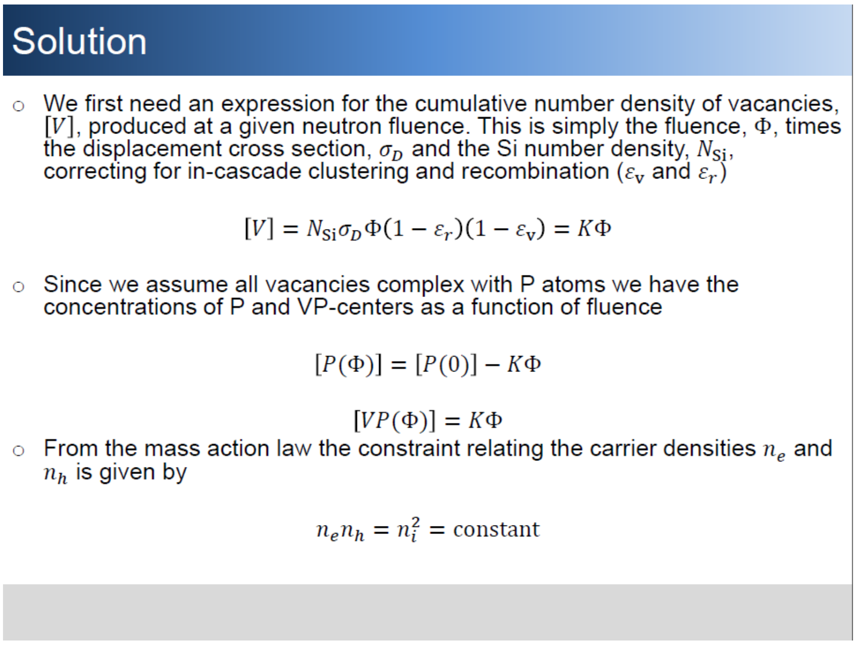
Example

- Consider an n-type Si doped with P. Vacancies will complex with P to form a V-P center (or E-center).

$$V + P_s \rightarrow VP$$

- The energy level of the V-P center is 0.4 eV below the conduction band (near mid-band). Assuming that the P concentration is sufficiently high so that the only secondary irradiation effects are V-P centers and neglecting Si interstitials, derive an expression for the conductivity as a function of neutron fluence for small fluence levels

Figure 2: Example problem from module 5



Solution

- We first need an expression for the cumulative number density of vacancies, $[V]$, produced at a given neutron fluence. This is simply the fluence, Φ, times the displacement cross section, σ_D and the Si number density, N_{Si}, correcting for in-cascade clustering and recombination (ε_{v} and ε_r)

$$[V] = N_{\mathrm{Si}}\sigma_D\Phi(1-\varepsilon_r)(1-\varepsilon_{\mathrm{v}}) = K\Phi$$

- Since we assume all vacancies complex with P atoms we have the concentrations of P and VP-centers as a function of fluence

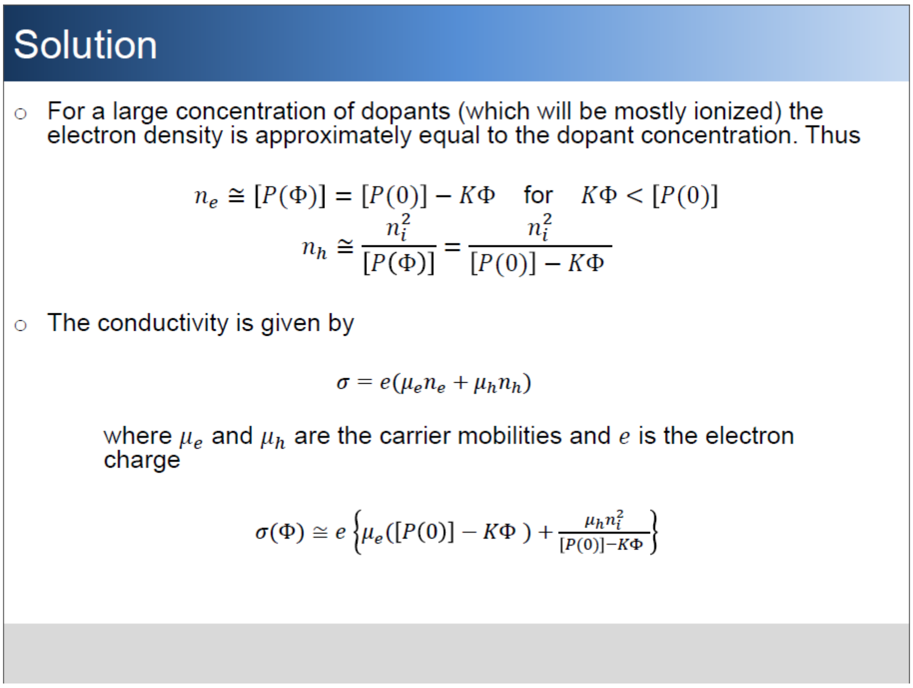
$$[P(\Phi)] = [P(0)] - K\Phi$$

$$[VP(\Phi)] = K\Phi$$

- From the mass action law the constraint relating the carrier densities n_e and n_h is given by

$$n_e n_h = n_i^2 = \text{constant}$$

Figure 3: Solution to example problem



Solution

- For a large concentration of dopants (which will be mostly ionized) the electron density is approximately equal to the dopant concentration. Thus

$$n_e \cong [P(\Phi)] = [P(0)] - K\Phi \quad \text{for} \quad K\Phi < [P(0)]$$

$$n_h \cong \frac{n_i^2}{[P(\Phi)]} = \frac{n_i^2}{[P(0)] - K\Phi}$$

- The conductivity is given by

$$\sigma = e(\mu_e n_e + \mu_h n_h)$$

where μ_e and μ_h are the carrier mobilities and e is the electron charge

$$\sigma(\Phi) \cong e\left\{\mu_e([P(0)] - K\Phi\ ) + \frac{\mu_h n_i^2}{[P(0)] - K\Phi}\right\}$$

Figure 4: Solution to example problem

3. Video Laboratories

Along with the lecture videos, there are four video laboratory demonstrations aimed at stimulating some of the hands on lab experience that the students in a conventional university setting might get. The labs are designed to demonstrate some of the concepts in a way that is simple, direct and also alludes to the radiation hardness testing of practical electronics. Although not a complete surrogate for the actual experience a student gets when performing a lab and doing the data analysis by herself or himself, the video lab does help make some of the lecture material more concrete.

Summaries of the four labs are as follows:

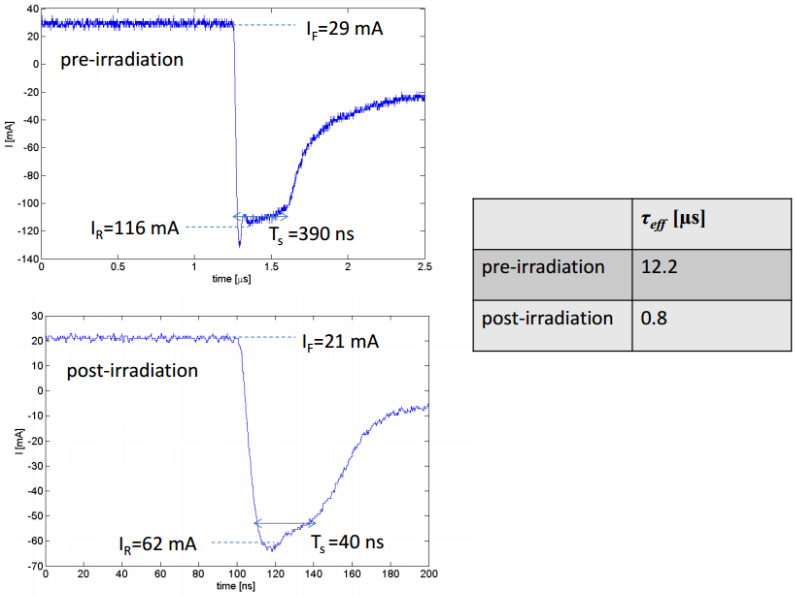
i) Sample irradiation – The instructor shows how an irradiation is conducted to accumulate neutron damage in an electronic component. A PN junction diode is placed in a vial and then shuttled into the core of a research nuclear reactor. The sample is left to decay until its activity has subsided.

ii) Minority carrier lifetime measurement – A measurement of the minority carrier lifetime of the diode irradiated in the first video lab is conducted using electronics testing equipment. The setup includes a function generator and a digital oscilloscope communicating to a computer through Labview software. Comparisons of the measurement of an unirradiated diode with the irradiated one are used to show the effects of neutron damage on carrier lifetime.

iii) Transistor gain degradation – Gain vs. base emitter voltage measurements are made for an irradiated and an unirradiated NPN transistor. The measurement setup involves three source measure units in a semiconductor parameter analyzer and a test fixture. Degradation of the gain in the irradiated transistor shows that recombination current in the base increases due to irradiation induced defects.

iv) Diode leakage current – An increase in diode leakage is demonstrated for the PN junction transistor. Current-voltage (IV) curves are measured before and after irradiation using a source measure unit. An increase in the reverse saturation current indicates an increase in the concentration of carrier generation sites (i.e. deep level traps) in the space charge region.

In each video lab there are cutaways to still frame diagrams of the experimental setups, graphed results of the processed data, and figures illustrating the physical explanation of the observed phenomena. One such cutaway used in the minority carrier lifetime lab is shown in figure 5.



	τ_{eff} [µs]
pre-irradiation	12.2
post-irradiation	0.8

Figure 5: Cutaway of plotted results from a video lab

4. Delivery

The first use of this course material is as part of the lecture material for a semester long course on radiation effects in electronic materials taught by the University of Kansas. It covers some of the topics contained within the full course. The material will also be hosted on a University of Texas at Austin password protected website where it can be accessed by students within the Nuclear and Radiation Engineering program or students from other academic disciplines.

5. Conclusions

A modular course of on-line short video lectures and video labs was made at the University of Texas at Austin to teach University students about the basics of radiation effects in electronic materials. The short on-line modular lecture is seen as an effective format for teaching subject matter which is outside the normal core course material in a typical nuclear engineering or science program. This is, in part, because such short courses provide the student with a moderate amount of information without demanding a large time commitment, and, in part, because they are non-traditional classroom based courses, they don't compete with the main course offerings or professor time. Furthermore the on-line format allows them to be distributed to other educational institutions or offered to the general public if desired.

6. Acknowledgements

We are grateful to the US Nuclear Regulatory Commission for funding this project entitled "*Characterizing Neutron Radiation Damage in Microelectronics Materials"* through a subcontract from University of Kansas. We are also indebted to Juan Diaz at the Faculty Innovative Center in the Cockrell School of Engineering in videotaping the lecture and laboratory portions.

DEVELOPMENT OF NUCLEAR POWER TECHNOLOGY PROGRAMMES IN SOUTHEAST TEXAS (USA) THROUGH USE OF A COMMUNITY-BASED EDUCATIONAL COALITION TO ACHIEVE COOPERATION BETWEEN STAKEHOLDERS

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ABSTRACT

Nuclear power technology programmes were developed at several community colleges in southeast Texas in 2007 to meet the manpower needs of the nuclear power industry in the area and elsewhere in the USA. The programmes now offer Associate and Baccalaureate of Applied Science degrees that are based on the *Uniform Curriculum Guide for Nuclear Power Plant Technician, Maintenance, and Nonlicensed Operations Personnel Associate Degree Programs* of the Institute of Nuclear Power Operations (USA). This report examines the process of establishing and expanding nuclear power technology programmes at community colleges through the development of an educational coalition to achieve community-wide consensus concerning the training programmes and to establish crucial linkages between educational, industry, civic, and economic development partners. It also examines the collaborative efforts of the coalition partners to secure financial support for the programmes, the strategies for recruitment of young men and women into the programmes, the achievement of racial and ethnic diversity in enrollments, and the use of state-of-the-art nuclear instructional equipment and computer-based simulators for 'hands-on' training of the students.

1. Introduction

In March 2007 the U.S. Department of Labour (DOL) published *Identifying and Addressing Workforce Challenges in America's Energy Industry* [1], which discussed the energy industry's needs for new workers, who would be recruited and trained with new skill sets in the coming 10 years. It also noted that the average energy industry worker in the USA was over 50 years of age and that approximately 50% of them were planning to retire within five to ten years. That meant that there would be a need to replace approximately 500,000 energy employees nationwide. In addition to the DOL assessment, two other workforce survey reports pointed out the same concerns. These survey reports included *Gaps in the Energy Workforce Pipeline* [2] by the Centre for Energy Workforce Development (CEWD) and *2007 Workforce Pipeline Survey* [3] by the Nuclear Energy Institute (NEI).

The NEI workforce report noted that Texas would need three new nuclear power plant maintenance training programmes and at least one new non-licensed operator training programme. At the time of the NEI study, Texas had only five generic nuclear training programmes and one radiation protection programme. Based solely on estimates of retirements and normal attrition, NEI recommended that two of the existing generic programmes be restructured to comply with the Institute of Nuclear Power Operations' *Uniform Curriculum Guide for Nuclear Power Plant Technician, Maintenance, and Nonlicensed Operations Personnel Associate Degree Programmes* (ACAD 08-006) [4] for maintenance staff and that another programme to be restructured for operators.

To meet current and scheduled employment needs of its nuclear plants (i.e., South Texas Project Nuclear Operating Company and Comanche Peak Nuclear Power Plant), the State of Texas faced the daunting task of educating new workers while upgrading incumbent worker skills to fill attrition and new vacancies. It was determined that workforce and education systems had to improve existing training programmes and develop new programmes, competency models, and career ladders.

In response to the specific needs of the nuclear power industry in southeast Texas, representatives of industry and economic development boards formed the Midcoast Industry and Education Alliance in 2006 to explore ways to promote nuclear technology programmes in southeast Texas. From this alliance evolved the Texas Nuclear Power Technician Programme Partnership that was formed in 2007-2008. This partnership was a coalition of stakeholders, including community colleges, industry partners, universities, professional organizations, community-based organisations and civic groups, school districts, chambers of commerce, and economic development agencies. The purpose of the coalition was to address two critical issues, namely: (1) the lack of adequate nuclear power technology training facilities, faculty, equipment, and curricula aligned with industry standards that were needed to educate and train workers to meet industry needs; and (2) the need for community colleges in southeast Texas to develop uniform accredited nuclear power technology curricula and to expand industry-specific certificate, associate, and baccalaureate degree programmes.

To fulfill industry needs, the partnering colleges required well-trained faculty to develop and teach curricula aligned with industry standards and in compliance with the *Uniform Curriculum Guide* (ACAD 08-006) of the Institute of Nuclear Power Operations (INPO). The community colleges realised that they would need to upgrade equipment to provide adequate classroom and laboratory training that would be compatible with industry standards and with the *Uniform Curriculum Guide*. The colleges also realised they would need to develop comprehensive recruitment and retention strategies to attract and retain students in the newly developed and expanded nuclear power technology programmes.

2. Literature Review

The theoretical basis for this report included organisational behavior studies of the institutionalisation of organisations [5,6,7,8], organisational change [9], organisational development [10,11], and organisational alignment with the environment [12]. It also included examination of the effort to establish nuclear training programmes at community colleges as an example of a community-based “coalition” in action. Community participation in health, safety, community development, and educational planning, especially through community-based coalitions, is noted in numerous theoretical perspectives found in the literature of organisational behavior.

Community participation in health, safety, and community development planning (including planning for education programmes) occurs through a variety of community-based advisory groups, but especially through community-based coalitions. These ‘coalitions’ can be loosely defined as a group of individuals representing diverse stakeholders (i.e., organisations, factions, or constituencies) within a community who agree to work together to achieve a common goal (adapted from Feighery and Rogers) [13].

Community participation in health, safety, social, and educational projects can take a variety of forms, and there can be variations in the extent of community participation. It has been found that community-based coalitions as organisations have many of the characteristics of ‘minimalist organisations’ as defined by Halliday, Powell, and Granfors [14,15] and can demonstrate progression through the stages of development noted by Aiken et al. [16]. Studies of community participation through the use of community-based coalitions have demonstrated repeatedly that these organisations have been successful in addressing a variety of health and social issues, including educational needs in communities. Coalitions as organisations are highly flexible and can engender strong support locally from the communities participating in this type of planning process.

Butterfoss [17] noted that the concepts and assumptions underlying community development, citizen participation, empowerment, community capacity, community competence, and social capital provided the groundwork for the coalition as a community-organising model and as a strategy for resolving community issues and achieving community goals [17: p.12]. It also noted that community coalitions have 'the potential to involve multiple sectors of the community and to conduct multiple interventions that focus on both individuals and their environments' [17: p.16] and that community coalitions are 'a promising strategy for building capacity and competence among member organisations and, ultimately, in the communities they serve' [17: p.17]. This is true of coalitions focusing on health issues as well as coalitions focusing on educational and job-skills training issues.

In an examination of the principles of collaborating and partnering in community health contexts, Butterfoss [17] developed definitions of collaboration, identified the intensity of collaboration, provided models of collaboration, and provided an explanation of the types of coalitions. The various types of coalitions [17: p.32-34] included the following:

- Grassroots coalitions: Organised by volunteers to pressure policy makers to act on an issue.
- Professional (agency-based) coalitions: Formed by professional organisations in times of crisis or as a long-term approach to increase their power and influence.
- Community-based coalitions of professional and grassroots members: Formed to influence more long-term health and welfare practices for their community. This type could also be used to exert long-term influence regarding a particular issue or issues of importance to a community or region.
- Organisation-set coalitions: Groups of cooperative organisations that provide resources or services under an umbrella organisation.
- Network coalitions: Subgroups of organisations loosely organised within an organisational system that provides services to a particular population or lobbies for a specific cause.
- Action-set coalitions: Issue-specific and can be more or less formal, depending on the purpose of the coalition.

The Texas nuclear power technology partnership has characteristics of several types of coalitions, including those pertaining to community-based coalitions of professional and grassroots members and action-set coalitions. The IAEA found that this type of integration and partnership is very conducive to the development of sustainable nuclear technology training programmes [18].

3. Methodology

This qualitative study of the establishment and development of the nuclear power technology programmes at community colleges in southeast Texas (namely, Wharton County Junior College and Brazosport College) utilised a variety of observational research methods, including attending and participating in planning meetings; attending and participating in specific subcommittee meetings; interviewing members of the coalition; interviewing key participants (including representatives of educational institutions, nuclear utilities, local economic development boards, civic organisations, and interested citizens); assisting with drafting applications for financial support from local, state, and federal sources; and examining documents related to the operation of the programmes since their inception in 2007-2008. It also included attendance at conferences sponsored by the Nuclear Energy Institute (NEI) and the Centre for Energy Workforce Development (CEWD).

4. Nuclear Power Technology Coalition Members

The following colleges, utilities, universities, economic development boards, state and federal agencies, school districts, and groups were important stakeholders in fostering and gaining community-wide consensus concerning establishment of nuclear power technology programmes at community colleges in southeast Texas. The Nuclear Energy Institute and the Nuclear Power Institute provided additional support for the effort to establish nuclear power technology programs and to align them with the Nuclear Uniform Curriculum (ACAD 08-006) of the Institute of Nuclear Power Operations.

Table 1. Stakeholders and Types of Organisation

Name of Organisation	Type of Organisation
Brazosport College, Lake Jackson, Texas	Community College Partner
Wharton County Junior College, Wharton, Texas	Community College Partner
Victoria College, Victoria, Texas	Community College Partner
Texas State Technical College, Waco, Texas	Community College Partner
Texas A & M University, College Station, Texas	University Partner
Nuclear Power Institute, Texas A&M University	University Partner
Health Physics Society	Professional Association Partner
South Texas Project Nuclear Operating Company	Nuclear Industry Partner
Excelon Corporation	Nuclear Industry Partner
Nuclear Energy Institute, Washington, DC	Industry Association Partner
Institute of Nuclear Power Operations	Industry Association Partner
Lyondell Basell	Petrochemical Partner
Celanese Chemicals	Petrochemical Partner
NRG Energy	Energy Industry Partner
Texas Governor's Office of Economic Development	State Partner
Texas Workforce Commission, Austin, Texas	State Partner
Bay City Community Development Corporation	Economic Development Partner
Economic Development Alliance of Brazoria County	Economic Development Partner
Victoria Economic Development Corporation	Economic Development Partner
Wharton Economic Development Corporation	Economic Development Partner
Bay City Chamber of Commerce & Agriculture	Business Association Partner
Wharton Chamber of Commerce & Agriculture	Business Association Partner
Brazosport Area Chamber of Commerce	Business Association Partner
Victoria Chamber of Commerce & Agriculture	Business Association Partner
Greater Waco Chamber of Commerce	Business Association Partner
Bay City Independent School District	School District Partner
Brazosport Independent School District	School District Partner
El Campo Independent School District	School District Partner
Victoria Independent School District	School District Partner
Wharton Independent School District	School District Partner
Calhoun Independent School District	School District Partner
Waco Independent School District	School District Partner
Christian Women's Job Corps	Community Partner
Boys and Girls Club of Brazoria County	Community Partner
Victoria Business and Education Coalition	Community Partner
Golden Crescent Workforce Development Board	Community Partner

5. Implementation of the Nuclear Power Technology Plan for Southeast Texas

The four colleges in the Texas nuclear technology training partnership included Wharton County Junior College, Brazosport College, Victoria College, and Texas State Technical College. These colleges jointly explored ways to obtain funding to develop and operate new or expanded nuclear power technology programmes. They sought funding to hire faculty, purchase state-of-the-art nuclear technology instructional equipment and simulation software programmes, and develop curricula that would comply with the *Uniform Curriculum Guide* (ACAD 08-006). Approvals for the colleges to develop new training programmes and expand current ones were quickly obtained from the Texas Higher Education Coordinating Board, which oversees academic and vocational training programmes in Texas.

Texas Agricultural and Mechanical University (i.e., Texas A&M University) provided significant assistance and guidance to the colleges as did the South Texas Project Nuclear Operating Company (an industry partner). Initially, the Texas Engineering Experiment Station at Texas A&M University provided 'start-up funding' as well as guidance in obtaining federal funding. The Nuclear Power Institute (NPI) at Texas A&M played a major role in providing guidance to the Wharton programme and in advocating for it at national and international meetings. The NPI made extraordinary efforts to highlight the achievements and quality of the nuclear power programme at Wharton County Junior College (WCJC) and arranged for Mr.Rudolph Henry, Director of Nuclear Power Technology Programme at WCJC, to participate in the September 2012 General Conference of the International Atomic Energy Agency. While at the conference, Mr.Henry met the leadership of IAEA and representatives of several national delegations, many of whom wanted to know more about the Wharton programme. The NPI also arranged for Mr.Henry to present a report in December 2012 concerning nuclear power technology programmes to members of the U.S. Congress, congressional staff members, the Deputy Secretary of Energy, and the Assistant Secretary for Nuclear Energy in Washington, DC. Discussions were also initiated in 2012 concerning admission of students from overseas into the Wharton programme and development of internships at the South Texas Project Nuclear Operating Company for these students. [Personal communication with Dr.Kenneth Peddicord, Fall 2012.]

6. Support from Industry Partners

The South Texas Project Nuclear Operating Company (STPNOC), as the industry partner, played a major role in the effort to establish nuclear power technology programmes at community colleges in southeast Texas. It facilitated meetings of the Midcoast Industry and Education Alliance, which led to the formation of the educational coalition in support of nuclear training programmes. To assist the college programmes, STPNOC provided timely letters of support, in-kind support, and an educational incentive programme for entry-level employment at STPNOC. The incentive programme is an effort to award grants, through a competitive process, to students enrolled in the nuclear technology programmes. Students selected for the award receive additional trainings at the STP facility during internships.

A second important industry partner in promoting and facilitating the establishment of nuclear power technology programmes at community colleges in southeast Texas was the Nuclear Energy Institute (an industry association), headquartered in Washington, DC. Both the Wharton and the Brazosport programmes were developed in strict compliance with the *Uniform Curriculum Guide* (ACAD 08-006), which requires adherence to a standardised curriculum for training nuclear technicians.

7. Funding for Nuclear Power Technology Programmes in Southeast Texas

Since 2008, the Wharton and Brazosport nuclear power technology programmes have been the recipients of grants from federal, state, university, and economic development agencies. These grants focused on upgrades to laboratory equipment and development of curricula and included major grants from the Bay City Community Development Corporation, Texas A&M University, Nuclear Power Institute, Texas Workforce Commission, American Recovery and Reinvestment Act (ARRA) Programme, U.S. Nuclear Regulatory Commission, and U.S. Department of Education.

Additionally, since 2009, the U.S. Nuclear Regulatory Commission has provided more than $1,000,000 in scholarship funds for students specialising in nuclear power studies at the Wharton and Brazosport programmes.

The award from the U.S. Department of Labour (2009-2012) was shared by the four colleges that originally participated in the Texas nuclear power training coalition. However, Victoria College withdrew from the partnership in 2011 after plans for constructing a nuclear power generating facility in its service area were cancelled. The training programme at Texas State Technical College has remained small and focused primarily on radiation protection. It has not participated in the ongoing expansion of the region's nuclear power technology programmes during the last five years.

The following table provides information on the funding that was obtained by the two leading colleges in the Texas partnership that have the largest number of trainees. These funds were used for facilities, operations, curriculum development, instructional equipment, and scholarships for students.

Table 2. Funding for Nuclear Power Technology Programmes

Period	Funding Source	Amount	Purpose
2007-08	Bay City Community Development Corporation	$4,500,000	Purchase & renovation of a large facility to house the nuclear & other programmes
2007-08	Residents of Bay City, Texas	$1,500,000	Instructional equipment for nuclear & process technology programmes
2008-10	Texas A&M University, Texas Engineering Experiment Station, Texas Workforce Commission	$105,000 (WC)	Implementation & operations of the nuclear power technology programme
2009-12	U.S.Department of Labour	$1,888,487 (for 4 colleges)	Nuclear instructional equipment & operations
2009-11	Texas A&M University, Nuclear Power Institute, & Texas Engineering Experiment Station	$175,000 (WC)	Operations & expansion of the WCJC nuclear power technology programme
2009-10	U.S.Nuclear Regulatory Commission	$150,000 (WC) $120,000 (BC)	Scholarships for nuclear technology students
2009-10	Jobs & Education for Texans (JET) Office of the State of Texas	$350,000 (WC)	Instructional equipment for nuclear & process technology programmes
2009-10	Bay City Community Development Corporation	$193,500 (WC)	Instructional equipment for nuclear & process technology programmes
2010-11	U.S.Nuclear Regulatory Commission	$120,000 (WC) $120,000 (BC)	Scholarships for nuclear technology students
2010-11	U.S.Dept. of Education	$220,000 (WC)	Instructional equipment
2012-13	U.S.Nuclear Regulatory Commission	$120,000 (WC) $120,000 (BC)	Scholarships for nuclear technology students
2012-13	U.S.Nuclear Regulatory Commission	$199,280 (WC)	Nuclear technology curriculum development
2013-15	U.S.Nuclear Regulatory Commission	$150,000 (WC) $120,000 (BC)	Scholarships for nuclear technology students
2013-15	U.S.Nuclear Regulatory Commission	$156,500 (WC)	Nuclear technology curriculum development

Abbreviations: WC = Wharton County Junior College; BC = Brazosport College.

The benefits of the original U.S. Department of Labour (DOL) grant to the Texas nuclear power technology educational partnership were significant, including:

- **Instructor Training:** The DOL grant provided funding for faculty members to receive an average of 120 hours of training at the South Texas Project Nuclear Operating Company (the industry partner), under the supervision of subject matter experts.
- **Curriculum Development:** The DOL grant provided for the faculty of the participating colleges to work with South Texas Project administrators to develop and modify curricula to conform to the *Uniform Curriculum Guide* (ACAD 08-006) of the Institute of Nuclear Power Operations. Additional funding for curriculum development was provided by the Nuclear Power Institute, the U.S. Nuclear Regulatory Commission, and the U.S. Department of Education.
- **Laboratory Development:** The DOL grant provided support for significant upgrades of laboratory facilities used in conjunction with the curricula for the nuclear power technology programmes. These included funding for nuclear instructional equipment, workstations, computer-based simulators, and 'hands-on' training skids (i.e., 'HOT

skids'), which ensure that students are being trained to use and operate the same state-of-the-art technology as currently found in the power generation industry.

8. Wharton and Brazosport Nuclear Power Technology Programmes

At the conclusion of the Department of Labour project, the Wharton and Brazosport programmes continued their partnership. Both colleges are public, two-year community colleges that are fully accredited by the Commission on Colleges of the Southern Association of Colleges and Schools. The colleges are authorised by the Texas Higher Education Coordinating Board to offer Associate of Arts and Associate of Applied Science degrees and curricula in preparation for baccalaureate programmes. Brazosport is authorised to award a baccalaureate degree. The Wharton and Brazosport service areas extend across eight counties in southeast Texas. The South Texas Project Nuclear Operating Company is located within the region served by the two colleges.

Wharton Nuclear Power Technology Programme. The training programme at Wharton County Junior College gained international recognition in 2011, when the International Atomic Energy Agency (IAEA) noted in its *Status and Trends in Nuclear Education* [18] that the Wharton programme was a 'best practice' programme among two-year nuclear power technology training programmes. The Wharton programme offers an Associate of Applied Science degree in Nuclear Power Technology. Upon completion of the two-year AAS degree, students have the prerequisite skills and training to work in the nuclear power generation industry in southeast Texas and elsewhere in the USA.

The Wharton programme offers three degree specialisation options, namely, (1) Non-Licensed Operator, (2) Electrical Technician, and (3) Instrumentation and Controls Technician. It also offers an Enhanced Skills Certificate in Nuclear Power Technology upon completion of the Associate of Applied Science degree in Process Technology and completion of required nuclear technology courses.

Table 3. Course Requirements for All Specialisations (during 1st Year)

Fall Semester (all students)		**Spring Semester** (all students)	
Course	**Course Title**	**Course**	**Course Title**
NUCP 1371	Math & Chemistry Fundamentals for Nuclear Power	NUCP 1370	Nuclear Fundamentals I
ELPT 1370 or PTAC 1302	Power Technology Or Process Technology	NUCP 1471	Nuclear Fundamentals II
BCIS 1305	Business Computer Applications	PTAC 1432	Instrumentation I
MATH 1314 or MATH 2312	College Algebra or Pre-Calculus	CHEM 1405 or CHEM 1411	Introductory Chemistry or Chemistry I
ENGL 1301	Composition & Rhetoric I	NUCP 1472	Nuclear Power Plant Organisation & Processes

- **Nuclear Option 1. Non-Licensed Operator (during 2nd Year):** DC-AC Circuits with Lab; Nuclear Power Plant Systems I and II; Principles of Quality; Digital Measurements & Controls; Social Science Elective; Humanities Elective; Critical Thinking & Problem Solving; Discipline-related Elective; Public Speaking; and Cooperative Education (Internships in Nuclear Power).

- **Nuclear Option 2. Electrical Technician (during 2nd Year):** AC/DC Circuits; AC/DC Motor Controls; Digital Measurements and Controls; Electromechanical Systems; Principles of Quality; Electronic Troubleshooting, Service, & Repair; Social Science Elective; Humanities Elective; Public Speaking; Critical Thinking & Problem Solving; and Cooperative Education.

- **Nuclear Option 3. Instrumentation and Control Technician (during 2nd Year):** AC/DC Circuits; AC/DC Motor Controls; Digital Measurements and Controls; Principles of Quality; Power Generation Instrumentation; Instrumentation II; Social Science Elective; Humanities Elective; Public Speaking; Critical Thinking & Problem Solving; and Cooperative Education.

Brazosport Nuclear Power Technology Programme. The training programme at Brazosport College offers an Associate of Applied Science degree in Chemical Technology (Process Operations Option) that includes a Nuclear Power Specialty with Enhanced Skills Certification. The programme is designed to train students in the essential skills that are needed to work in the nuclear power generation industry. Courses include mathematics, chemistry, process technology, as well as nuclear fundamentals and nuclear power generation technology, including the following:

Table 4. Nuclear Power Specialty with Enhanced Skills Certification

Course	Course Title
ELPT 1370	Introduction to Power Generation Technology
NUCP 1370	Nuclear Fundamentals I
NUCP 1371	Mathematics & Chemistry Fundamentals for Nuclear Power
NUCP 1471	Nuclear Fundamentals II
NUCP 1472	Nuclear Power Plant Organisation and Processes
NUCP 2470	Nuclear Power Plant Systems I
NUCP 2471	Nuclear Power Plant Systems II

Brazosport College also offers a Bachelor of Applied Technology degree that is designed to broaden career opportunities and better prepare nuclear power trainees for promotion to supervisory positions. The upper division classes expand students' understanding of business operations (including management, human resources, accounting, legal issues, and technology). Coursework incorporates internships and other practical real-world learning activities to ensure that students acquire technical competencies and managerial skills in order to be effective supervisors.

Additional Information about the Programmes. The Cooperative Education courses (i.e., NUCP 1380 and NUCP 1680) provide options for internships at nuclear power facilities. A student can select NUCP 1380 for a 16-week internship at a nuclear power facility during a regular semester. After the AAS degree requirements have been completed, a student can select NUCP 1680 for a 7-month internship at a nuclear facility.

Students participating in the Wharton and Brazosport training programmes may be eligible to receive a National Academy for Nuclear Training Certificate (NANT Certificate) upon graduation. This certificate is administered jointly by the Institute of Nuclear Power Operations (INPO) and the National Academy of Nuclear Training (NANT) in collaboration with each college and its nuclear industry partner. To be eligible for this certificate, students must obtain a minimum passing grade of 80% in all required courses.

9. State-of-the-Art Instructional Equipment

The courses offered at the Wharton and Brazosport programmes are aligned with the *Uniform Curriculum Guide* (ACAD 08-006) for training nuclear technicians, including operations, electrical, and instrumentation/control technicians. Experiential learning exercises are designed to be almost identical to actual on-the-job industry training, job shadowing, and industry discipline. In addition to course work in nuclear power technology fundamentals, the programmes include 'hands-on' laboratory exercises as reinforcement for classroom lectures. This experiential learning component includes training on state-of-the-art instructional equipment such as the following:

- ABB Digital Fieldbus Technology Demo Box
- Hampden Boiler/Turbine Generator Power Distribution Skid

- Intellitek Electrical Training Modules
- Computer-based simulators for operating Pressurised Water Reactors (PWRs) and Advanced Boiling Water Reactors (ABWRs)

The computer-based simulation exercises reinforce lecture material and facilitate experiential learning for the students by providing opportunities for ‘hands-on’ use of actual state-of-the-art nuclear power generation equipment. Training modules have been developed that integrate computer-based nuclear power plant simulation applications into the training programmes. The computer-based nuclear power plant simulations provide an opportunity for faculty to train students to become familiar with plant startup and shutdown, plant operations, and analysis of common problems at nuclear power plants. The curriculum developed for operating PWRs and ABWRs at nuclear power plants has been made available through the Nuclear Energy Institute for distribution to other educational institutions offering training programmes in nuclear power technology.

10. Programme Results

The Wharton and Brazosport training programmes have been successful in recruiting and training students, who will become the next generation of highly skilled workers in the nuclear power generation industry in southeast Texas and elsewhere in the USA. The following table shows the accomplishments of these training programmes.

Table 5. Wharton and Brazosport Nuclear Programmes – Combined Results

	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13
Enrollments						
Total Students	13	72	140	116	109	87
Gender						
Male	11	58	117	93	90	70
Female	2	14	23	23	19	17
Race/Ethnicity						
White non-Hispanic	10	46	92	75	68	57
Hispanic or Latino	3	19	29	32	31	22
Black non-Hispanic	--	1	5	8	8	8
Other/No Response	--	6	14	1	2	0
Graduates of the Nuclear Technology Programmes						
Associate Degree	--	5	43	22	33	33
Certificate	--	4	12	6	6	1
Status Post-graduation						
In Nuclear	--	5	32	10	9	4
In Non-Nuclear	--	--	2	13	30	24
In Other Studies	--	--	7	2	3	3
Unknown	--	4	14	3	3	3

Diversity in enrollments and graduations is an important goal for the Wharton and Brazosport programmes and both colleges have made efforts to foster gender, racial, and ethnic diversity in their programmes. Beginning in 2009-10, diversity in enrollments was achieved, with approximately 35% of enrollments being students from the racial and ethnic minority communities in the region.

For the 2013 Fall semester a total of 64 students enrolled in the Wharton and Brazosport programmes. This drop in enrollments can possibly be linked to a significant decline in actual job openings at nuclear power facilities in the USA. The nuclear power industry in the USA has an aging workforce and the original industry projections in 2007-08 showed there would be hundreds of retirements of senior technicians. However, the industry’s original projected retirements have not yet started to occur. During the past three years, students began to realise there might not be jobs for them when they completed a nuclear power technology training programme. They became hesitant to enroll and opted, instead, to enroll in other training programmes. As the projected retirements begin to occur at some point in the future, enrollments in the Wharton and Brazosport nuclear power technology programmes are expected to increase.

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THE UTILIZATION OF REACTOR LR-0 FOR TRAINING PURPOSES

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ABSTRACT

The LR-0 research reactor is a light-water, zero-power, pool-type reactor. It serves as an experimental reactor for measuring neutron-physical characteristics of VVER (Water-Water Energetic Reactor) type reactors. As a research reactor it has unique characteristics that can be used for education and training and offers excellent opportunity to teach practical lessons. Based on this fact the Research Centre Rez (CVR) began with enhancement of the training activities. The LR-0 reactor has a large experience with training of the nuclear experts, has a regulator-approved program for training the reactor operators, and now provides opportunity for universities to teach their students via trainings, customized and delivered by their teachers together with the research institute experienced staff. The courses are typically built on the framework of existing curricula covering basics of reactor physics. All courses consist of theoretical and practical part, complementing each other during the whole course. A typical general course is one week long. The courses are divided to three categories. It is served basic, special and on-demand courses. The all training programs are led according to the approved methodology. Also courses for nuclear and non-nuclear professional are being prepared.

1. Introduction

Owners and operators of many research reactors are finding that their facilities are not being utilized as fully as they might wish. Every research reactor facility is capable of being used for education and training purposes. When reviewing the potential uses of existing reactors, then this application should not be dismissed lightly as being a trivial or unworthy mission. Conversely, it should be thoroughly explored and utilized to the benefit of the facility [1].

2. History of training activities

Research Centre Rez has a regulatory-approved program for training of the reactor operators and other reactor staff. All the training is according to the quality assurance conducted by schemes and syllabus with defined records [2]. To secure high standard during the training the most skilled and experienced persons are involved.

As a nuclear facility the reactor is often visited by students from technical universities and other type of schools for technical visits and short term lectures and demonstrations. This collaboration is not treated as commercial activity but as a part of open access to research infrastructure. Part of the open access is also to provide open days and excursions for general public.

Certainly CVR provided several courses for external participants in the past as well, however these were not done regularly and had no central coordination. The management brought a idea to build a training centre as one department of the research institute to assure high quality training and education. At first the focus was aimed at LR-0 reactor for better utilization of this facility.

3. Foundation of the training centre

At begging of 2013 CVR started to build the training centre with own staff responsible only for training and education. The staff is mainly responsible for a new courses development, courses coordination, communication with customers and business strategy preparation. The members of the training centre cooperate with experts across the research institute and external experts regarding to develop the courses content. Due to the previous experience with the staff education, the technical qualification of the lectors has high level. To assure not only quality of the courses content but also a pedagogical high level of teaching and presentations CVR started to cooperate with Czech universities and training centres to provide regular educational soft skills seminars for our internal lecturers.

Strategy and plans of the activities, which are necessary to be done, have been prepared at the begging of the establishment of the training centre. Other steps went to the concept of providing courses. Three kinds of courses as basic, advanced and tailor-made have been defined to cover whole spectra of potential topics and training methods for candidates.

As it was mention above training centre was established mainly to support LR-0 nuclear reactor and to secure better occupancy. However there are plans to enhance it beyond reactor courses to offer other trainings coming from various fields which are supported by CVR.

Main milestone during the centre preparations was the creation of a main text book which will provide the basic coverage of topics and experiments [3] and web site for better provision of information [4]. The textbook has been prepared in the form for self study of reactor physics mainly focusing on LR-0 experiments and as a study material for theoretical teaching containing also the experiment descriptions and methodology.

The first course which was carried out was „Basic Reactor Physics“ course. This course consists of theoretical and practical parts. The trainees repeated the necessary theoretical background, but the program is mainly focus on reactor physics experiments. Farther CVR started to define topics of advanced courses and explore environment to find topics of tailor-made courses.

4. Current status of the training centre

Currently CVR provides three different kinds of courses. The first one contains basic summary of the nuclear reactor physics and experiments. The trainees are acquainted with topics like nuclear reactions, principals of fission reactions, characteristic of the ionizing radiation, construction of nuclear reactors or introduction to nuclear safety and basic demonstrations and experiments are demonstrated to them.

Typical time and topic schedule of the basic course is listed in the next table:

Monday	
▪ Radioactivity, ionizing radiation (IR), IR types and characteristics, shielding ▪ Detector properties, dead time, gamma and neutron detection	▪ Neutron instrumentation modules and detectors, counting and current mode, measurement with a neutron source:
Tuesday	
▪ Nuclear reactions, fission, fission generation cycle, multiplication coefficient, critical state ▪ Reactivity control, absorber worth and characteristics, delayed neutrons and kinetics basics	▪ Detailed visit to the LR-0 reactor: design and operation, reactor start-up, operation on power, delayed neutrons demonstration
Wednesday	
▪ Nuclear safety: basic principles and standards, operational reactor safety, instrumentation and control system ▪ Safe achieving of initial critical state, basic critical experiment	▪ Performing basic critical experiment ▪ Measurement of basic core characteristics: control rod differential characteristics, moderator reactivity coefficient
Thursday	
▪ Overview of experimental program on LR-0 reactor: measurement of criticality dimensions, power distribution, absolute power ▪ Gamma and neutron spectrometry	▪ HPGe, gamma spectroscopy measurement: handling, calibration, spectrum analysis ▪ Activation detector measurement

Friday	
▪ Measurement assessment, discussion, summary, conclusion	▪ Visit of other experimental facilities in the area: LVR-15 reactor, hot cells, experimental loops, accelerator

Tab 1: Basic course time schedule

Advanced courses are treated as second group. These courses go to the more details and prepared for more experienced user with higher level of education and knowledge. There are running various courses in this group. Here are topics with short description:

- **The Pin Power Distribution Measurement on the LR-0 Research Reactor**

Trainees will get acquainted with various aspects of the determination of neutron fluence and power distribution in the LR-0 reactor core by means of the fission products activity measurement in irradiated fuel pins. They will master the theoretical and practical principles of semiconductor gamma-ray spectrometry and its application for fuel pins measurement on a prototypic gamma-scanning device. They will participate in relevant parts of reactor experiment and they will analyze the measured results.

- **The Neutron Fluence Determination in LR-0 Reactor by Activation Detectors**

Trainees will get acquainted with various aspects of the determination of neutron fluence distribution in the LR-0 reactor core by means of the activity measurement of radionuclides induced by neutrons in activation detectors. They will master the theoretical and practical principles of semiconductor gamma-ray spectrometry and its use for the activation foils measurement. They will participate in relevant parts of reactor experiment and they will analyze the measured results.

- **Semiconductor Gamma-Ray Spectrometry and Its Experimental Reactor Physics Application**

Trainees will get acquainted with principles of semiconductor gamma-ray spectrometry with a view to HPGe detectors. They will learn about detectors fabrication and their qualities, about interaction of gamma-ray with the semiconductor, about electronics for processing the signal from detector and about programs for gamma spectra analysis. They will apply the acquired knowledge on the gamma-spectrometric device at the LR-0 in practical problems of reactor physics.

- **Environmental Radioactivity**

Participants learn how different radioactive substances in the environment behave and how to measure their radioactivity. They will get the answers to these questions in our course of radioactivity in the environment. The participants also learn what is the impact of the nuclear industry on the environment, what are the biological effects of ionizing radiation and radiation protection principles. In practical exercises you can try measuring the selected environmental samples at a gamma-spectrometric apparatus with semiconductor detector.

- **Experimental Verification of Nuclear Safety During NPP Temelín Commissioning**

The participants learn basic experiments implemented during the physical start-up of the Temelín NPP (first criticality, efficiency of clusters, temperature coefficient of reactivity, effect of boron, core symmetry verification, and measurement of boron injection system lag.). Experiments of ascension power start-up, focusing on nuclear safety – physical characteristics such as temperature and power coefficient of reactivity, effects of xenon and xenon oscillation, calibration of neutron instrumentation and thermal power distribution, neutron characteristics of the core, test the core cooling system base function, the residual heat removal by natural circulation.

- **Heavy Liquid Metals Technology**

The course aims to get the trainee familiar with issues related to materials for Gen IV reactors, in particular HLM cooled reactors. All the issues related to the basic interaction of construction materials with liquid PbBi and Pb will be considered in terms of corrosion and mechanical properties. Moreover, as a way to better understand these phenomena, focus will be placed on the chemistry of the liquid metals, in terms of impurities control and oxygen dosing and measurement. The attendants will have the opportunity to follow the experimental procedures for testing of materials in the CVR facilities and will work on data recording and interpretation.

Tailor made courses belong to the third group. This kind of courses is made to exactly satisfy customer needs. For example it offers the courses for nuclear reactor operators, the course of nuclear power plant start-up and operation, behaviour of the nuclear fuel in the reactors, reactor dosimeter, decommissioning etc. CVR had a special requirement for a one month intensive training from French IRUP institution with request to cover concrete topics in the program. After the collaboration a very unique offer was prepared.

Trainings focus is mainly on the following target groups:

- Student of nuclear physics
- Student of non nuclear physics using results of reactor physics
- Researches of nuclear fields
- Researches of non nuclear fields
- Other employees of nuclear organizations
- The general public and enthusiasts

5. The infrastructure

The reactor LR-0 is one of the experimental nuclear reactors which are operated in CVR. It is a very unique facility for reactor physic research but also suitable for special training and education. The basic scheme is shown in Fig 1.

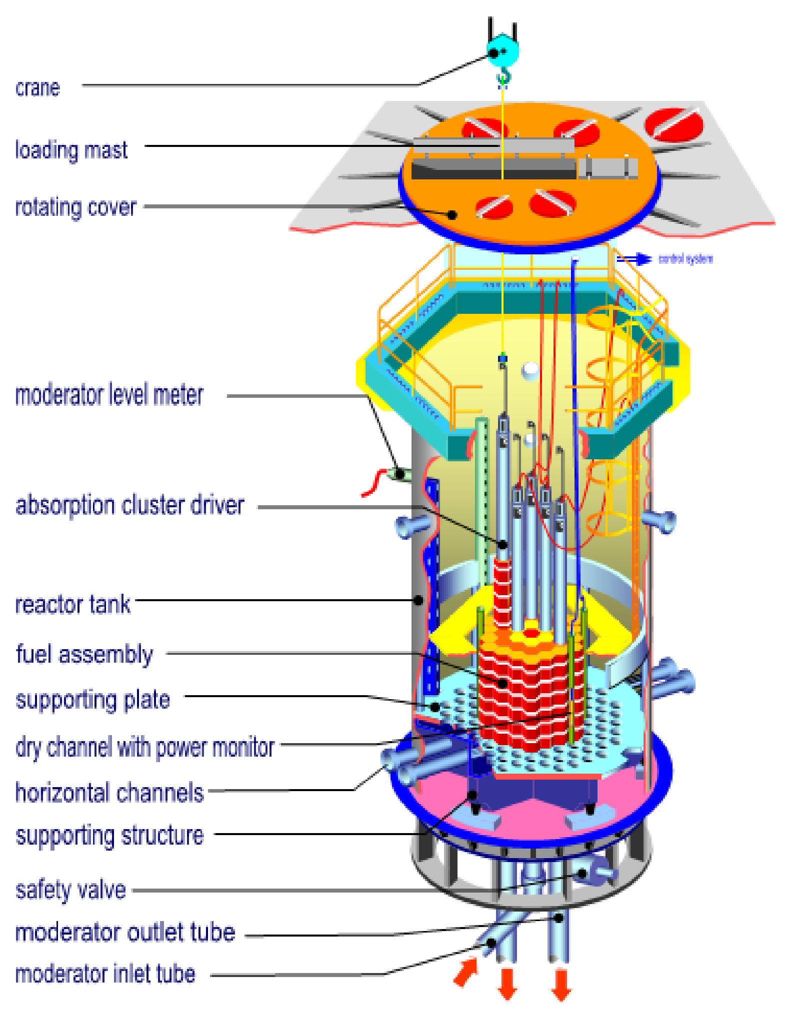

Fig 1: Reactor layout

The reactor LR-0 is the experimental light water reactor of zero power. It is dedicated mainly for training and research of active zones, reactor lattices and typical experiments for VVER-1000 and VVER-440 type reactor. Reactor LR-0 is constructed as widely configurable and flexible. There is removable fuel assemblies type VVER-1000/440 with optional enrichment from 1.6 to 4.4% 235U. The reactivity changes are provided by the change of the level of the moderator or by cluster movement.

There are available neutron spectrometry detectors and a gamma scan apparatus with possible axial movement to measure gamma activities of the fission which is used for the study of power distribution in fuel pins. The neutron and gamma radiation is also studied as a part mock-up and benchmark experiments connected with radiation transport and core behaviour.

The training staff consists of both young scientists and professionals with over forty years of experience in the field of reactor physics. Experts like Mr. Čeněk Svoboda, who was head of the expert team during start-up of Temelin NPP, or Mr. Vojtěch Rypar, who worked as a chief of experimental reactor physics department, are the main lecturers in the training centre. Both of them have practice in the nuclear field for nearly fifty years.

During this year CVR provided many courses. Among them CVR organized two summer schools. The first one was addressed mainly for Czech students. The second one was prepared for foreigners. The research institute was visited by researches and students from around the world - participants from South Korea, Saudi Arabia, Italy and Poland participated on this event.

During the course full services like the accommodation and full board can be provided by local hotel. On every educational and training course a special social events is organized because, according to last research of psychology, education supported by emotional experience brings better memorizing of the lectures. Furthermore education is interactive as much as possible.

To increase the possible connections and expansion of the training centre, CVR has become member of two international educational programs and projects like CORONA [5]. This project is oriented to provide educational and training program for VVER type reactor specialists, operators and other personnel. The main partners are FOTUM from Finland, Tecnatom from Spain and Bulgarian power plant in Kozloduy. As a part of collaboration CVR has prepared educational materials within this project and organized a one week training course this years for the partners. The second project was started in the middle of 2013. The project groups together four universities from Czech Republic and CVR and is focused onto educational balance between the partners. The main goal is to build a multimedia lab for the distance collaborative learning within this project.

6. Future development

CVR wants to use several channels for the educational program. It means that the new courses for local training, e-learning and distance training will be developed.

In the near future the main effort is to enhance the number of the advance courses. New experiments, where students and researches can perform calculations in local PC lab and directly verify their results by experimental measurements on LR-0 reactor are going to be prepared.

To enable spreading the education simply beyond the boundary of institute, CVR begins to participate in e-learning courses on the platform Moodle to be compatible with platform which is utilized by IAEA.

To enlarge the possible way of education a new multimedia technologies will be applied. The multimedia and PC lab will consist of a interactive whiteboard and a special video conference system for the distance collaborative education which enables to train participants not only by CVR experts but also by teachers from partner’s universities or even from abroad. Furthermore 3D stereoscopic visualization for the core design during the training will be prepared. A teaching tool like a simulator of the reactor will be implemented and which will enables trainees to carry out operation which are not allowed for them directly on the reactor.

7. References

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A Significant Breakthrough in EDF Licensed Operator Training: ANS3.5 compliant FSS using control room software replica

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ABSTRACT

The real-time, high-fidelity simulation industry, servicing nuclear training organizations throughout the world, is facing a number of challenges due to rapid technological changes. In response CORYS, the unrivalled market leader, has innovated a number of industry firsts to help utilities achieve excellence in training and plant operations.

The paper will present the challenges and solutions posed by the EDF's project for an ANSI ANS3.5 compliant soft-replica control room interfaced with a Full-Scope Simulator for Licensed Operator Training. These innovative solutions were developed following an EDF Nuclear Energy Production division working group deliberation held in 2010, which focused on the adaptation of high-fidelity simulators to future decennial unit overhauls, the changes in the related Man-Machine Interfaces, and the avoidance of training operators on a simulator which does not fully represent their reference plant.

These simulator requirements, combined with the necessity to provide early training for operators within the framework of the 1300MW series third- decennial overhaul, created the concept of a tactile Digital Control Room (SDCN), a full-scope, faithful to operator movement, customizable and reconfigurable for an easy adaptation of trainees to the reference plant and based on touch screens, faithful to control room operation.

Different objectives are associated with this project, in particular the use of standard, easily obtainable materials in order to keep cost below that of current simulators replica control rooms, thus shortening production times and allowing easy replication. This would also minimize associated complications with the removal of obsolescence issues as well as adapted maintenance and shorter adaptation time. Its ability to be used for operator licensing will be evaluated in Spring 2014.

The paper will explore different project challenges. First, we will describe the critical technology choices required to realistically replicate the number and complexity of control room instruments and their implementation on high-resolution touch-screens with haptic feedback.

Next, we will focus on the human factor engineering approach taken by senior EDF operators, instructors and maintenance engineers in association with AREVA human factor experts and CORYS project team.

This outlook will conclude with an overview of the design choices made to ensure long-term maintenance capabilities and seamless design changes using nonproprietary software solutions, industry recognized standards, and COTS hardware, implemented on modular, open and evolutive architecture.

1. Introduction

Over the past year, the EDF, the world's largest nuclear power utility (58 reactors in operation), together with CORYS and its partner, Euriware, has been designing a 100% replica digital control room, interfaced with a full scope training simulator load, to be used for initial and refreshing operators training. This digital control room, or SDCN (Salle De Commande Numérique) meets the requirements of the ANSI ANS 3.5 standard. It could become the standard for future nuclear training simulators if it meets the objectives of EDF: high-fidelity replica of the control room panels, easy customization and flexibility, lower upfront investment, and maintenance costs.

This technical innovation is a world first and has already been well received, with the EDF planning to install these SDCN in 2014 in five of its 900 and 1300 MW nuclear stations for operator training.

This paper will successively address the six major themes that characterize this project:

- Reasons that led EDF to develop SDCN
- Guiding principles of the project
- Challenges associated with meeting the requirement for an actual fidelity control room will then be detailed as they relate to EDF user-centered design.
- Technical choices made for SDCN maintenance
- Operator assessments for licensing purposes
- Objectives of simulator cost reduction.

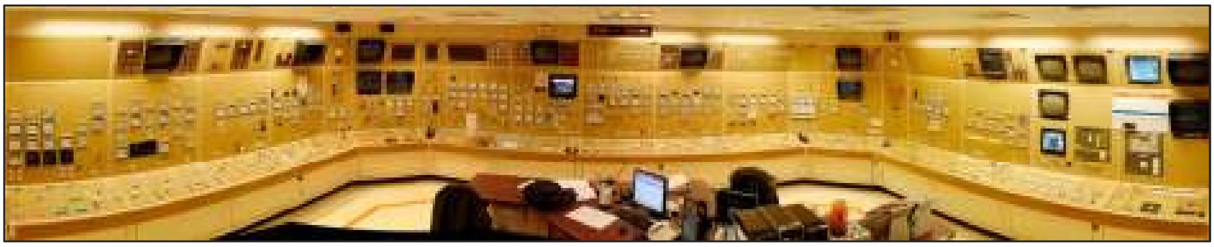

Fig 1: 1300 MW nuclear station control room

2. Development of SDCN

Two reasons, based both on experience as well as the future investment needs for the operating nuclear fleet, explain the EDF choice to move towards control room software replica (SDCN) for its fleet of full-scope training simulators.

The large number of personnel retirements and development projects require the continued renewal of highly qualified staff in several EDF core businesses—particularly for operator teams. In fact, due to an unbalanced age pyramid, teams will soon face a significant number of retirements. This impending shift presents a potential safety issue for the EDF and underscores the need for strengthened skills management to ensure the integration of newcomers as well as normal services. This context will lead to significant increases in the number of operators enrolled in initial training course and will likely result in a training simulator deficit at some training centres.

On the other hand, the EDF's nuclear fleet is regularly subject to change due to continuous improvement in safety, evolving regulatory requirements, and new plant performance improvement objectives. For example, the implementation of the third decennial works at the 900 MW Tricastin nuclear station led to the incorporation of many improvements. It is assumed that the upcoming third decennial works on the 1300 MW units will result in as many enhancements.

The design standardization on the same site enables multiple training operator teams (six at some sites) on a single full-scope simulator. However, the magnitude and duration of the modification on the same site forced its implementation to last several years. The full scope simulator is interfaced with a hardware replica of the control room and is therefore not easily adaptable. It is updated when half of the units on the site have been upgraded, which means that training is being conducted on an only semi-representative tool. Under these conditions, it becomes increasingly difficult to have a true to life simulator that is timeline compliant to EDF requirements.

Because of this, it became necessary to find a new solution in anticipation of the arrival of large-scale third and fourth decennial upgrades on the EDF 1300 and 900 MW reactors, respectively. These changes will include improved instrumentation & control systems, recorders, man-operated control relay, and adaptations to new plant regulations.

Operators will be faced with significant changes of the control room human-machine interface and therefore, training drills must precede the implementation of the new control room upgrade.

EDF then had two options: modify existing simulators, knowing that the final design of future control rooms will evolve over the project execution, or launch the concept of a digital control room, interfaced with the simulator and its process models.

In the latter case, the control room simulator becomes a series of screens. The change is to modify the images that appear on screens, rather than to replace hardware. The result is faster, less expensive modifications.

3. Guiding Project Principles

To anticipate these changes, EDF established a working group in 2010 led by plant operations training experts, to rewrite its simulator guidelines. This led to four main principles that would shape the project's direction:

- Easily customizable and reconfigurable simulators, to represent different reference unit designs operated daily: 900 MW first and second generation, 1300 MW first and second generation with their version to the modified status (second, third or fourth decennial visits)
- Full scale SDCN, faithful to the operator movements as a shift member and within the control room, allowing the number of operators in the control room ranging from 4 to 5
- SDCN matching with component close sights and the overall control room view, as well as to the sound noises emitted by the operated components, both in nature and intensity
- Fully tactile and faithful handling of real equipment controls: there are no more buttons, neither recorders, nor alarm tiles, but screen representation of push buttons, recorders or alarm tiles on which one acts through touch screen, similar to a giant smartphone with haptic feedback.

EDF has added to these four principles along with other important rules of the game: exclusive use of off-the-shelf hardware, a significant time saving for the simulator control room manufacturing, duplication or upgrade, not to mention the significant reduction in cost compared to its current full-scope simulators.

4. The High-Fidelity Challenge

The main challenge is to identify technological solutions to reproduce on-screen components, actuators, colors, layout space, the different sounds of a real control room, with features that allow a setting as close as possible to the operator gesture that should be performed during the use of the plant operating procedure.

EDF had the experience of "simulated control rooms" in mind, as they had installed on some sites. They dictated the use of a mouse for all actions and the instructors for this reason, only used them as a supplementary tool not usable for operator training.

In the case of SDCN, a partial or complementary solution of the conventional control room was then totally excluded. EDF's request was as follows: to have a tool that allows bringing operators at the same level of competence as a through the use of full-scope simulator interfaced with a hardware replica control room, requiring the use of state-of-the-art technology.

High-definition 27-inch touch screens were chosen after several phases of prototyping. Though the market offers larger monitors, for example, 55 inches with a 0.6 mm pixel, these offering proved inadequate as the pixel size could lead to errors in reading values, particularly on some paper recorders. The 27-inch provides a 0.32 mm pixel, allowing more precise displayed information, as verified during the user-centered working group sessions.

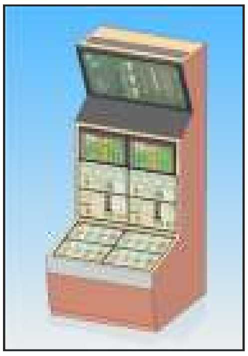

Fig 2: SDCN single panel

This screen choice meant installing 4 times more screens than if using 55 inches, requiring extensive studies to ensure optimized assembly and settings as well as unaffected planned maintenance. Among the solutions implemented include the use of an electronic card for multiple monitors control and a system of sliding and hoists for screen replacement.

Regarding the tactile slabs that are placed on these screens, extensive market research identified five different technologies. A technical and financial analysis concluded that optical infrared were best suited for the display rather than technology-based resistive or capacitive sensors, which account for 95% of the market. This was for several reasons: it is a "multitouch" reliable technology (the ability to detect up to twelve simultaneous contact points on the monitor), the calibration is stable for the lifetime of the monitor, the monitor can be acquired separately from the computer display.

Fig 3 – Tactile Slab

Finally, haptic actuators for vibrating the touch screen to give the operator the impression of a force feedback: by pressing a button, it must have the feeling that this button opposes its usual resistance. Similarly, if this button is pressed while watching another part of the panel, the force feedback confirms that the operation performed is taken into account.

Fig 4 - Haptic actuators on the tactile slab

These haptic actuators are glued and vibrate the tile monitor perpendicularly to its plane. Four of these sensors are placed on each tile of four screens. The technology chosen would have been able to generate a number of different levels of strength. In practice and after validation with users, three varying intensities were chosen to representatively force feedback for all components.

Finally, we can quote the graphical editor toolset that allows to design and develop high fidelity software replica of the different control panel components. A library of 60 objects was designed, each defined by its visual appearance, the sounds it produces, its operation and the touch or haptic feedback it generates, allowing the faithful reproduction of the 2300 components installed in the plant control room.

5. A User-Centered design

One of the risks of such a project, which introduces a totally new and breaking concept, is to leave the entire design responsibility to engineers without having them endorsed by experienced users. To avoid this, a User Working Group (UWG) of twenty members was established. The group included 900 MW and 1300 MW plant operators and instructors, maintenance staff, human factor specialists, and CORYS / EURIWARE experts and team leaders. During the SDCN specification phase, UWG met five times for three consecutive days to validate the mock-ups, solve critical issues, and suggest improvements.

Fig 5 – UWG first meeting

The UWG had a decisive role in design validation. It led to a detailed understanding of each control room action operators have to implement—is such button being operated with one or two fingers, should it be selected before activation. This working group made it possible to identify the most accurate way to reproduce different gestures.

Whenever a new solution had passed the first development stage, the UWG was also involved in its validation. The requirement of actual representativeness applies more particularly to the hardware components, for example the right timing of haptic feedback when a control is activated. But it also extends to the development of dynamic processes.

An example: When operating a 900 MW reactor, 40 arm-and-depress luminous buttons (ADLB) could have to be successively activated within a maximum defined allowed operation time, this in order to achieve pressure balancing inside the primary circuit. An experienced operator checked that, with the digital ADLB, the operation was achievable within the time required by the procedure, without roundabout means introduced but this technology on the effectiveness of the action of the operator.

This work on the representativeness has mobilized a lot of effort, sometimes with major difficulties because it is not always possible to digitally reproduce every component. A remarkable takeaway from the experience was UWG members themselves identifying and proposing solutions in these complex cases.

One example applies to the reproduction of a push-button that is technically impossible. According to the operation rules in place on French nuclear reactor, any push-button to be activated shall first be designated by the operator finger, and its tag name loudly pronounced to the team shift supervisor. The challenge is then to allow the finger designation without causing its maneuver (reliability Practices) Group members spontaneously proposed operations very close to reality using a finger or two fingers depending whether it was for tag name designation or maneuvering the actuator. Of course, each of these discrepancies with the reality has been duly validated. For each lack of fidelity, design work then targeted the 100 % effective, then the best representativeness.

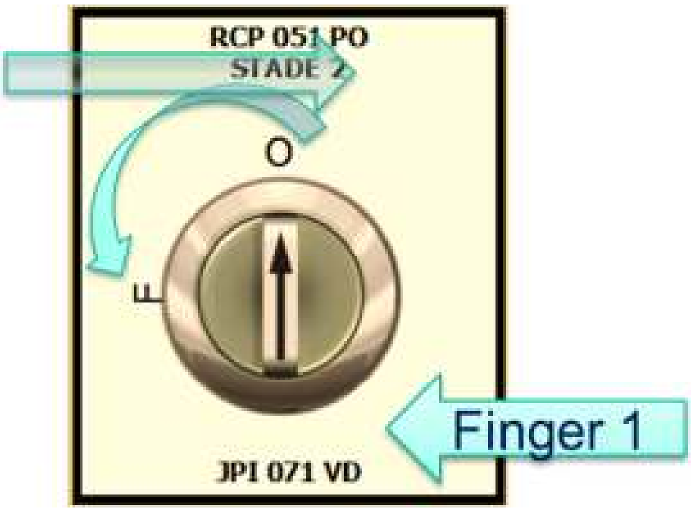

Fig 6 – Movements on push-button

6. Easy maintenance

Given the training stakes, complicated by the challenge of anticipated training availability, as mentioned at the beginning of this paper, EDF set a requirement for a maximum troubleshooting time; its maintenance technicians must be able to remedy any failure within 2 hours.

This constraint, which excludes the solution to repair screens or tactile slab onsite, led to the exclusive selection of off-the-shelf products manufactured in large volume and readily available to enable their availability in a replacement stock that can be easily mobilized. Two ergonomists reporting to the project team helped defining, always with the UWG, easy to use technical solutions.

This is no more computing nor software programming, but mechanical and thoughtful gestures. For screens, a system of hoists, runner slides, check prop, and hatches was developed to enable the screens removal, rotation from the panel backside, then to descend to a storage box on wheels. The replacement screen is installed with the same equipment, following the reverse path.

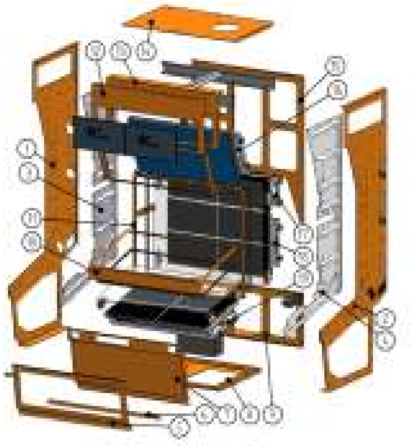

Fig 7 – SDCN single panel design

For the tactile slab, suction cups, identical to that used by glaziers are implemented. Two maintenance operator can rotate it at 180 °, lift and move, this move being guided by a ruler built-in the panel structure.

In both cases, screen or slab, developers must be mindful of French labor laws, which prohibits the handling of objects over 15 kg, while the complete set weight "screen + slab + haptic actuator" can vary from 12 to 21 kg.

Also for maintenance, many issues have been reviewed and improved over the first design: the type of casters for the screen storage box, the most suitable steel for the tactile slab runner slides, the way the wiring cables are embedded in the panel sides to facilitate the screens replacement. Finally, screens and tactile slab have been selected, among other criteria, for their very low failure rate.

7. Assessments of operators for licensing

The ultimate goal of the project, in addition to the initial and refreshing training, is to ensure the ability of this new tool to assess the operators to pass their nuclear operating license. Even with equipment conforming to standards, in particular the U.S. standard ANSI ANS 3.5, the question of acceptance by the operators themselves or by instructors remains. Is a software replica control room able to provide the fidelity needed in a skills assessment tool? What risk does the introduction of a new tool pose to its the operators? If their assessment results on the new tool are not as expected, who shall be blamed–the assessment or the trainee?

These issues are particularly important in France where the operators licensing emerged there only from about 10 years under the pressure of international peer reviews and more generally, from the world nuclear industry. For teams, this is a sensitive subject which still raises some concerns.

EDF has clearly identified the risks from the design and implementation stage and now mainly rely on the assessment organization to remove the obstacle. This is born by the preparation time, sequences of trainings, additional tutorials integrated imaging to make sure that operators have succeeded in the upstream tool appropriating.

8. A cost-optimized solution.

At the end of the current phase of design and manufacturing, it is possible to estimate a SDCN allow substantial financial gain compared to the interface with a replica control room. This is even truer when integrating the maintenance costs. This cost improvement is explained by the use of screens and tactile slabs that, like all electronic equipment, follow a downward trend, while the hardware components increases with their rarity. CORYS, as a manufacturer of simulators for the power and transportation industries, is regularly confronted with this problem. The full-scale replica of a nuclear control room or locomotive cabin, you have to order each component per item, with some of them having been discontinued from commercial circuits for years.

The example of the Bugey, Dampierre Gravelines simulators, three 900 MW nuclear station, is particularly illustrative. They were originally built in the 80s and have been upgraded. But to replace exactly as they were some of the relays, push buttons, alar tiles or paper recorders that are no longer manufactured, it is currently required to award an industrial vendor ready to produce, but also to redesign the A to Z. Even when the components are still available, they can be very expensive—a single paper recorder can cost up to 40,000 euros.

The use of screens and tactile slabs will completely change the perspective: fewer parts to supply, spares easily and quickly available at controlled costs and predictable returns.

9. Conclusion

As with any project where innovation plays a major role and makes a significant break from the state of the art, the challenges are many and their treatment is further complicated by a very tight schedule. However, the current project progress now allows EDF and CORYS to be confident about the ability to successfully achieve most goals.

But what is particularly noteworthy is the involvement and cooperation that exists between the many project team members belonging to various entities very different in size, culture, and organization.

As with any emerging technology, difficulties with implementation and migration remain. However, the major challenge for EDF remains the ability to transition extant hardware control room simulators to software based SDCN without compromising the quality of operator licensing assessments or their training.

OPERATOR TRAINING ON SEVERE ACCIDENT AFTER FUKUSHIMA: A REAL-LIFE EXAMPLE

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ABSTRACT

It is more than two years now from the Fukushima-Daiichi nuclear disaster. Since then, severe accident has become one of the main topics of interest for international organizations, regulatory bodies, academia, research centers and, of course, industry. Lessons learned from the catastrophe highlight the need for improved education and training, at all levels, in this subject. In particular, it is recognized that faced with accident scenarios beyond design basis, nuclear plant operators, managers and technical support teams would benefit from new training tools with specific severe accident capabilities.

Several of these solutions have been proposed already but, even today, very few of them have been fully implemented. The way these tools should be used, the goals to be achieved and the personnel that should be targeted are still a matter of considerable debate.

In this article we describe in detail the experience at Monticello Nuclear Generating Plant, sister to the badly damaged Fukushima I, in the Minnesota plains. There, as a result of a successful training simulator improvement program, carried out over the last few years and recognized by INPO in 2012, instructors can design simulator exercises which include all phases of a severe accident, from core damage to vessel and containment failure. The severe accident simulation models have been developed by CORYS by tightly coupling THOR, their widely used advanced thermal-hydraulics code, with MELCOR, the US NRC severe accident code developed by Sandia National Laboratories. The code integration is transparent to the users of the full scope training simulator and the different models are automatically called as required by the evolution of each sequence. Detailed models of the spent fuel pool are included too.

This kind of training has been conducted for over a year now so real-life lessons can be extracted in different areas. We discuss, for example, the observed benefits in operator training with a better understanding of the severe accident phenomena, and also the improved response of the integrated severe accident models as opposed to the standard stand-alone execution of the code. At this time, analogous simulator improvement projects are under way or have been recently implemented at a number of plants in the US.

1. Introduction

In March 2011 the full scope training simulator at Xcel Energy's Monticello Nuclear Generating Plant, a General Electric BWR-3/Mark I reactor, was already in the middle of an ambitious upgrade plan. Site acceptance testing of a new electric distribution model was under way while a detailed radiation transport model, including reactor building, turbine building and ventilation system, was being developed. The momentum built up after the multiple meltdowns at Fukushima-Daiichi and additional upgrades followed, making the Monticello simulator one of the most advanced in the world. Eventually, two-phase non-equilibrium thermal hydraulic models for the primary system, balance of plant and containment were coupled to the well-known severe accident code MELCOR [1] so that training sequences could progress beyond fuel damage, vessel and containment breach, and recreate a complete severe accident scenario.

This paper describes how this simulator has been used during the last year for Licensed Operator Requalification Training (LORT) on Severe Accident Management Guidelines (SAMGs) and the lessons learned from the experience.

Two and a half years after the earthquake and tsunami in the Japanese coast, and while the need for new tools to improve severe accident training at all levels has been widely recognized, the discussion about how best to achieve the desired goals remains open. Different approaches have been proposed but only a few have been developed and even less fully implemented. Regulatory changes have not taken place yet, but are expected. In this context, Monticello case is quite unique and should help to evaluate future trends and possibilities.

Fig 1: Monticello Nuclear Generating Plant

2. The Monticello full scope training simulator

By mid-2012 all the upgrades were ready. Factory acceptance testing was completed in July and site acceptance tests extended during the summer. Training was scheduled for late 2012 using the new severe accident models. By then, the simulator was a truly state-of-the-art tool, in every area, exhibiting the following features:

- High-fidelity two-phase models of primary system and balance of plant, as well as primary, secondary containments and HVAC to correctly simulate radiation and gas transport across the whole reactor and ventilation release paths. The thermal hydraulic code is THOR [2], by Corys, the most widely used real-time two-phase models in the American nuclear sector with more than forty installations in training simulators since its introduction in 1998.

- Spent Fuel Pool model, also in THOR, and support for multiple modes of operation in order to blend loss of cooling, loss of flow, and mode 5 refuel modes with vessel and containment heads removed
- Detailed electrical distribution model of all AC, DC and sub-yard, with particular attention to batteries, diesel generators and large DC loads affecting battery discharge
- MELCOR model of the reactor pressure vessel to support severe accident sequences with faulted core geometry allowing for live transition from regular scenarios
- 3D visualization tool as an additional help during severe accident training
- Earthquake simulation
- Full sound system
- Full scope glass-top simulator complementing the training sessions on hard panels

An additional change had to be made as simulator computer time increased noticeably. Computer hardware had to be updated along with the models in order to guarantee sufficient processor spare time during execution. The simulator now runs on Dell Precision machines with Dual Quad Core 3.6 GHz processors. The CPU load never exceeds 40% on the most limiting processor. Operating system is Microsoft Windows 7, 64 bit.

Even before the upgrade process was totally finished, in early 2012, Monticello commitment to excellence regarding its training simulator was recognized. As a result of a joint plant evaluation by INPO (Institute for Nuclear Operations) and WANO (World Association of Nuclear Operators), Monticello received a “strength” related to the simulator [3]. The strength is defined as “*a beneficial cross-functional or significant functional area practice, activity, or process employed by a station that results in achieving a high level of performance or desired high quality results and benefits*”. Obviously, the significance of the events in Japan had not been underestimated and the plant was taking decisive steps ahead of the emerging industry challenges.

3. SAMGs training implementation

Before the upgrade, Licensed Operator Requalification Training on severe accidents was limited to classroom discussions of the SAMGs using case studies. With the new models operators can evaluate plant conditions, including core collapse into the lower head and vessel breach, and take mitigating actions according to the guides [4][5]. The transition to the severe accident models, triggered by fuel clad temperature reaching 1200°F, is seamless as the sequence degrades but can be disabled by the instructor to avoid affecting license exams or some other kind of training. When the transition happens, the booth operator is notified that the simulator is now in out-of-bounds conditions.

Since the severe accident model is a continuous part of the regular simulator load and does not cause an interruption in training, it was possible to design a SAMG training exercise based on pre-existing initial conditions. The scenario is initiated by a small break LOCA followed by a design-basis earthquake which results in high power ATWS, safety relief valve tailpipe breakage and, eventually, station blackout (SBO) conditions with major fuel damage requiring hard-pipe containment venting.

The whole scenario time line evolves during several hours. At one point, the crew will identify the need to exit all EOPs (Emergency Operating Procedures) and enter all the SAMGs. Sometime later, command and control will be transferred to the Technical Support Center due to the inability to restore and maintain sufficient reactor water level. The vessel will finally fail and drywell temperature and pressure will increase rapidly. The exercise ends when the remaining DC power is lost causing all lights to go off and all indicators fail downscale.

As the training exercise cannot extend for so long, time compression is required. Figure 2 is a graphical depiction of how the scenario was developed and implemented. First, the complete sequence was executed in real time, with no operator actions, for development. Snapshots were taken prior to the most significant events, such as high hydrogen levels after extended core damage, core collapse and, finally, vessel breach. During the training session the sequence will divert from the baseline path due to the mitigation actions performed by the operators. Then, in order to progress to the next stage, the simulator will be reset to the following snapshot and the crew briefed that the actions could not be performed, time has elapsed and what the current plant conditions are. After every snapshot, the simulator will continue to run in real time allowing the operators to follow the guides and carry out new actions.

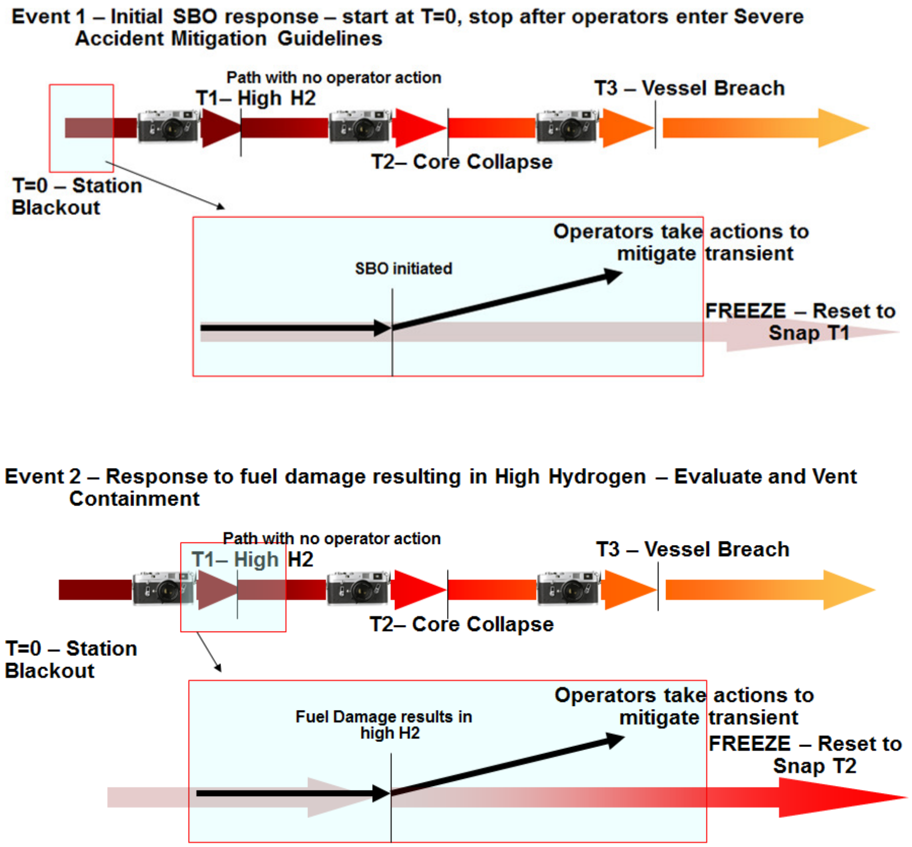

Fig 2: Severe accident scenario implementation during LORT

At certain times during the exercise, the simulator will be placed in freeze to explain the severe accident phenomena and analyse plant response. A 3D dynamic visualization tool with a detailed representation of the vessel and the core is used for support. The graphic is connected to the running simulator and animated in real time. It allows the operators to understand what is happening inside the reactor and how this relates to the indications observed in the control room. Figure 3 shows the 3D graphic during a partial meltdown, with a large amount of molten fuel and debris deposited on a pool of water in the lower head.

Although the uncertainty involving the severe accident models is still high and it cannot be guaranteed that the plant will behave exactly as predicted during the severe accident phase of the sequence, the training value is clear. Operators are faced with situations they would likely encounter, sooner or later, during such an event, with plant conditions that differ greatly from the scenarios used in periodic EOP training.

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RPV DOME PRESS(F):69.4
RPV DOME GAS TEMP(F):2219.4
LOWER HEAD TEMP(F):716.9
FUEL ZONE WATER(IN):-305.6
STEAM FLOW RATE(LBM/HR):52887.6
ECCS/FEED FLOW(LBM/HR):-67.2
MAX FUEL TEMP(F):3940
DEBRIS SURFACE TEMP(F):4002.7
INTACT FUEL MASS(KG):55304.4
DEBRIS FUEL MASS(KG):92464.1
MASS OF H IN DRYWELL(LBM):334
DW PRESS(PSIA):36.05
TORUS PRESS(PSIA):36.09
DW TEMP(F):232.1
SUPPRESSION POOL TEMP(F):174.3
DW RADIATION DETECTOR A:0.83 e7
DW RADIATION DETECTOR B:0.83 e7

TIME(S):16561
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Fig 3: THOR-MELCOR 3D dynamic visualization tool

In this exercise two examples can be highlighted. First, the core collapse into the lower head, causing a pressure spike, safety relief valve open alarms and hydrogen production. By seeing real time integrated indications in a control room setting, the crews were able to perform a diagnostic exercise previously done using a PowerPoint slide. This exercise allowed for discussions regarding what could cause these indications and application of operator fundamentals in understanding the differences between the indications for core collapse and injection from an emergency system. The observation of the collapse in the 3D graphic reinforced the explanations.

Second, the evaluation of the vessel breach. Prior to vessel failure containment temperature was around 300°F; multiple crews evaluated it as high drywell temperature meeting one of the criteria for indications of a vessel breach. When the failure actually happened, as observed in the 3D graphic, “high or rising drywell temperature” (the SAMGs indication) was demonstrated. Once again, by using simulator training combined with the 3D graphics, procedures steps were better understood by the operators allowing for a more robust training experience not available in a classroom setting.

At Monticello, feedback from the severe accident training has been very positive from operators and managers and additional upgrades are already being evaluated. Examples are the incorporation of revised mitigation strategies into the simulator models, such as emergency power sources or water injection from portable equipment, and the improvements to the simulation of control room conditions under long term SBO regarding indications and lightning. Extending the use of the simulator to emergency planning and engineering training is in progress.

The severe accident training exercises have also drawn interest from outside the plant and the simulator has been visited by various external groups willing to observe the training sessions, among them a delegation from the Nuclear Power Training Center in Japan (NTC) responsible for operator training at all the Japanese PWR plants.

4. The real-time severe accident model

The coupling of MELCOR, developed by Sandia National Laboratories for the US Nuclear Regulatory Commission, with Corys' THOR is thoroughly documented in several references [6][7]. The integration of both codes is based on the design decision to continue using the THOR models, already implemented at most American simulators, for the primary system under all non-severe accident conditions. They would also continue to be used for the containment and balance of plant systems in all situations, even under severe accident conditions. In this way, only the required packages of MELCOR latest available version, 1.8.6, are incorporated into the severe accident model as most areas are left to THOR, including Emergency Core Cooling Systems (ECCS), containment and radiation transport outside the primary.

In Monticello's case, the boundaries between MELCOR and THOR are established at the reactor vessel nozzles. After transition to the MELCOR model, all phenomena occurring inside the vessel are calculated by MELCOR, and all phenomena occurring outside remain within THOR's scope. Figures 4 and 5 are different views of the integration of both models at Monticello. Figure 4 displays the integrated severe accident model nodalization, MELCOR for the vessel and THOR for the containment. Figure 5 describes the interface between the MELCOR model of the vessel on the left with the rest of models run by THOR on the right.

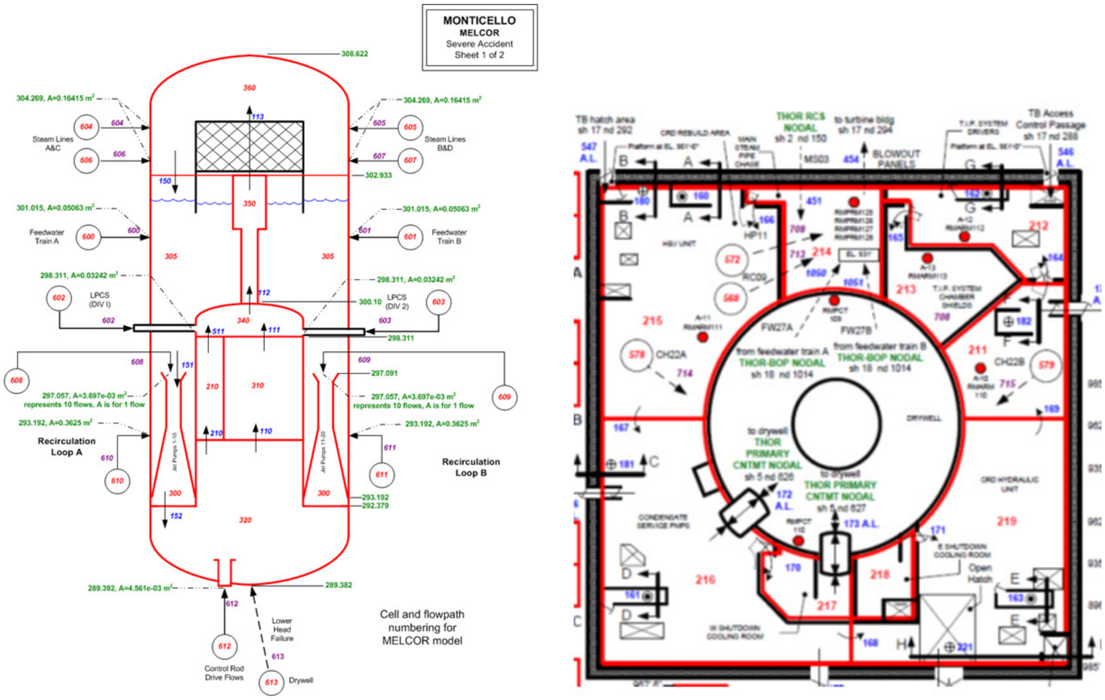

Fig 4: MELCOR vessel and THOR containment nodalization

The transition to the severe accident model occurs just before the onset of large scale clad oxidation which could result in fuel damage and loss of core geometry. At that moment, the vessel model in THOR stops execution and an interface file containing the current primary system conditions is created on the fly. The file is then used as the starting point for the MELCOR models. The entire process takes place in about a tenth of a second and is completely transparent to the trainees. As the sequence progresses, additional MELCOR packages may come into play to simulate in-vessel and ex-vessel severe accident phenomenology such as core collapse, vessel failure, corium relocation or molten corium concrete interaction (MCCI) in the reactor cavity.

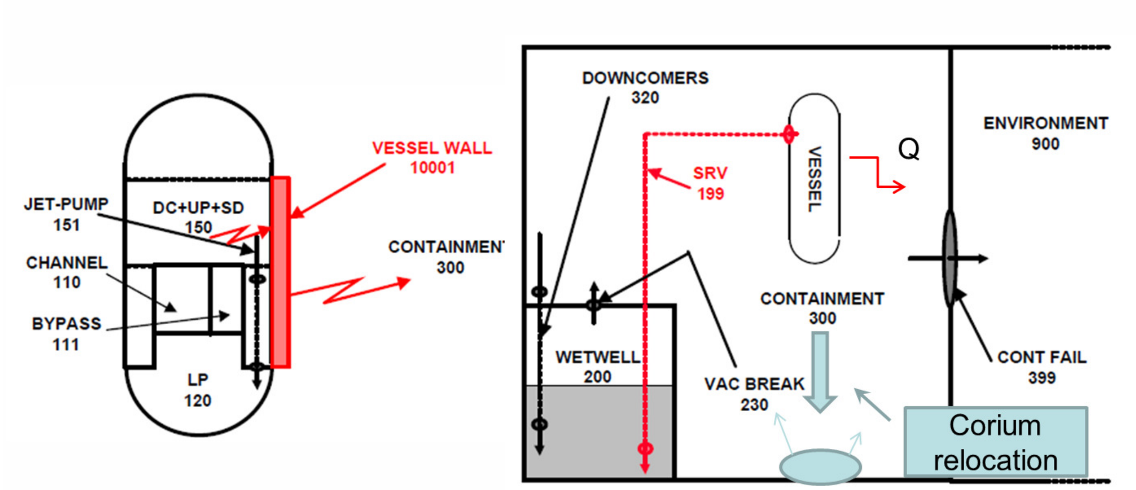

Fig 5: Interfaces of MELCOR vessel with THOR containment models

Significant amounts of data need to be exchanged between the THOR and MELCOR models. At every boundary, MELCOR outputs become THOR inputs and vice versa. Figure 6 shows a schematic representation of the process. Some of the main magnitudes being exchanged are: fluid mass and energy, convective heat transfer from the vessel, energy from ex-vessel phenomena and radionuclide information which will be fed into the radiation detectors model. The data is exchanged at a high rate, ten times per second, to ensure repeatability.

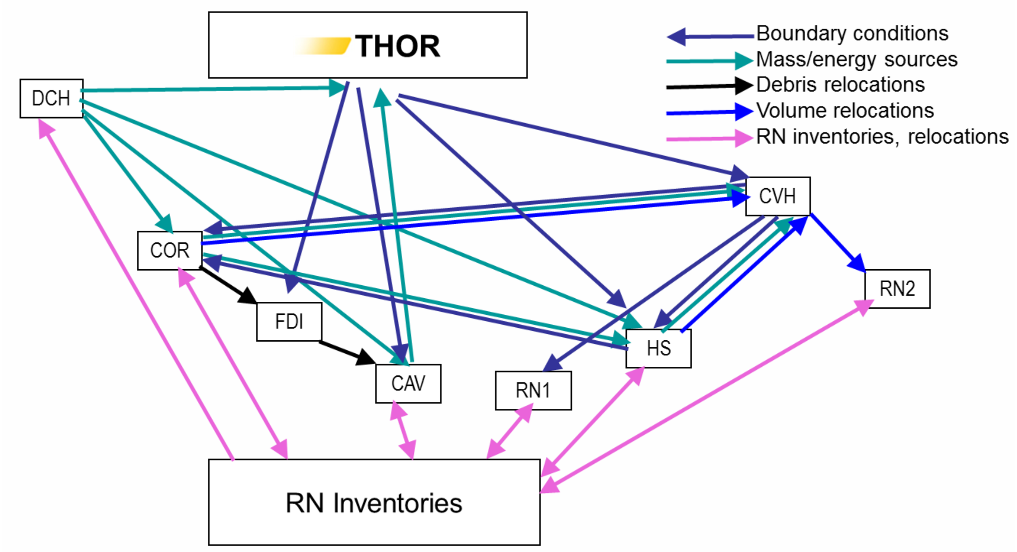

Fig 6: Data exchanges among THOR and MELCOR packages

The THOR-MELCOR integration has been benchmarked against standalone MELCOR runs of the same scenarios and against published MELCOR results for similar plants. The agreement is generally good and the sequences follow similar paths in all cases. Some differences between the integrated and standalone models could require further analysis but, in any case, they should not affect the quality of the severe accident training being pursued. As explained before accuracy is not, at least at the moment, the main requirement for this type of training.

At the time of writing this article, the first THOR-MELCOR models of a pressurized water reactor are being completed. The plant is Calvert Cliffs, a two-loop Combustion Engineering reactor. Furthermore, contracts to implement the MELCOR severe accident models at two more American plants are already in place: Point Beach (a Westinghouse two-loop PWR) and Perry (a General Electric BWR).

5. Conclusions

Monticello's experience demonstrates how full scope training simulators can provide valuable operator training in severe accidents using existing technologies. A well designed integration of robust high-fidelity thermal hydraulic models such as THOR, with well-known severe accident codes such as MELCOR, will allow the instructors to extend training scenarios beyond fuel damage and generate realistic severe accident conditions in real time. The quality of the training will be determined not only by the severe accident model, but also by the detail of the rest of plant models, especially the secondary and containment systems, ventilation, radiation transport and electrical distribution.

The potential of this type of tool is obvious and additional training applications should be explored. At the same time, the severe accident models will continue to improve as the knowledge obtained from the many research programs under development is incorporated. This will reduce the current uncertainties and bring the training in severe accident closer to the mandatory training in emergency procedures we are used to now. In the near future, regulatory requirements in this direction may come into force. As different approaches are being proposed and some of them implemented, the results will need to be shared for the benefit of the whole industry.

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DIGITAL CLASSES IN PROVIDING EXPERIENTIAL LEARNING PLATFORM FOR STUDENTS WITH NO ACCESS TO EQUIPMENT AND LABS: AN EXAMPLE OF "DIGITAL NAA CLASS"

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ABSTRACT

A number of programs and classes pertaining to nuclear science and engineering worldwide do lack infrastructure in sufficient quality and quantity, and therefore lack ability and capacity in providing valuable hands-on learning and training of their students. Collaboration and sharing of such facilities, especially virtually, is one way in bringing real-lab experiences to students without direct access to infrastructure and equipment of interest to their curricula and class contents. Recently we have developed a so-called "digital NAA" as a supplement to the class on radiochemistry taught at the University in Montevideo, Uruguay. Together, we have created a real-time practice on neutron activation analysis, more specifically on how gamma spec systems operate and how we measure the samples after irradiation in a research reactor. Our practical exercise consists of sending the blind gamma spectra we generate at the University of Utah Nuclear Engineering Program, to the group of students at the University in Montevideo in Uruguay. After a week from sharing these spectra, we connect again through the Skype-system to discuss the elements as detected and shown in these spectra. We develop detailed discussions on the meaning of the spectra and provide final analysis on the nature of the samples. The class includes graduate and undergraduate students from both programs in live discussion and exercises on neutron activation analysis. We plan to develop additional exercises and establish this digital class as a practice among our programs. We will present the class practice in emphasizing it as a model for developing similar international digital classes.

1. Introduction

Montevideo, Uruguay: The Laboratory of Radiochemistry in the Faculty of Chemistry in Uruguay offers courses related to nuclear science and applications to pre and postgraduate students in Chemistry, Pharmacy, Clinical Biochemistry, Chemical Engineering and Food Engineering. Annually approximately 100 students participate in the theoretical lessons while 30 students are also involved in experimental activities both on basic topics (safe handling of radionuclides, decay law, radiochemical equilibrium, gamma spectroscopy) and on applications in areas such as health, industry and analytical chemistry. The specific topics covered depend not only on the importance of the different areas but mainly on the available infrastructure. Neutron activation analysis (NAA) is a very important application that was included in the programmes until 1990 using a ^{252}Cf neutron source provided by the International Atomic Energy Agency. After the source was completely decayed, nuclear activation analysis experiments could not continue since there are no nuclear reactor facilities in Uruguay.

Salt Lake City, USA: The Utah Nuclear Engineering Program (UNEP) mission is in supporting the development and exploration of advanced nuclear science and technology while bridging different engineering and science disciplines and by advancing the education with modern laboratory practices. Our program promotes nuclear power and engineering education as a resource that can help green energy development, environmental, and nuclear security needs. The program emphasizes that technical and regulatory barriers can be overcome through education, training, research and development. In 2009/2010, we successfully established a new educational program inclusive of the advanced graduate program and undergraduate minor degree in nuclear engineering centering on hands-on experience using our TRIGA reactor (UUTR), radiochemistry, radiation and measurement laboratories, and nuclear forensics laboratory, in emphasizing nuclear safeguards, radiation detection, and simulations visualizations applicable to reactor neutronics and other systems inclusive of radiation transport phenomena. In the interest of making positive contributions to nuclear energy challenge world-wide, we focus on the development of our nuclear energy-related infrastructure and basic capabilities necessary to further promote R&D in support of nuclear science and engineering educational mission. Utah has a growing economy and the University of Utah is continuously re-building, modernizing and innovating the nuclear engineering program to prepare for the growing need of nuclear engineers. Our program is also *unique* in becoming the only one that operates its facilities under the DevonWay Corrective Action Program (CAP) software system, and trains our graduates in mirroring in full although at the smaller scale, the environment of nuclear power plants safety rigor. [1]

In addition to education, training and research, our radiation measurement laboratories are used for creating digital classes. Namely, we develop laboratory practicies and share with the classes in the programs that do not possess laboratory equipment for hands-on training of their students. One such international example is our so called “digital NAA” class we have developed in cooperation with the radiochemistry class in Montevideo, Uruguay.

2. NAA Capabilities at the University of Utah Nuclear Engineering Program

The University of Utah is one of dozen universities in USA that operates a research nuclear reactor; the TRIGA Mark I is licensed to operate at the maximum power level of 100 kW providing good neutron population in the expected energy range as applicable to neutron activation analysis, sample irradiations and other experiments of interest to nuclear science and engineering and associated disciplines such as but not limited to medicine, agriculture, material science, space engineering, nuclear forensics, environmental engineering, and concrete chemistry. Neutron activation analysis became one of our main usages of the reactor in the last few years. Besides using it for research and sponsored projects, the NAA is used widely for training the students in sample science, safety aspects of NAA and sample handling, NAA basic science, and radiation measurements. [2] Our graduate and undergraduate students have solely developed the NAA protocol as established in 2011; the NAA protocol is shown in Figure 1. Every raw sample entering the Utah nuclear engineering facility is logged-in following internal code system. The samples are logged-in according to their origin, nature, quantity and reason for being examining using the NAA. The samples are then prepared for irradiation following strict protocol of *sample science for irradiation*. Our students are trained in sample preparation that includes details on why the steps are strictly required to be followed, such as for example why samples are not to be handled by bare hands, or how to wash the instruments used to grain or cut or dissolve samples. Once samples are prepared and their mass is measured, the users are required to enter the NAA pre-calculator. [3] The easy-to-use pre-calculator is developed by graduate student and is tailored toward not just pre-determining the activity and dose rate of the samples are irradiation, but better train and educate our students and users at large. The graphic user interface of the NAA pre-calculator is an advanced tool allowing to optimize the irradiation time, reactor power and dose rate after required cooling time in the reactor. Every sample to undergo NAA has to some extent known composition. That elemental composition is developed based on our existing extensive NAA data library [4] and then used within the NAA pre-calculator. The request for sample irradiation is placed by the user into our DevonWay software system. [1] In this way, reactor supervisors plan the operation of the facility in highly organized and optimized ways. Once the sample is irradiated in the thermal irradiation port of the reactor, and after predicted cooling time, the dose rate at three feet distance is measured and compared to the predicted value. This is the first indicator of how well the estimates were provided for the NAA experiment. When the dose rate satisfies limits, the sample is moved into our radiation measurement laboratory and placed into gamma spectroscopy station for analysis and measurements. Not every sample requires the same counting time. The starting counting times are determined based on the NAA data library for similar types of samples, and if and when needed, the counting times are adjusted for better results. When the samples are measured and analysis is completed, the samples' faith is determined based on the research involved. As shown in Figure 1, a sample can be stored at our facility for later use, destroyed or returned to the customer.

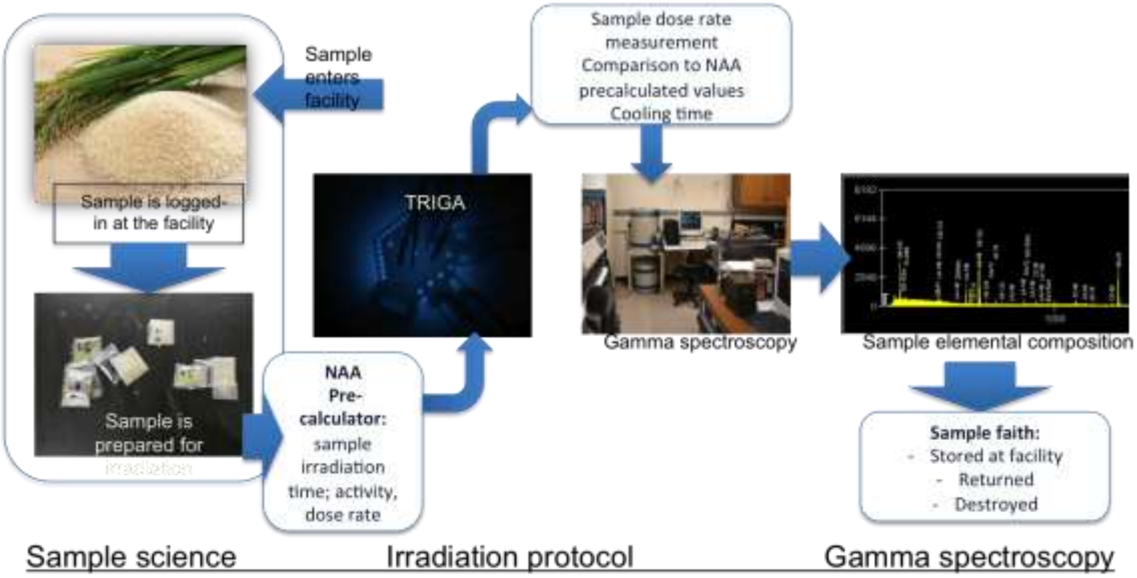

Figure 1. NAA protocol at the University of Utah Nuclear Engineering Facility

3. Digital Class on Neutron Activation Analysis: “Digital NAA”

The Nuclear Engineering Program at the University of Utah in the USA and the Catedra de Radioquimica from Montevideo in Uruguay, together, we have created a real-time practice on neutron activation analysis, more specifically on how gamma spectra systems operate and how we measure the samples after irradiation in a research reactor. Our practical exercise consists of sending the blind gamma spectra we generate at the University of Utah Nuclear Engineering Program, to the group of students at the University in Montevideo in Uruguay. After a week from sharing these spectra, we connect again through the Skype-system to discuss the elements as detected and shown in these spectra. We develop detailed discussions on the meaning of the spectra and provide final analysis on the nature of the samples. The class includes graduate and undergraduate students from both programs in live discussion and exercises on neutron activation analysis.

The “digital NAA” class sequence is shown in Figure 2. [3] The class is mainly prepared and led by the UNEP students trained in neutron activation analysis and the associated radiation measurement techniques. The class is initiated by sending the NAA document to the student group in Montevideo. The document consists predominantly of a series of blind gamma spectroscopy spectra. The students learned about the NAA and spectroscopy measurements prior to receiving this document. Usually, a week or two are given to the students to work on the spectra with the goal to identify the elements based on the energy peaks in the spectra, and then provide conclusions of what are the possible samples for which these spectra are provided. While the student group in Montevideo works on the spectra analysis, the UNEP students trained in the field of NAA and gamma spectroscopy, prepare for the digital class. The class starts with the overview of NAA and gamma spectroscopy followed by the UNEP laboratory tour using Skype. Once the students virtually tour the spectroscopy stations at UNEP and their operation is demonstrated, the students start discussions on previously provided spectra and conclude the class with complete “discoveries” on the elemental compositions of the samples and the nature of the samples.

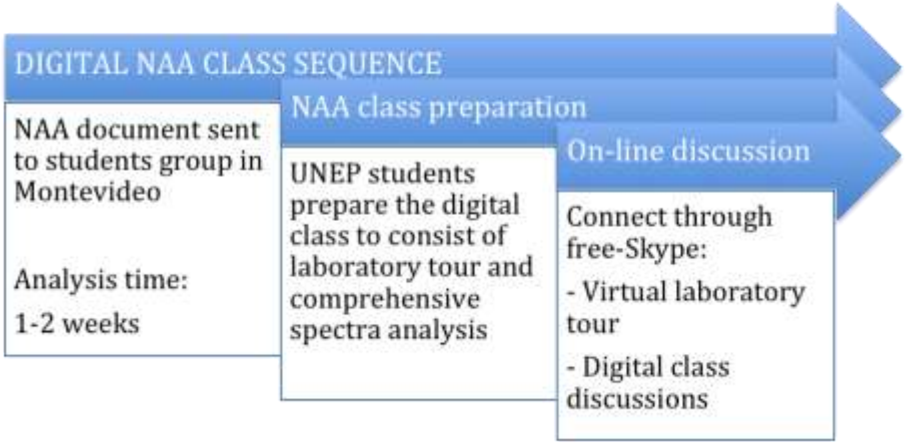

Figure 2. Digital NAA Class Sequence

4. Conclusion

Neutron activation analysis is non-destructive and powerful technique for identifying and quantifying elemental composition of a sample. It requires a neutron source and gamma spectroscopy system with well-equipped labs for clean preparation of analysed samples. It is as such, an advantageous educational and training technique for the students in providing them with hands-on experience and knowledge of the basic nuclear physics and nuclear engineering principles. Many universities world-wide do not possess capabilities to demonstrate theory in practice, by providing the whole experience in preparing, irradiating and measuring the samples as a part of neutron activation analysis technique. We, at the University of Utah Nuclear Engineering Program, came to develop what we call, a “digital NAA” class in providing simple yet interesting class on neutron activation analysis through cyber-space. Using free Skype-capabilities, we broadcast a few hours demonstration on the technique and gamma spectroscopy system and measurements. We have developed this class in collaboration with the University in Montevideo, Uruguay. We continue to advance this class and continue to offer to other universities world-wide.

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