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Poster Session

PERSONNEL MANAGEMENT POLICY OF EDO «GIDROPRESS» TO RETAIN AND TRANSFER NUCLEAR KNOWLEDGE

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ABSTRACT

Experimental and design organization EDO «GIDROPRESS» was set up in 1946 to participate in developing nuclear engineering. The work team gained its position among the leading organizations in the world in creating new technologies of nuclear energy. In the early 90-ies as a result of socio-economic problems in the Russian Federation a lot of efficient specialists left their work in nuclear industry for other activities that were far from NPP designing. It was the most urgent task of EDO «GIDROPRESS» save the nuclear knowledge and to recruit a new generation of engineers. Thanks to the consistent policy in personnel management the situation changed for the better and the staff vacancies were filled up with skilled specialists. Today EDO «GIDROPRESS» has a structured system of nuclear knowledge retention and its transfer to university graduates. The given paper covers the work with promising young people, which is one of the most important elements of the system.

1. Introduction

EDO «GIDROPRESS» was set up on January 28, 1946 and has been developing the designs for equipment and systems for nuclear industry since then. Today EDO «GIDROPRESS» performs a lot of design, computational, engineering, industrial, research and development work in creating reactors and is a leading enterprise in the nuclear power industry of the Russian Federation. Thanks to successful operation of the designed equipment the organization enjoys recognition and respect both in Russia and abroad.

In working on the problem of qualified personnel recruitment, nuclear knowledge retention and transfer, the personnel management service of EDO «GIDROPRESS» is guided by the principle: Correct policy of personnel management is a key to successful operation of the enterprise. The challenges of the policy of personnel management at EDO «GIDROPRESS» are:

- personnel recruitment;
- creation of favorable conditions for an early adaptation of graduates at the enterprise;
- support of highly qualified specialists;
- nuclear knowledge transfer to the new generation of specialists in the industry;
- advanced training of the specialists.

The experience in personnel management at EDO «GIDROPRESS» made it possible to develop and improve the system of personnel recruitment, improvement of employees' qualification, retention and transfer of the nuclear knowledge the enterprise had gained for many years. The basic elements of the system are as follows:

- communication with technical schools and universities;
- annual internship of graduates;
- annual conference for specialists below 33 years of age;

- visits of graduates to NPPs;
- improvement of qualification for all employees by continuous training course in the organization and at specialized Russian and international training centers;
- creation of favorable conditions for scientific activities;
- generalization of experience gained at EDO «GIDROPRESS», related to the process and history of VVER reactor development by issuing special leaflets, books and guides.

The present paper briefly covers the activities in one of the key elements of the above system, namely, a choice of promising students for their subsequent employment at EDO «GIDROPRESS» and transfer of nuclear knowledge to young engineers.

2. Work with high schools

EDO «GIDROPRESS» is situated in the town of Podolsk, Moscow region. Podolsk is one of the largest industrial centers of the region. The population of Podolsk is 179,5 thousand people. Most employees who work for the enterprise are local residents and therefore one of the main tasks of the service is to make an assessment of amount of qualified personnel to be recruited in the future and orientation of high school students to get a higher education in appropriate engineering sciences in the best national engineering universities. For this purpose once every year the enterprise opens its doors to welcome the best students of the town. A questionnaire is circulated while the students are at the enterprise to learn how they do at school, what their hobbies are and what universities they plan to enter after they leave school.

The students visit the design departments and familiarize themselves with experimental and research facilities of the enterprise. The top management and the leading specialists of EDO «GIDROPRESS» inform them of the challenges and prospects of the enterprise and the nuclear engineering industry, as a whole and of the role of a young engineer in the up-to-date society. Usually after the action the students decide to devote their life to nuclear power industry and work for EDO «GIDROPRESS». The data from the questionnaires are processed and saved in the personnel management service database for subsequent work.

Thanks to constructive dialogue and continuous keeping in touch with the teachers the personnel management service of EDO «GIDROPRESS» every year gets information on the school leavers Podolsk who enter universities. The information is the source for creating the database on the students who study at universities that train engineers for nuclear power industry. The database is periodically updated. 23 students entered universities to get a profession needed at the enterprise in 2007. Today the database has entries on more than 200 students of different grades who are local residents.

3. Work with universities

Most employees of EDO «GIDROPRESS» have graduated from Moscow Institute of Physical Engineers, Moscow Power Engineering Institute and Bauman Moscow State Technical University. A number of departments at these universities have been traditionally training specialists for nuclear power industry.

Today the enterprise is in need of young specialists with up-to-date knowledge. Along with the work with the students who are in the database of the enterprise the top managers of the personnel management service of EDO «GIDROPRESS» and the top management of design and calculational departments work at the Vacancy Fairs in the universities. We give the students information on the domestic and international projects EDO «GIDROPRESS» participates in, inform them on the conditions of work, salary and carrier prospects for young specialists, social guarantees and invite them for cooperation.

It is worth mentioning that in their first years at the university diligent students can work at the enterprise during their summer holidays. Senior-year students have part-time work at the enterprise. They have a supervisor as they write their graduation papers at the enterprise. The graduation paper generally corresponds to the specialization of the division the students work in. The students get a salary and enjoy the medical care at the polyclinics of the enterprise free of charge. They are granted medical insurance certificate and they enjoy the company social activities and make tours of the Russian Federation arranged by the trade union of EDO «GIDROPRESS». Thus, good working conditions as wellas salary and professional and carrier prospects attract the graduates of the universities and confirm them in their wish to work for EDO «GIDROPRESS» after they get a higher education.

4. Internship of graduates

Every year university graduates come to work for EDO «GIDROPRESS». The administration of the enterprise do their best to let the young specialists become efficient in their scientific and technical activities, master their knowledge and gain new knowledge of patents and specific technical information and within a short period of time become a highly skilled engineer. For this purpose a system for internship of the graduates was established many years ago and «Positions on the work with young specialists at EDO «GIDROPRESS» were updated in 2003. The positions establish the procedure of internship for young specialists who have just graduated from universities and define the work of the department manager with the graduate during work for the first year at the enterprise.

The purpose of the internship of the young specialists is their training to expand the range of interests and learn the processes of design work. During the internship the efficiency and skills of the young engineers are determined to use their knowledge the best possible way at the enterprise. They acquire the needed practical and organizational skills to perform their duties and learn their job responsibilities, specific features of their work and gain specific knowledge.

During the first year of his work internship program is compiled for a young engineer and he has a coach who is a highly qualified specialist of the division. The main task of the coach for the graduate is to transfer the knowledge and experience gained by the former during his work for EDO «GIDROPRESS». The young specialist is supposed to get acquainted with the organizational structure of the enterprise, regulatory documents that are in force at the enterprise and are used there, get ready for the exams in national and international NPP safety standards.

The young engineers go to an operating nuclear power plant. V.P.Denisov, chief specialist in NPPs and the oldest employee of the enterprise has written a leaflet «The activities at EDO «GIDROPRESS» in the field of using the nuclear power for 60 years». It gives a detailed description of the principles of NPP operation, the physical fundamentals of the chain reaction, the design of VVER reactor and the history of nuclear power industry and of the enterprise.

As soon as the internship is over, the young specialist and his coach make a report for a board of specialists to sum up the results of the internship. The managers and leading specialists are the members of the board. By the results of the interview the board draws the Protocol with an assessment of the results of the internship and gives the recommendations for the further work of the young specialist. As a rule, following the successful internship the young specialist is given a promotion by certification commission.

5. Advancing the professional level of young engineers

Annual training course is realized in EDO «GIDROPRESS» divisions, its purpose being elevation of professionalism and qualification of the employees. The curriculum of the course and the subjects are approved by the heads of divisions and the most qualified and experienced specialists of the enterprise present the lectures.. Besides, Rosatom has centers for advanced training of specialists in nuclear industry. The specialists of the enterprise take part in seminars and training courses that are performed within the framework of IAEA Department for technical cooperation. Publishing of 12 volumes entitled «Creation of VVER reactors for NPPs» was an important event in the history of the enterprise, that summed up the work of a few generations of specialists at EDO «GIDROPRESS». The books were written both by the specialists who had worked for more than 50 years and young engineers who had started working not long before.

The top management and administration of EDO «GIDROPRESS» encourage the wish of talented engineers, including young engineers to take up post-graduate courses to get a doctor's degree. On December 11, 2006 EDO «GIDROPRESS» got a license that gives it the right to work in the field of post-graduate education. The council of Doctors of Science was set up to award a degree of a Candidate of Science in engineering that comprises. The post-graduate education envisages training in the following aspects of nuclear engineering:

- «Reactor construction, machines, units and processes for materials in nuclear engineering»;
- «Nuclear power plants, their designing, operation and decommissioning».

Every year 10 people take up the post-graduate course in EDO «GIDROPRESS».

6. Popularization of engineering art

Young engineers from EDO «GIDROPRESS» actively participate in conferences, seminars and meetings at regional, all-Russia and international level. It enhances the engineering art and the attractiveness of the work of a skilled engineer and creates interest in the carrier of an engineer among youngsters.

A Conference of young specialists has been arranged at EDO «GIDROPRESS» since 1999 where young engineers, students and post-graduate students coming from the enterprise and the leading universities of Russia make their presentations. The conference gives them an opportunity to show the creativity and a capability to solve complex and off-standard problems. Winners of the conference are determined by the results of the presentations. Top management and administration of the enterprise gives them prizes and later promotes them. In 2007 three additional promotional prizes were set up to encourage the young engineers. S.L.Lyakishev, a design engineer who was the winner of the Conference was sent to international conference of young engineers in power industry (IYCE 2007), that took place in Budapest in 2007.

It is a tradition to host the «International seminar on horizontal steam generators» and «The Scientific and Technical Conference on Safety Assurance of NPPs with VVER » at EDO «GIDROPRESS». A specific feature of these actions is the integration of generations because they are joint efforts of work teams of experienced specialists and the new generation of engineers.

Since 2003 the specialists of EDO «GIDROPRESS» have actively participated in all-Russian competition «Engineer of the year» that is sponsored by the Russian Union of scientific and engineering organizations. The Competition had a few nominations including the nomination «Nuclear power engineering» and in two versions:

- «Engineering art of the young» - for engineers aged below 30.
- «Honoured engineers» for specialists aged above 30 who have worked as engineers for more than 5 years.

For the period of participation in the competition 2 specialists of EDO «GIDROPRESS» became the laureates in the nomination «Engineering art of the young», 1 engineer was awarded in the nomination «Engineer of the year» among qualified engineers and

4 specialists from EDO «GIDROPRESS» got the diplomas of Honoured engineer in the nomination «Nuclear power engineering».

7. The results of quality management policy of EDO «GIDROPRESS»

It was stated above that the peculiarity of the early 90-ies was a decay in many branches of the Russian national economics. Nuclear power industry was unfortunately incapable to avoid it, too. A lot of educated, efficient and skilled specialists, most of them young and efficient people, left their work in nuclear industry enterprises, including EDO «GIDROPRESS» for other activities that were far from NPP designing and as a result of it ageing of the personnel at the enterprise can be observed. In order not to lose the experience gained by a few generations of nuclear power engineers a reserve was formed from the key experts who possess critical knowledge. The reserve is expanded by young engineers of new generations. Thus, no trends in the activities of EDO «GIDROPRESS» were lost.

As the socio-economic situation in the Russian Federation changed for the better, young engineers began joining the work team of EDO «GIDROPRESS». It became possible thanks to a consistent personnel management policy of the enterprise in personnel selection, adaptation and training to improve the qualification of young specialists and opening up the prospect for their carrier. In 1996 the average age of the employees was 50 years and beginning with 2001 it has been 46 years.

Today EDO «GIDROPRESS» is staffed with qualified personnel and has designs to work on for the future, which permits to offer Russian and international partners projects of advanced reactors and equipment. The designs have accumulated the 60 year experience of design activities, analytical, theoretical and experimental substantiation of design solutions and engineering judgment in developing the equipment for different types of reactors for NPPs. The designs were developed on the basis of up-to-date regulatory documentation of the RF with account for its development and with account for the international requirements and recommendations of the International Atomic Energy Agency (IAEA), European Utility Requirements (EUR) and publications of International Nuclear Safety Advisory Group (INSAG). The latest generation of improved reactors ensures a high and qualitatively new safety level.

8. Conclusions

Nuclear technologies go through the period of active development today. Nuclear power engineering has experienced stagnation not only in Russia but also in a number of the countries in the world. Unfortunately, the knowledge in the field of nuclear power engineering was not much in demand at that time and the problem of nuclear knowledge management is quite acute for further existence and successful development of nuclear engineering. Under the circumstances EDO «GIDROPRESS» works in mastering the up-to-date approaches and methodologies in the field of nuclear knowledge management and retention and to offer the world community their experience in retaining the qualified personnel of the enterprise.
To improve the efficiency of operation EDO «GIDROPRESS» plans to use international experience as well as the guides issued under the auspices of IAEA in issues covering the nuclear knowledge management and participate in educational programmes of IAEA devoted to NKM.

EDO «GIDROPRESS» plans to participate in the work of international conferences, meetings and forums on issues of nuclear knowledge management and retention. The representatives of our organization are ready to take part in technical meetings on the exchange in experience of nuclear knowledge retention, improvement of the skill of the personnel in scientific and design organizations and preparation of appropriate regulatory guides.

THE CURRENT CONDITIONS FOR TRAINING OF NUCLEAR POWER PLANT PERSONNEL IN HUNGARY

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ABSTRACT

The state owned Paks NPP Ltd. as a unit of the Hungarian Power Utilities (MVM) Group since 2005 has recently had to meet challenges such as the strengthening on the liberalized energy markets, the drastic increase of competitiveness and the difficulties of manpower supply appearing due to the 25 years of plant history.

To correct the current situation the MVM Holding and of course Paks NPP Ltd. therewithin intend to make multi-level measures to not only reverse the negative tendencies but to give a boost for necessary development actions.

Despite the general problems with skilled personnel training so typical to the energy industry, the in-site training system together with the required infrastructure operate with uniquely good conditions and at high quality.

1. Introduction

The only commercial nuclear power plant of Hungary has been in service since 1982. The four WWER-440 design units with their nearly 40% representation play a decisive role in the domestic electric energy supply. As a result of every effort of the country, the Russian-design reactors have always operated with high safety and availability indicators.

Among the most spectacular results of the on-going refurbishment programs, the most important ones are the reactor power uprating (2 out of 4 reactors run with 510 MWe, while the other 2 at 470 MWe output) currently underway and the extension of the unit service times with additional 20 years is just right in the last phase of the licensing process. Additionally, the 74% public acceptance of nuclear in the country is a promising condition to give space for two new units at the Paks site estimated to accrue around 2020.

2. Description of the training organization and infrastructure at Paks NPP

The Paks NPP as the sole nuclear utility in the country maintains its own training organization and infrastructure primarily mandated to provide all required special qualifications for both the plant staff and the employees of its contractors performing work within the site.

The plant's training system along with its supporting infrastructure – considering the special Hungarian environment – have developed more or less in consonance with the global nuclear expectations. While at the end of the 70s and the beginning of 80s, the first generation of operators received their initial training abroad, only those were allowed to participate in the commissioning and start-up of unit 1 in 1982 who had attended the internal courses and passed the corporate exams.

Further important milestones of the development are represented by the inauguration of the first training centre building suitable primarily for the training of operators in 1986, the full-scope replica simulator in 1988 and for the last, the Maintenance Performance Improvement Centre in 1997, respectively. The latter have been completed in frame of an IAEA sponsored project which – while before that the Paks development programs had attempted to cope with the always more and more stringent international expectations – appeared to have set a good example and represent vision from many aspects for all the other nuclear training centres. As the results accomplished by the project, not only a unique maintenance training centre facility has been constructed but also the existing training system has been completely recomposed according to the principles of Systematic Approach to Training.

The plant and the training organisation has always turned much attention to continuously improve the means of training. Among the modifications implemented in the full-scope simulator, the reactor protection system refurbishment was the most significant (making the Paks units the first to have digital reactor protection system applied), where the simulator – after meeting all conditions – has not only been used for testing but also had served before as a developers' environment for the project.
The currently running reactor uprating project requires replacement of further basic hardware and software equipment and the balance of plant upgrading necessitated by the service time extension of the Paks units envisages the construction of a completely new full-scope simulator.

The exclusive feature of the Maintenance Performance Improvement Centre (MPIC) created to respond to maintenance training needs is primarily the training oriented placement and use of real primary circuit main components (reactor, steam generator, reactor coolant pump, etc.). The initial and once for a lifetime fortune that these equipment were imported from Zarnowiecz of Poland and Greifswald of Germany established only a framework for using the MPIC. The real value of the installation – all in all – are the SAT-based training programs tailored to maintenance job-positions, the extremely well prepared instructor staff and the new culture of initial- and continuing training, making the best of the opportunities with an intensity never experienced in the maintenance area before.

The training, training organization and development roles are played by a department with somewhat 50 persons with a representation of nearly 20 full-time instructors. Besides, approximately 40 additional staff members play – with more or less frequency – part time training roles. Unlike in the general practice, full time instructors are required to have nuclear professional history providing them with proper skills and prestige in addition to a so called 'Qualified Nuclear Power Plant Instructor' certificate to be held by both full- as well as part time instructors. This is a program of about six months of initial and annual continuing training that involves a university (Technical University of Budapest – Faculty of Ergonomics and Psychology) focusing on pedagogy, methodology as well as transfer of knowledge and skills in training of adults and presentation, available for 8 years.

3. Human resource management aspects

The state-owned Paks Nuclear Power Plant until the end of the 1990s has taken human resource management with ease and comfort. As the only but securely marketable product of the plant has always been and is electric energy, its managers and professionals have never been expected to function day-by-day in an innovative, competitive environment as the other players of the market. Besides, in the "rural environment" – as required in the early years – striving for self-supply, the plant has maintained staff for many fields of services (IT, engineering support, vocational secondary and high-school, security, transports, industrial medical services, water sports centre, etc.). The relatively low production cost of the electric energy generated in Paks as well as the lack of competition environment has not necessitated any downsizing for long. At the beginning of the millennia though, the plant's HR policy was strongly affected by the earnest of the energy market liberalization as well as by labour-, taxation and retirement laws. The increase of efficiency and cutting production costs there within stepped into the front light with much emphasis. After 2005 – as an affiliate of the MVM-holding - for the foundation of the long-term objectives and as a response to market challenges, the program of efficiency increase became even more definitive.

Considering the high mean age of the plant personnel, the headcount rationalization currently underway can practically be managed by retirements. This - painless as it is – solution generates difficulties in workforce provision and knowledge management. Since the beginning of the 1990s, the headcount of Paks NPP has continuously been decreasing and this phenomenon in response to actions of the past years have considerably accelerated. Besides the conscious downsizing, the very low rate of fluctuating manpower results, that the amount of professionals to be replaced is minimal.

4. The needs of Paks NPP for professionals

The direct need of an operating nuclear power plant for supply of professional is generally low which is especially true as there is a program of many years targeted to increase organizational efficiency. The first unit of Paks NPP has been operating for more than 25 years therefore the mean age of the personnel is fairly high. Out of the annual retired staff only 2/3 is replaced with new hires. The tasks of the not-replaced retired staff members are handled with internal reorganization or if necessary with cross-training. Thus, typical to the posts that remain to be filled in with fresh supply, that diverse academic education/qualifications are required. The need for new headcount in the specific areas or professions is 1-2 per year typically in more fortunate situations a maximum of 5-10. These figures themselves are not a problem with the plant as the resources of this low headcount are most certainly available in the labour market.

The problem is with the schools and institutes developing young professionals or graduates, whether or not they can or dare maintain classes or faculties specializing in nuclear with these low volume needs. Should this phenomenon reside for many years the situation may evolve to the obvious conclusion that the vocational schools and universities shall lose their knowledge base and skills to teach on disciplines in the non-sustainable areas.
If the universities' scientific labs fade away, that would very fast affect to the performance of the complete scientific- and industrial support in service for the power plant. The situation above was analyzed from the plant's point of view however, similar conditions can be identified from the aspects of other players of the Hungarian nuclear area, let it be a research institute or regulatory organization.

5. Options that can help manage the problems of supply of professional sin the Hungarian nuclear area

The proper response to the above challenges must be found in a short period. The MVM-group and the Paks NPP Ltd. therewithin intends to bring in a multi-level series of actions to initiate the mitigation of these negative tendencies and to give a kick to the necessary development for the secondary and higher level education as well as in the area of adult training.

The basic principles of this package of actions are the following:

- The problems of the nuclear area must be addressed and resolved as part of the energy sector.
- The planned actions must be based on a declared and approved medium-term Hungarian energy- and the associated development strategy.
- The academic education and training capacities must be calculated on the basis of the medium-term needs of the absorbing market (energy- and nuclear installations, schools, research institutes, authorities and background design, fabrication, installation, etc. industry)
- In the reformed national vocational and higher education system, the opportunity of cross-region enforcement of interests of the sector must be found.
- Actions must cover the complete education spectrum, from hiring into vocational schools to mastering.
- At last, spheres of interests must be identified along which willingness to finance medium-term accomplishment of goals for the provision of professional to the energy sector - both on a state- and private investors' level – is showing.

6. Actions underway

The Paks NPP Ltd. is determined to further strengthen its corporate, internal training system and while retaining its values, to improve its functioning and increase its efficiency to meet the expectations of the changing environment.

Within that a significantly higher emphasis is placed on the training of the contractors' employees. In the new training system under construction the most important goal is to rigorously retain the high requirements but the modular structure and the partial qualifications concentrating on particular task groups shall allow a higher flexibility and cost-efficiency for both the training organization and the partners.

In Paks, there has been a secondary vocational school specializing in energetic fields since 1985. The school, run basically on plant support but operated by a foundation indeed used to be the primary resource of professional to meet the needs of the plant. The stagnating and later, the decreasing recruitment needs has had its kickback on this excellent education institute also which has more and more changed its profile to include curricula without direct relevance to the energy industry. To cure this problem, with agreement of the management of the MVM and the Paks NPP, the operating organization was renewed in 2007, which immediately developed a brand new medium-term concept. Its essence is that the school must be developed to become a national centre for secondary vocational education in energetic studies. For this goal, the Pask plant shall continue to provide basic financing support but the school must build a live and vivid relationship with the affiliates of MVM and the Suppliers, extending the scope of opportunities for skills training and building closer ties between the student and the potential employers. An important item of the concept is the description of employment and career opportunities provided by and the increase of popularity of the energy sector.

The plant maintains a traditionally good relationship with institutes of the higher academic education moreover the Technical University of Budapest has operated a branch faculty in Paks for 15 years specializing in energy sector studies. Co-operation agreements are in place to be the framework for bringing the needs of both the universities representing the basic resources of engineer supply on the most critical areas and of the plant closer, as well as to build relationships.

Among the contents of these agreements it should be highlighted that 15 out of the students of the Technical University of Budapest, are awarded by the plant with scholarship. It should be noted that these bilateral relationships and the fiscal support made available by the plant themselves are insufficient to maintain great and expensive laboratories, workshops or the study reactor operated at the Technical University of Budapest therefore, the financing of such features must be placed on a different basis according to the above principles.

Taming the Chernobyl Avalanche

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ABSTRACT

The neutron kinetics equations are one of the cornerstones of the theory of nuclear reactors. The awareness of the nuclear engineering students of its importance is a precondition that the new generation will handle the presently operating and future nuclear power plants safely. They have to learn how to design control systems for reactors with an inclination to an avalanche like power increase.

The classical neutron kinetic equations with six delayed groups are not solved analytically. Here they are solved both numerically and with a corresponding block diagram and applied for a Chernobyl type reactor. The results are displayed graphically.

The Chernobyl type reactors have positive void coefficients. When water is replaced with steam the power is increasing. A sudden increase of the steam content causes a rapid power increase.

The importance of choosing the magnitude of the void coefficient and the parameters for the automatic control system is demonstrated.

1. Introduction

Now, 22 years after the Chernobyl accident it is important for today's and tomorrow's generations of nuclear engineers to learn to design control systems for reactor with runaway characteristics.

The Chernobyl type of reactor (RBKM) core is a huge graphite cylinder (7 m high, 12 m diameter) and within some 1600 channels with water and steam cooled fuel rods inside. The fission neutrons are slowed down (thermalised) mainly in the graphite and a portion of them is absorbed in the water. When a part of the water is replaced by steam (void) the absorption becomes less, causing a positive reactivity contribution. This is the positive void coefficient. After the accident the enrichment of the fuel was increased the neutron spectrum became harder resulting in a lower positive void coefficient

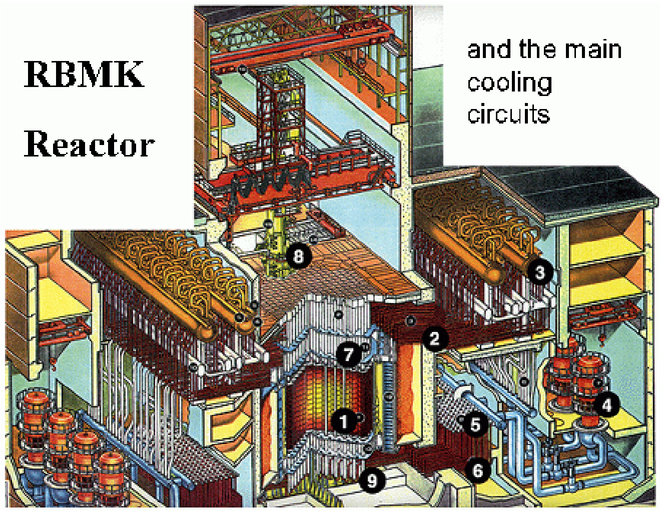

Figure 1, the Chernobyl Reactor

2. The experiment

At the Chernobyl experiment due to the abrupt decrease of the speed of the main circulation pumps and the sudden drop of the reactor pressure at low reactor power and heavy Xenon poisoning the steam (void) content in the coolant channels increased suddenly from a few percent to about 50%. Thus the positive void coefficient - about 30 pcm/% - caused a large reactivity insertion.

The neutron flux and thereby the reactor power increased very fast. Due to the thermal inertia of the fuel and the small value of the fuel temperature coefficient the Doppler effect could not break the power excursion. Therefore, to characterize the process at the initial phase, to use only the reactor kinetics equations is sufficient.

3. The simplified neutron kinetics equations

$$\frac{dN}{dt}=\frac{\delta k-\beta}{l}N+\sum_{i=1}^{6}\lambda_i c_i \qquad \text{and} \qquad \frac{dc_i}{dt}=\frac{\beta_i}{l}N-\lambda_i c_i$$

Here
t time (sec)
N neutron flux (proportional to the reactor power)
δk change of the effective neutron multiplication factor (k_{eff})
ß sum of the delayed neutron fractions (here 0.006502)
$ß_i$ the i:th delayed neutron fraction
l neutron mean lifetime (here 0.001 sec)
λ_i i:th decay constant (sec^{-1})
c_i concentration of the i:th fraction of the delayed neutrons' precursors,
At steady state, when time is zero t=0 all time derivatives are equal to zero, all d/dt=0 and the initial value of the relative power equals unity N(0)=1, and also no reactivity perturbation is present $\delta k=0$

$$N(0)=1 \qquad \frac{dN}{dt}=0 \qquad \delta k=0 \qquad \sum_{i=1}^{6}\lambda_i c_i=\frac{\beta}{l} \qquad \frac{dc_i}{dt}=0 \qquad c_i(0)=\frac{\beta_i}{l\,\lambda_i}$$

Delayed neutron data for thermal fission in U^{235} is used

Group	1	2	3	4	5	6
Fraction ßi	0.000215	0.001424	0.001274	0.002568	0.000748	0.000273
Decay constant λ_i	0.0124	0.0305	0.111	0.301	1.14	3.01

The initial values of the delayed neutrons' precursors are;

i	1	2	3	4	5	6
$c_i(0)$	17.3387	46.6885	11.4775	8.5316	0.6561	0.0907

4. Using the MATLAB notations

x(1)=N x(2)=c_1 ………… x(7)=c_6 the code is

```
%Save as xprim7A.m
function xprim =xprim7A(t,x,i)
```

```
DeltaK=i*0.010*0.50; %voidcoef=i*0.010pcm/percent void change, void increase 50percent
xprim=[(DeltaK/0.001-
6.502)*x(1)+0.0124*x(2)+0.0305*x(3)+0.111*x(4)+0.301*x(5)+1.14*x(6)+3.01*x(7);
0.2150*x(1)-0.0124*x(2);
1.4240*x(1)-0.0305*x(3);
1.2740*x(1)-0.1110*x(4);
2.5680*x(1)-0.3010*x(5);
0.7480*x(1)-1.1400*x(6);
0.2730*x(1)-3.0100*x(7)];
```

To study the importance of the magnitude of the void coefficient, it is enough to plot the first colon of the xmatrix. The rows of the x matrix are the time steps.

```
%Save as ReaktorKinA.m
figure
hold on
for i=0:1:3
[t,x]=ode45(@xprim7A,[0 0.2],[1; 17.3387; 46.6885; 11.4775; 8.5316; 0.6561; 0.0907],[] ,i);
plot(t,x(:,1))
end
hold off
```

5. The result

Is given in the following plot;

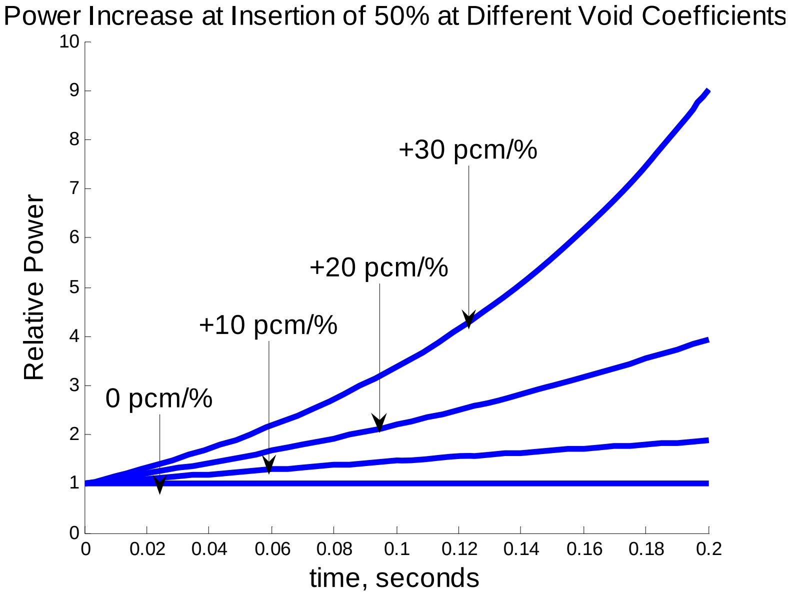

Figure2. Power Increase at the Insertion of 50% Void at Different Void Coefficients

6. Block diagram

Using the same parameters a block diagram is created here with SIMULINK

Delayed group 1
Gain1A = 0.2150 Gain1B = 0.0124 Gain1C = 0 0.0124 Integrator1 = 17.3387 (is the initial value of the first delayed group)

Delayed group 2
Gain 2A = …………………….

GainN = -1.502 [= 6.502 – 5 (= the void reactivity perturbation)]
IntegratorN = 1 (is the initial value of N)

The controller is represented with a zero pole block; (s – 1)/s(s – 1)
Here are the; zeros: [1], poles: [0 1], gain: [1]
Here the absorber rods are represented with an amplifier, the gain is 50

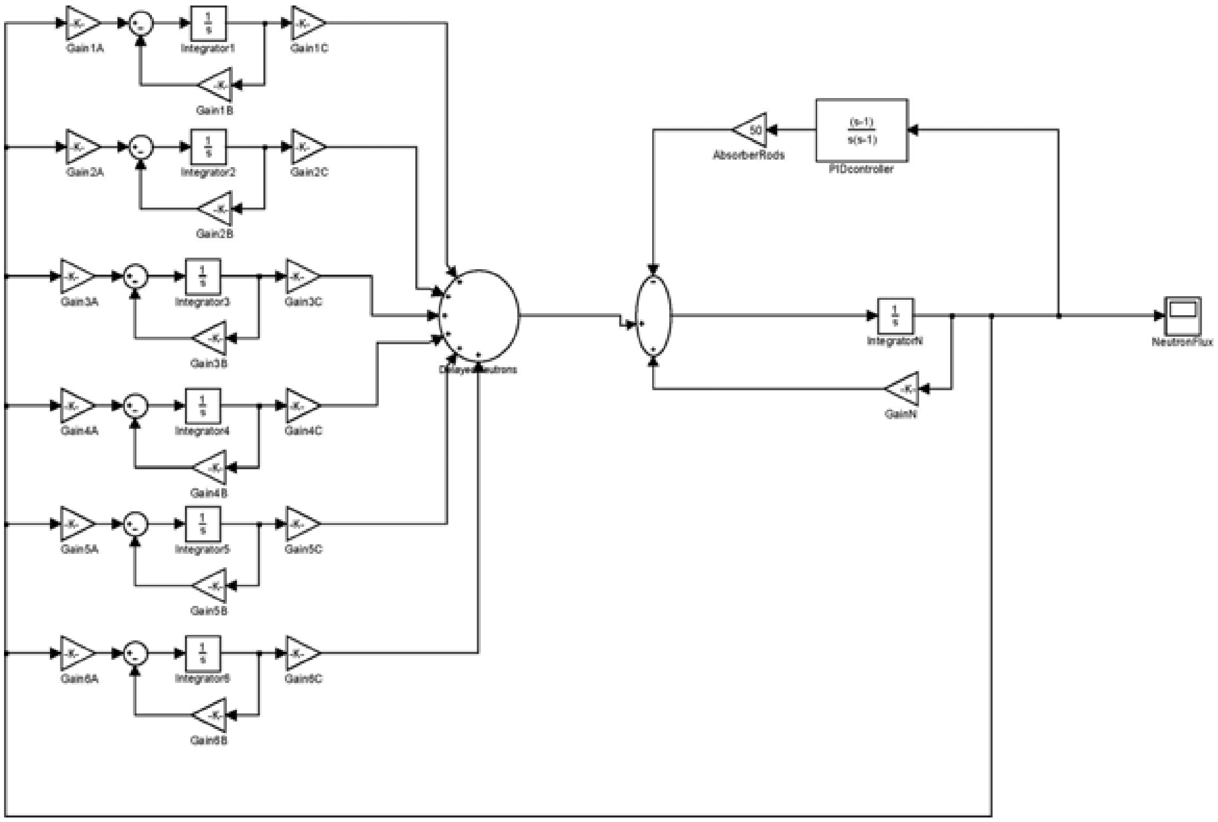

Figure 3. Block diagram of the neutron kinetics (with six delayed groups) and the automatic control system with a PID (Proportional and Integrating “1/s” and Differentiating “s”) controller

In this case study, a 10 % pcm/% void coefficient is used and the perturbation is as earlier 50% void increase. The system response without an automatic control system is like an avalanche

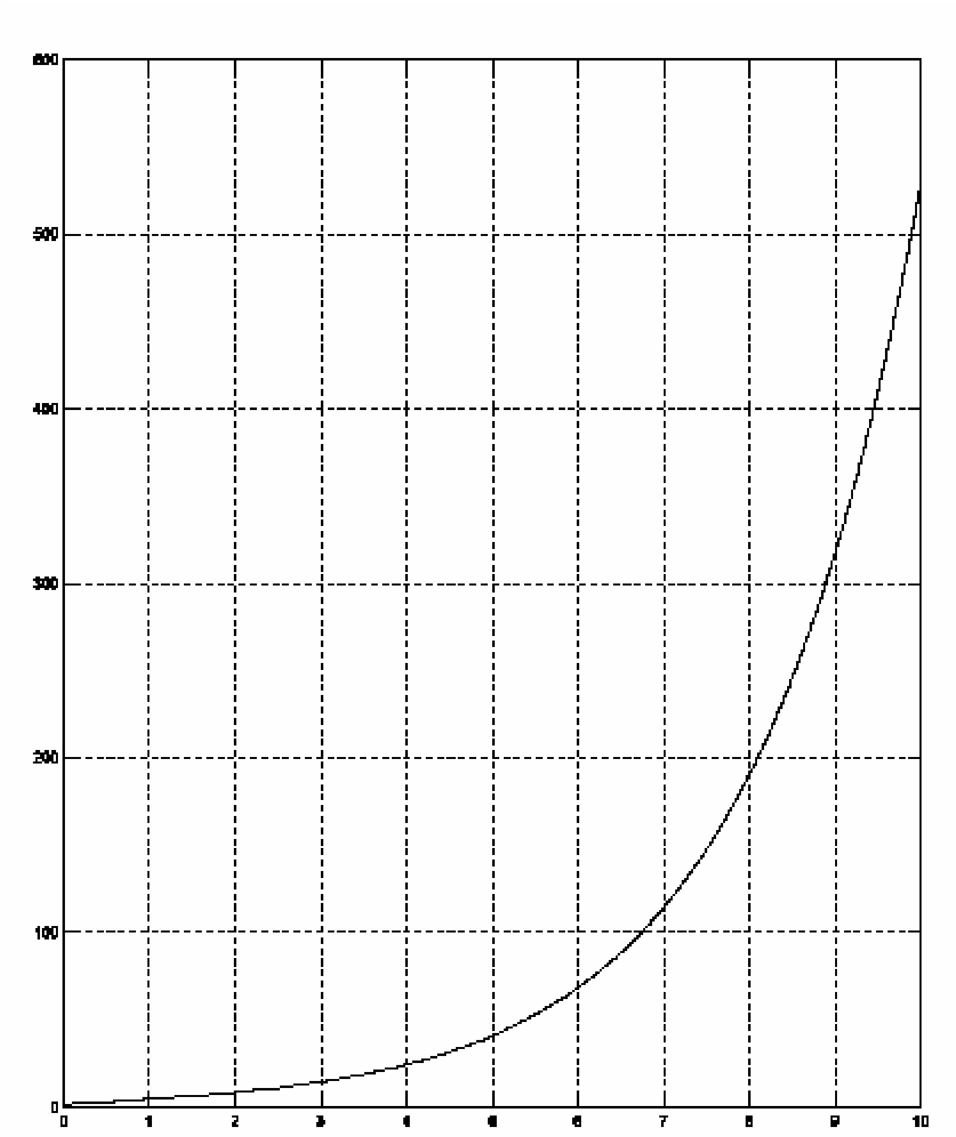

Figure 4. System response **without** an effective automatic control system.
Relative neutron flux (Power) vs. time (sec)

There is of course no construction which can take a 500 times power increase in 10 seconds. At the Chernobyl accident the result was a disaster with and elapsed time much shorter than 10 sec.

7. Automatic control

In theory one can specify a control system and a connected absorber rod actuator to team this transient. To achieve this, the control action must be extremely fast and must start effectively within a fraction of a second. However to realize a mechanical absorber rod operating device with the required speed is very difficult. For this example a PID controller is chosen and the absorber rods are represented with an amplifier which follows the output of the controller. The result is quit reasonable.

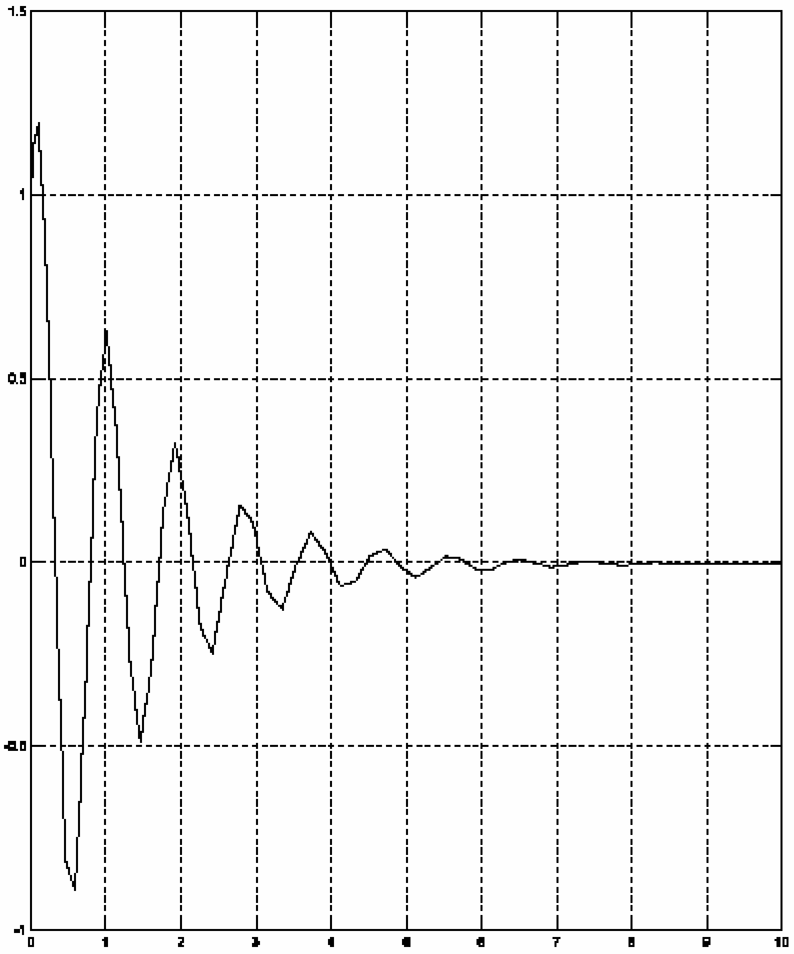

Figure 5. System response **with** an automatic control system (PID).
Relative neutron flux (Power) vs. time (sec)

The Chernobyl disaster demands many analyses to really understand what happened there and how to avoid anything similar in the future. This article is such a one.

8. References

University textbooks on nuclear engineering contain the applied equations. Textbooks on information technology and numerical analyses contain the applied methods.

To be published, ENS 2008
Computing the Chernobyl Avalanche
Calculation of the neutron flux, fuel and moderator temperature transients for Research Reactors
Proceeding of the NEST^{et}, Nuclear Engineering Science and Technology, energy technology
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ENS news, Issue: 2006/13, Neutron Kinetics of the Chernobyl Accident
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NUCLEONICA SCRIPTING

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ABSTRACT

An overview of the Nucleonica scripting language and module is presented. A detailed case study on targeted alpha therapy is described which demonstrates powerful features of Nucleonica for modelling experiments through the use of batch scripts.

1. Introduction

Nucleonica applications are designed to be very user friendly, intuitive, and require a minimum of learning time [1,2]. For users, who prefer a more “hands on” approach, Nucleonica provides this with its scripting module. Scripting refers to a programming task, in which pre-existing components or applications are connected to accomplish a new task. In accordance with this definition, the Nucleonica scripting gives the user a powerful programming interface through which he/she can access basic nuclear data and run all the Nucleonica applications.

2. The Scripting Language in Nucleonica

The Nucleonica scripting is an easy-to-use physically intuitive object oriented programming language. The basics of the language, such as variable types (*int*, *double*, *string* or arrays), logical (&&, ||) and mathematical (+, -, *, /, %) operators, control structures (*for* and *while* loops, *if* statements) and built-in functions (*sin*, *log*, *print*, *abs*, *exp*, *sqrt, pow* etc.), are described in detail in the respective section of the Nucleonica wiki [3]. This wiki also serves as an on-line reference on the features of the implemented classes, their properties and methods. With ready-to-use examples and pre-defined scripts, which are largely enriched with comments and explanations, users can easily learn the language and save the time when developing their own scripts. The basic components of the language (classes) are summarised in Table 1.

Class	Main methods	Related applications	Related classes
nuclide, *vnuclide*	*Decay()*	*Decay Engine*	*decayResult*
	Dosimetry()	*Dosimetry and Shielding*	*doseResult*
	DecayInfo()	*Nucleonica database*	*decayInfo*
	Radiations()	*Nucleonica database*	*radiations*
range	*CalculateMono()*	*Range and Stopping Power*	*rangeResult*
	CalculateCompound()	*Range and Stopping Power*	*rangeResult*
transport	*Calculate()*	*Transport and Packaging*	*transportResult*
korigen	*callKorigen*	*webKORIGEN*	*korigenResult*

Tab 1: Basic components of the Nucleonica scripting language

In the script, the classes are instantiated through the objects which provide access to specific properties (*object.property*) and methods (*object.method(parameterlist)*). The *nuclide* class is of the central importance in the Nucleonica scripting, as it gives access to all basic properties of nuclides and implements the most important Nucleonica applications, such as “Decay Engine” and “Dosimetry and Shielding”. The *nuclide* class is instantiated in two steps. First, the *nuclide* object is declared and, then, its properties are initialized using the *Create()* method:

```
nuclide Th232;                  // Declare the nuclide object with name Th232
Th232.Create("Th", 232, 0);     // Get properties of Th-232 from the Nucleonica database
```

Three parameters of the *Create()* method define a nuclide of interest, i.e. specific element, isotope and isomeric state (0 refers to the nuclide's ground state). Once the *nuclide* object is created, one can use its properties and methods to access and manipulate the related nuclear data. For example, the *Th232.Halflife* property returns the half-life of ^{232}Th, and the *Th232.Activity(amount, fromQuantity, toQuantity)* method converts given amount of ^{232}Th between different quantities (activity, mass, number of atoms) and measurement units (e.g. Bequerels, Curies).

Using the *print()* function, which accepts a string as an input parameter, one can readily display the nuclide properties in the script output window. As shown in the following examples, the string to be displayed can be composed by the concatenation of ordinary strings and implicitly or explicitly (using *format()* function) converted numerical values (“+” serves as the concatenation operator):

```
// the integer atomic number Z is converted implicitly to a character string
print("Atomic number of Th-232 = " + Th232.Z);
// the explicitly formatted atomic mass (AWR_C12) shows 3 digits after the decimal point
print("Atomic mass of Th-232 = " + format(Th232.AWR_C12, "0.000") + " a.m.u.");
// the decay constant (natural log(2) divided by the half-life) is shown in scientific notation
print("Decay constant of Th-232 = "+format(log(2)/Th232.Halflife,"0.00E+00")+" per sec");
```

More specific nuclear data can be retrieved from the Nucleonica database using the *nuclide.DecayInfo(daughterIndex)* and *nuclide.Radiations(RadiationType)* methods. The *DecayInfo()* method retrieves decay data for a specified daughter nuclide in the nuclide’s decay chain, which are returned as properties (such as *BranchingRatio*, *Energy, DecayMode*) of the *decayInfo* object. The *Radiations()* method returns the list of energies and per-decay emission probabilities for the decay radiations of the requested type (α, β, γ, n, p, spontaneous fission fragments, discrete energy electrons, X-rays or annihilation photons) emitted in the decay of the given nuclide.

Among other *nuclide* object methods, the *nuclide.Decay()* method allows the user to perform radioactive decay calculations. Through its extensive lists of input and output parameters, the method provides the full functionality and flexibility of the respective Nucleonica Decay Engine application. The input parameters include the amount of the nuclide, the length of the time interval, the number of time steps, the accuracy of the calculation, and 15 additional options specifying the list of the target quantities (such as, gamma emission rate, ingestion and inhalation radiotoxicities, α, $\alpha+\beta$, and $\alpha+\beta+\gamma$ isotopic powers etc.), which are required in the calculation output. The results of the decay calculations are returned in the *decayResult* object, containing an array of the cumulative (e.g. the total activity and radiotoxicity of the parent nuclide and all its decay products) and nuclide specific (for the parent and each daughter nuclide) data, evaluated for the specified points of time.

Whereas the *nuclide* represents a real physical object, the *range* object corresponds to setting up an experiment. Through the *range.CalculateMono()* method, one can calculate the range and stopping power for the specified projectile type and single element target. To define the "experimental setup", the method uses 7 parameters, namely: 1) the type of the projectile (e.g., 2 – protons, 7 – other ions); 2) the projectile material index, if projectile type is 7; 3) the projectile energy; 4) the energy units (e.g., 0 means MeV); 5) the atomic number of the target element; 6) the density of the target material; and 7) the physical state of the target (e.g., 0 - for solids and liquids). The results of the calculation are returned in the *rangeResult* object, which, first, has to be created, as shown in the following example:

```
range ProtonsInTh;                    // Declare the range object for protons in thorium
rangeResult Range_Results;            // Declare the rangeResult object
// Calculate the range and stopping power for 33.5 MeV protons in the thorium target
Range_Results = ProtonsInTh.CalculateMono(2,0,33.5,0,Th232.Z,Th232.Density,0);
```

In addition to the built-in functions, user-defined functions, e.g. for numerical integration, can be included in the script. The scripts can be directly entered and run in the Nucleonica source editor page. Scripts can be also developed locally on the user's computer and then uploaded, stored and run in the server. The stored scripts can be further modified, downloaded or distributed to other users.

3. Case Study: A Nucleonica script for ^{230}U production optimization

The isotope pair ^{230}U/^{226}Th has been recently identified [4] as being suitable for targeted alpha therapy. In the current case study, a Nucleonica script is described, which models the production of ^{230}U through the proton irradiation of natural thorium, as shown in Fig.1.

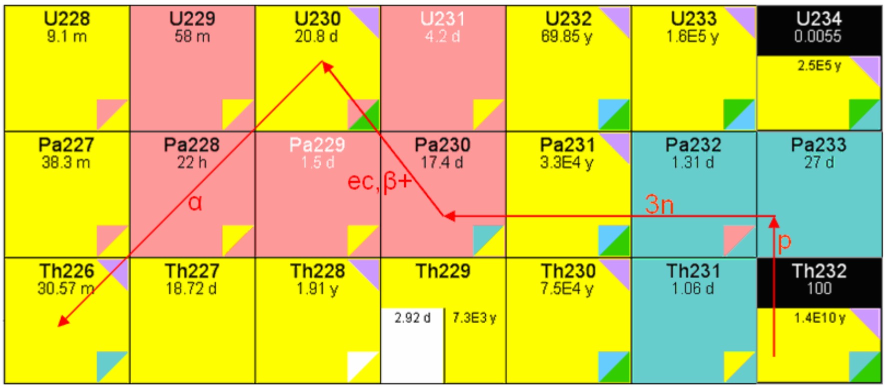

Fig.1. ^{230}U/^{226}Th production scheme: ^{230}U is accumulated in ε/β^+-decay of ^{230}Pa, produced in (p,3n)-reaction on ^{232}Th (graphic from the Nucleonica Nuclide Explorer).

In the following sections the production steps are described in detail and illustrated by the most significant lines of the script. The full script is available on the Nucleonica wiki [3].

3.1 Modelling the production of ^{230}Pa

At this stage of the experiment, the thickness of a thorium foil is the most important parameter. It determines the amount of ^{230}Pa produced at the end of the irradiation and influences the efficiency of the subsequent radiochemical separation. From the threshold behaviour of the ^{232}Th(p,3n)-reaction (see Fig.2), one can infer the lower limit of the useful energy range of protons to be $E_{min} \approx 15$ MeV. Assuming $E_{max} = 33.5$ MeV for the energy of the incident protons, the estimate for the foil thickness is then $X_{foil} = R_p(E_{max}) - R_p(E_{min}) \approx 2.23$ mm – 0.58 mm = 1.65 mm, where $R_p(E)$ is the range of protons with energy E in thorium. The respective Nucleonica script looks as follows:

```
Range_Results = ProtonsInTh.CalculateMono(2,0,33.5,0,Th232.Z,Th232.Density,0);
double Emax_Range; Emax_Range = Range_Results.ProjRange;
Range_Results = ProtonsInTh.CalculateMono(2,0,15.0,0,Th232.Z,Th232.Density,0);
double Emin_Range; Emin_Range = Range_Results.ProjRange;
double FoilThickness; FoilThickness = Emax_Range - Emin_Range;
```

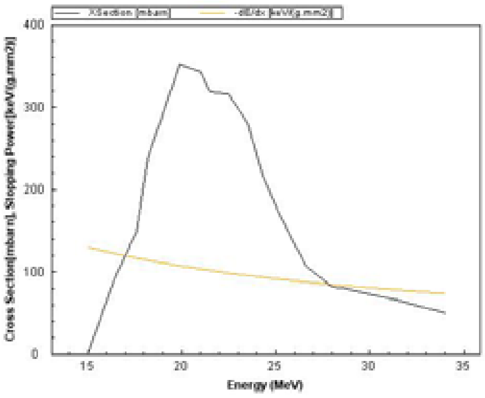

Fig.2. The experimental cross-section $\sigma(E)$ for the reaction ^{232}Th(p,3n)^{230}Pa [4] and the calculated stopping power $S(E)$ for protons in thorium as functions of the proton energy.

To calculate the amount of ^{230}Pa produced by the end of the irradiation, one needs first to evaluate the average cross-section $\langle\sigma\rangle$ for the (p,3n)-reaction. Assuming constant proton flux inside the target, one can obtain the following formula:

$$\langle\sigma\rangle = \frac{1}{X_{foil}}\int_0^{X_{foil}}\sigma(x)dx = \frac{1}{\rho X_{foil}}\int_{E_{\max}}^{E_{\min}}\sigma(E)\frac{d(\rho x)}{dE}dE = \frac{1}{\rho X_{foil}}\int_{E_{\min}}^{E_{\max}}\frac{\sigma(E)}{S(E)}dE = 163\ mb$$

where ρ - the target density, $\sigma(E)$ - the reaction cross-section and $S(E) = -dE/d(\rho x)$ - the proton stopping power as functions of proton energy E (see Fig.2). Below is a part of the user-defined function *AverageXSection*(), which implements this formula using a trapezoidal integration:

```
double AXS = 0;                                // Average cross-section
for (i = 1; i < 16; i += 1)                    // Loop on the proton energies
{  Range_Results = ProtonsInTh.CalculateMono(2,0,pE[i-1],0,Th232.Z,Th232.Density,0);
   double F_Emin; F_Emin = XSection[i-1] / Range_Results.STotal;
   Range_Results = ProtonsInTh.CalculateMono(2,0,pE[i],0,Th232.Z,Th232.Density,0);
   double F_Emax; F_Emax = XSection[i] / Range_Results.STotal;
   AXS += (F_Emin + F_Emax) * (E[i] - E[i-1]) / 2;  }
AXS = AXS / (FoilThickness*Th232.Density);     // Final normalization
```

Here, *E*[] and *XSection*[] are the proton energy and reaction cross-section arrays respectively, *STotal* is the property of the *rangeResult* object giving the value of the total stopping power. Having evaluated the average cross-section, one can easily calculate the production rate of ^{230}Pa as $R_{Pa\text{-}230} = N_{Th}\,\langle\sigma\rangle\,X_{foil}\,I = 1.0\cdot10^{12}\ \mathrm{s}^{-1}$, assuming the atomic density $N_{Th} = 3.04\cdot10^{22}\ \mathrm{cm}^{-3}$ and the proton current $I = 200\ \mu\mathrm{A}$.

Once the production rate of ^{230}Pa is known, the amounts of ^{230}Pa and ^{230}U, obtained by the end of the irradiation period, can be evaluated. Using Bateman's analytical solution for the system of differential equations, governing the nuclide decay and buildup, one can obtain:

$$A_{Pa}(t) = R_{Pa-230}(1-e^{-k_{Pa}t}), \qquad A_U(t) = R_{Pa-230}\frac{k_U\cdot k_{Pa}\cdot BR_{Pa,U}}{k_U - k_{Pa}}\left(\frac{1-e^{-k_{Pa}t}}{k_{Pa}} - \frac{1-e^{-k_U t}}{k_U}\right),$$

where $A_{Pa}(t)$ and $A_U(t)$ - the activities of ^{230}Pa and ^{230}U at time t, k_{Pa} and k_U - the decay constants of ^{230}Pa and ^{230}U, and $BR_{Pa,U}$ - the branching ratio for the decay of ^{230}Pa to ^{230}U. In the script, these quantities are calculated by the user function *Production*():

```
for (t = 0; t <= time; t += time/10)          // loop over 10 time steps from 0 h to 50 h
{  APa = R_Pa230 * (1 - exp(-kPa * t));
   AU = R_Pa230*kU*kPa*BR_PaU * ((1-exp(-kPa*t))/kPa-(1-exp(-kU*t))/kU) / (kU – kPa);
   print("" + (t/3600) + ", " + (APa) + ", " + (AU));  }
```

In addition, the function outputs the results in a form suitable for the Nucleonica graph module (see Fig.3). The calculations show that, by the end of the 50 h irradiation, 80.5 GBq of ^{230}Pa together with 0.23 GBq of ^{230}U are produced.

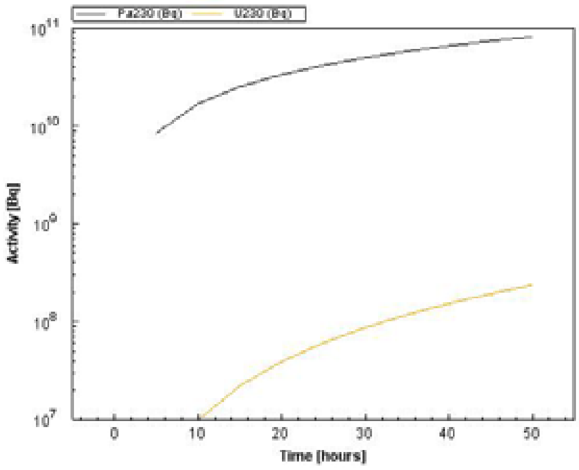

Fig 3. The production dynamics of ^{230}Pa and ^{230}U during 50 h proton activation of the Th foil

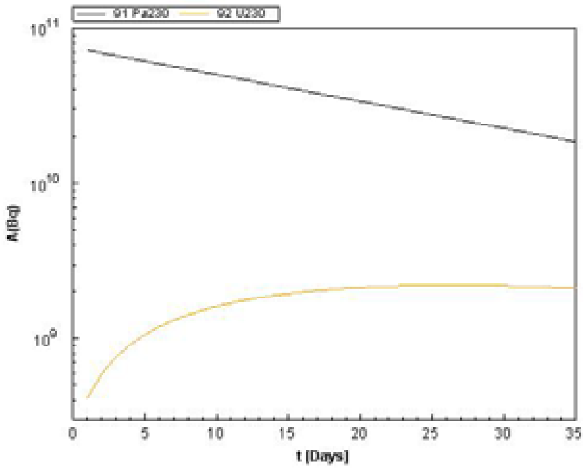

Fig 4. The 35-day-dynamics of ^{230}U accumulation in the decay of ^{230}Pa

3.2 Modelling the accumulation of ^{230}U

To model the accumulation of ^{230}U following the irradiation period, an object of the nuclide mixture class *vnuclide*, consisting of 80.5 GBq of ^{230}Pa and 0.23 GBq of ^{230}U, was created and the *vnuclide.Decay*() method was employed. Fig.4 demonstrates the obtained dynamics of the ^{230}U activity within the 35-day-long post-irradiation interval. One can see from the graph that the ^{230}U activity reaches its maximum in 24-30 days after the irradiation. The more accurate value t_{max} = 26.9 days for the optimum accumulation time interval has been obtained in the script by implementing the formula:

$$t_{\max} = \frac{1}{k_U - k_{Pa}} \ln\left(\frac{k_U}{k_{Pa}} + \frac{A_U(0)}{A_{Pa}(0)} \right) .$$

From Fig.4, however, it follows that the actual separation of ^{230}U can be performed up to 2 weeks earlier without a significant loss in the resulting activity of the target nuclide (compare A_U(12 day) = 1.88 GBq and $A_U(t_{max})$ = 2.34 GBq). This process of in-growth and separation can be repeated as long as significant activity of ^{230}U can be produced.

4. Conclusions

The Nucleonica scripting is an object oriented language which is based on the physically intuitive classes, methods and properties. Through the script interface the user has access to the main Nucleonica applications and nuclear data. By combining results from multiple Nucleonica applications and nuclear data, users can go beyond the conventional single-application approach for solving their specific experimental tasks and problems.

5. References

[1] J. Magill et al., Nucleonica: A Nuclear Science Portal, ENS News, Issue No.17 Summer (July 2007), see www.euronuclear.org/e-news/e-news-17/nucleonica.htm
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[3] NucleonicaWiki: see www.nucleonica.net:81/wiki/index.php/Special:Allpages/Help:
[4] A. Morgenstern et al., Appl. Rad. Isotop. 2008, in press.

USING SPREADSHEETS FOR PROMOTING STUDENT UNDERSTANDING OF LIGHT WATER REACTOR OPERATION

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ABSTRACT

There is a universal need for engineers to understand dynamic physical systems and being able to determine the outcome of such systems. The training of nuclear reactor control room staff involves the use of full-scale simulators with very accurate models of the nuclear reactor process. However, it is not feasible to use such simulators to study the underlying fundamental processes in order to help students of reactor physics to obtain an understanding of the basic principles. For this purpose simple spreadsheet simulations that illustrate different aspects of the nuclear reactor process are very useful. Using examples from courses in basic reactor physics, it is shown how Microsoft Excel can be used as a tool for the study of dynamic problems, e.g., natural circulation cool down and xenon poisoning, as well as steady state calculations of steam quality and void.

1. Introduction

Simulations and simulators are commonly used for the training of personnel required to operate complicated dynamic systems such as aircraft, ships and nuclear power plants. It is recognized that simulations allows the student of such a system to acquire an accurate mental model of the system and to become proficient in its operation. Simulators also provide a safe environment where accidents can be simulated and emergency procedures practiced. For students of physics and engineering there is a universal need to understand the basic principles governing dynamic, i.e., time-dependent physical systems and being able to determine the outcome of such systems. For this purpose, simulations on a much smaller scale can provide a useful means of promoting the understanding of basic physical principles. It is important to emphasize that in most cases, these simulations cannot stand on their own. The simulations need to be accompanied by introductory presentations of the concepts.

Given the constraints sometimes imposed by the mathematical skills of students, different softwares that facilitate the modelling and simulation of dynamical systems have been developed. One often-overlooked alternative to these softwares is to use commonly available spreadsheet programs, e.g., Microsoft Excel. The first spreadsheet program, VisiCalc by Dan Bricklin and Bob Frankston, was released to the public in 1979. The concept of a computerized accountant's grid where one could modify the content of any cell, and the entire spreadsheet would be automatically recalculated, quickly caught on and spreadsheet programs became the most commonly used tools for accounting and financial calculations. Today Microsoft Excel, which remains true to the original concept of the accountant's grid, has evolved into a powerful mathematical software that is of use in almost all fields of science and technology [1]. Although spreadsheet programs are probably not the ideal solution for any given problem, they have advantages that in many cases far outweighs the limitations:

- Spreadsheet programs do not have the steep learning curve of other more complex, and possibly more capable, software.
- Modern spreadsheet programs combine powerful calculation capabilities with very useful graphing features, which is extremely important for the visualization of results

of calculations. Custom controls, e.g., spin buttons, allow a high level of interactivity where changes in parameter values are immediately reflected in the data output.

- A spreadsheet program is almost always included in software bundles installed on personal computers giving students easy access to the software.

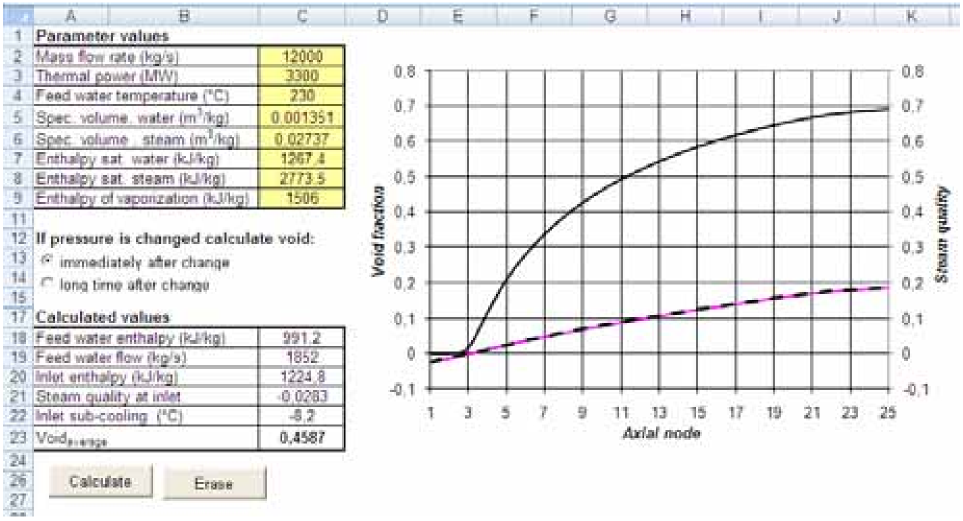
From a science education point of view spreadsheet programs can be used for many different purposes such as calculations, visualizations and also simulations of dynamic systems [2].

2. Steady state calculations

The calculation of quantities such as steam quality and void in a BWR operating at constant power involves steady state calculations, which for training purposes can be performed using spreadsheets. Spreadsheet programs are suited for the visualization of different concepts and allow a high level of interactivity allowing students to try out different “what if” scenarios.

2.1 Steady state calculation of steam quality and void in a BWR

In a BWR a complicated relationship exists between the steam quality and the resulting void fraction. Depending on whether or not the two-phase flow is considered to be in thermal equilibrium and whether or not the two phases are moving with the same velocities, several different models for calculation of the void fraction exists. From a student point-of-view it is of interest to perform calculations of steam quality and void fractions using different models in and parameter values in order to obtain an understanding of the process. The task is easily performed using spreadsheets, e.g., Excel as shown in Fig 1 where the spreadsheet itself mainly serves the purpose of visualizing the results of the calculation. Most of the calculations are performed using Visual Basics for Applications (VBA), Microsoft’s common application scripting language that is fully integrated with Excel [3].



Parameter values

Mass flow rate (kg/s)	12000
Thermal power (MW)	3300
Feed water temperature (°C)	230
Spec. volume, water (m^3/kg)	0.001351
Spec. volume , steam (m^3/kg)	0.02737
Enthalpy sat. water (kJ/kg)	1267.4
Enthalpy sat. steam (kJ/kg)	2773.5
Enthalpy of vaporization (kJ/kg)	1506

If pressure is changed calculate void:

● immediately after change
○ long time after change

Calculated values

Feed water enthalpy (kJ/kg)	991.2
Feed water flow (kg/s)	1852
Inlet enthalpy (kJ/kg)	1224.8
Steam quality at inlet	-0.0283
Inlet sub-cooling (°C)	-8.2
$\text{Void}_{\text{average}}$	0.4587

Fig 1. An example of a spreadsheet for the calculation of the axial distribution of steam quality and void fraction in a BWR for a given axial power distribution. The model used does not include sub-cooled void.

In the example the steam quality, x, and void fraction, α, are calculated assuming a thermal equilibrium model with an algebraic relationship between the velocities of water and steam, i.e., slip ratio S [4].

$$x_i = x_{i-1} + \frac{\dot{Q}_i}{\dot{m}r}, \quad a_i = \frac{1}{1 + \frac{1-x_i}{x_i}\frac{\rho_v}{\rho_l}S}, \quad \mathrm{S} = 0.93\left(\frac{\rho_\mathrm{l}}{\rho_\mathrm{v}}\right)^{0.11} + 0.07\left(\frac{\rho_\mathrm{l}}{\rho_\mathrm{v}}\right)^{0.56} \tag{1}$$

where $\dot{Q}_i$ is the nodal thermal power, $\dot{m}$ the mass flow rate and r is the enthalpy of vaporization.

3. Dynamic simulations

The simulation of a dynamic system involves the solution of differential equations. Spreadsheet programs are well suited for the purpose of solving various problems involving ordinary differential equations by means of the Euler method

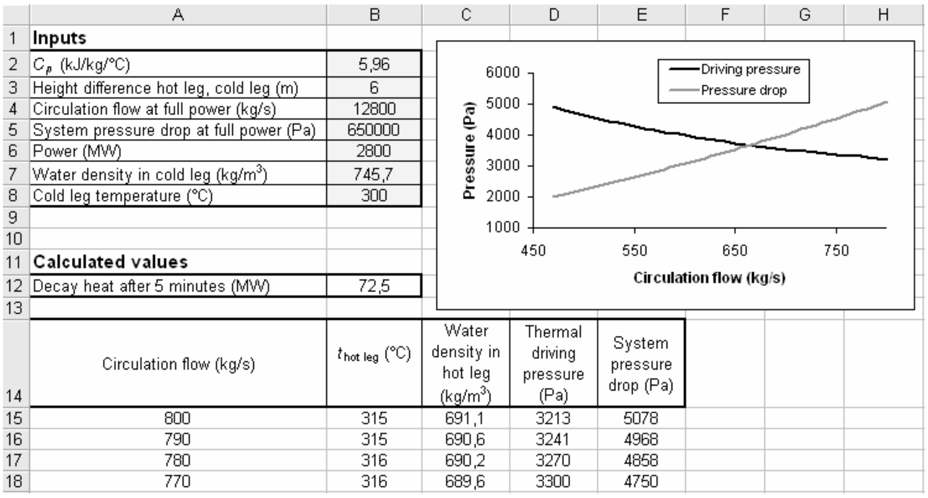
$$y_{n+1} \approx y_n + h \cdot f(x_n, y_n), \tag{2}$$

which advances the stepwise solution of an ordinary differential equation from x_n to $x_{n+1} = x_n + h$ [5]. At the expense of simplicity it is of course possible to use other solutions methods such as Runge-Kutta.

3.1 Natural circulation cooldown in a PWR-type reactor

In pressurized water nuclear reactors (PWR) the coolant water is circulated in a primary-coolant circuit consisting of the reactor core (hot leg) and steam generators (cold leg) by means of recirculation pumps. In the steam generator heat is transferred from the primary coolant to a secondary system involving a steam cycle, usually a steam turbine and a condenser.

In the event of a recirculation pump failure, an emergency stop (scram) is initiated to stop the fission process. Even after the scram, decaying fission products in the nuclear fuel will release significant amounts of decay heat to the coolant. If a temperature difference is maintained between the hot and cold legs of the primary coolant circuit, the resulting difference in density between the two areas will give rise to a thermal driving pressure causing a natural circulation flow to be established. The thermal driving pressure is balanced against the total pressure drops associated with the fluid flow in the primary coolants system.



	A	B	C	D	E
1	**Inputs**				
2	C_p (kJ/kg/°C)	5,96			
3	Height difference hot leg, cold leg (m)	6			
4	Circulation flow at full power (kg/s)	12800			
5	System pressure drop at full power (Pa)	650000			
6	Power (MW)	2800			
7	Water density in cold leg (kg/m^3)	745,7			
8	Cold leg temperature (°C)	300			
9					
10					
11	**Calculated values**				
12	Decay heat after 5 minutes (MW)	72,5			
13					
14	Circulation flow (kg/s)	$t_{\text{hot leg}}$ (°C)	Water density in hot leg (kg/m^3)	Thermal driving pressure (Pa)	System pressure drop (Pa)
15	800	315	691,1	3213	5078
16	790	315	690,6	3241	4968
17	780	316	690,2	3270	4858
18	770	316	689,6	3300	4750

Fig 2. Worksheet for the simulation of natural circulation flow in a PWR nuclear reactor following a pump failure. In this case, using typical PWR data, the natural circulation flow 5 minutes after a scram will be $\dot{m} = 660\,\text{kg/s}$.

To determine the resulting natural circulation flow rate with the thermal driving pressure balancing the total pressure drop of the primary coolant system an iterative approach is used, Fig 2:

1. Calculate the decay heat.
2. Choose an initial value for the mass flow rate $\dot{m}$.
3. Calculate the temperature of the water exiting the reactor core using

$$T_{\text{hot leg}} = T_{\text{cold leg}} + \frac{\dot{Q}}{\dot{m} \cdot c_p}. \tag{3}$$

4. Calculate the density of the water exiting the reactor core, $\rho = f(p, T)$ [6].
5. Calculate the thermal driving pressure,

$$\Delta p_{\text{driving}} = \left(\rho_{\text{hot leg}} - \rho_{\text{cold leg}}\right) g h \,. \tag{4}$$

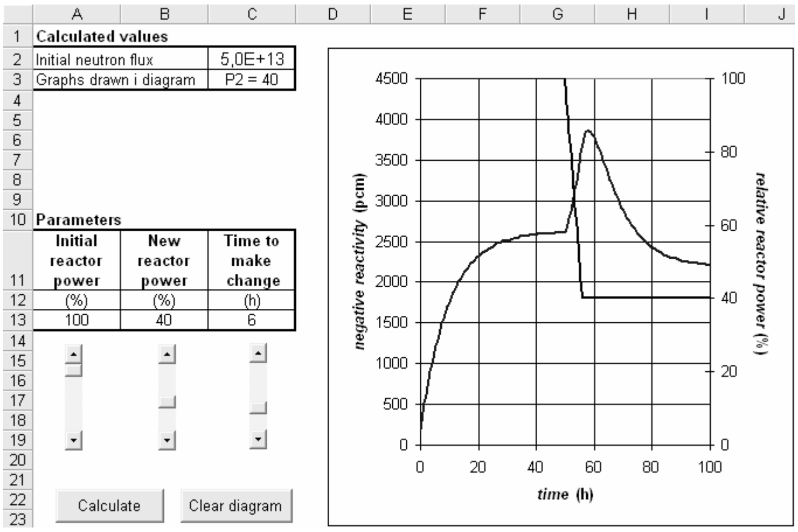
6. Using the Darcy-Weisbach equation for fluid flow it can be shown that the total pressure drop due to friction is proportional to $\dot{m}^{1.75}$,

$$\Delta p_{\text{total}}(\dot{m}) \approx \Delta p_{\text{total}}(\dot{m}_0) \cdot \left(\frac{\dot{m}}{\dot{m}_0}\right)^{1.75} \,. \tag{5}$$

7. If $\Delta p_{\text{driving}} > \Delta p_{\text{total}}$ increment the mass flow rate $\dot{m}$ and repeat from step 3, otherwise stop.

3.2 Xenon poisoning in a nuclear reactor

When the first reactor with higher power, the "Pile B" in Hanford, WA, was started on September 26, 1944, the researchers came across the phenomenon of xenon poisoning. A few hours after the first start-up, the reactor stopped unexpectedly. The following day it started without any external intervention but after a few hours it stopped again. It turned out that the isotope Xe-135, which has the highest neutron absorbing ability of all the known nuclides, was created when running the reactor. When the concentration of Xe-135 became high enough, the resulting reduction in neutron flux caused the reactor to become subcritical.



Calculated values

Initial neutron flux	5,0E+13
Graphs drawn i diagram	P2 = 40

Parameters

Initial reactor power	New reactor power	Time to make change
(%)	(%)	(h)
100	40	6

Fig 3. Simulation of Xe-135 concentration, expressed in terms of negative reactivity, in a typical reactor core. Approximately 2 days after the start of the reactor the Xe-135 concentration has reached an equilibrium level. A decrease in reactor power from 100% to 40% over a period of 6 hours creates a peak in the Xe-135 concentration that occurs approximately 8 h after the change was initiated. Approximately 2 days after the change a new, lower equilibrium level is reached.

In modern reactors xenon poisoning is a well-known effect that plays an important role from an operational point of view. All changes in reactor power and neutron flux will have an influence on the concentration and rate-of-change of Xe-135. The negative contribution to the total reactivity of the reactor from Xe-135 must be constantly predicted and corrected for when making reactivity changes to the reactor. For example, after a power increase, the Xe-135 concentration will initially decrease. If this is not taken into account, the power increase will become larger than anticipated. The concentration will reach a minimum some hours after the power increase and then increase to a new, higher equilibrium value.

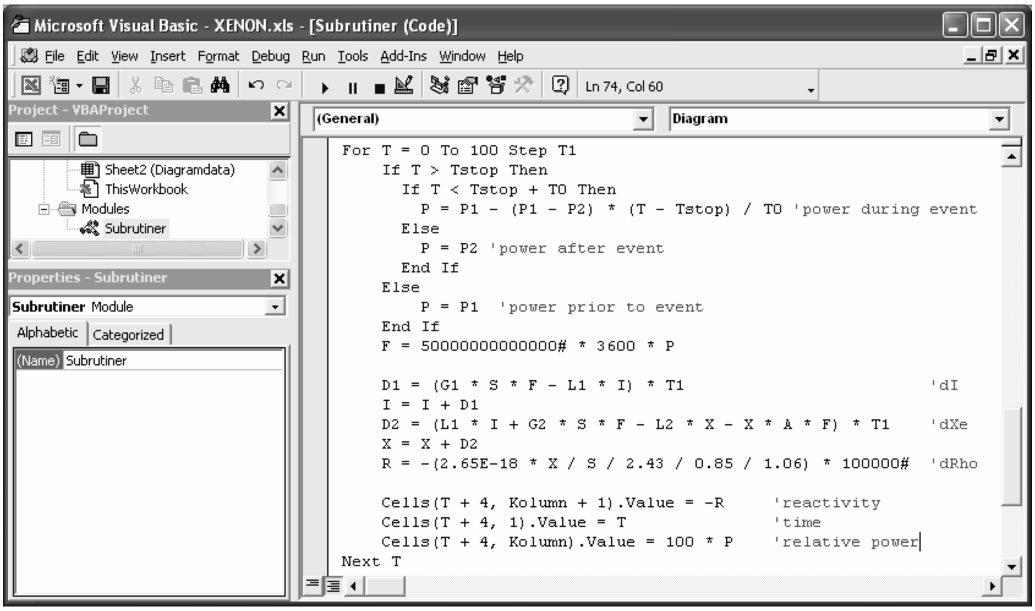
In the operation of a nuclear reactor an equilibrium concentration of both Xe-135 and I-135 is reached as a result of competing processes. Xe-135 is produced directly as a fission product and indirectly following the β-decay of another fission product, I-135, that has a half-life of 6.7 h. The production rate of xenon is proportional to the neutron flux and also the amount of I-

135 present in the fuel. Xe-135 is removed from the reactor core by two processes, radioactive decay and neutron capture. The radioactive decay rate is proportional to the amount of Xe-135 present. Neutron capture converts Xe-135 to Xe-136, which has a low absorption cross-section. In this way Xe-135 can be "burned away" at a rate proportional to the neutron flux in the reactor. The rate of change of xenon concentration is expressed by the following equations,

$$\begin{cases} \dfrac{dN_{Xe}}{dt} = \lambda_I \cdot N_I + \gamma_{Xe} \cdot \Sigma_f \cdot \phi - \lambda_{Xe} \cdot N_{Xe} - N_{Xe} \cdot \sigma_{a,Xe} \cdot \phi \\ \dfrac{dN_I}{dt} = \gamma_I \cdot \Sigma_f \cdot \phi - \lambda_I \cdot N_I , \end{cases} \qquad (6)$$

where λ is the decay constant, γ the fission yield, Σ_f the macroscopic fission cross-section for U-235 and ϕ the neutron flux in the reactor core. The equations can be solved using Euler's method in a spreadsheet, Fig 3.

Although the calculations can be done directly in the spreadsheet grid, in this case the calculations are performed in VBA, Fig 4. The advantage of using VBA for this purpose is that the resulting spreadsheet can be kept clean, only the data of interest for the students are shown. Compared to in-line formulas in worksheet cells, the VBA-code can be made much more complex while maintaining readability.



```
For T = 0 To 100 Step T1
    If T > Tstop Then
      If T < Tstop + T0 Then
        P = P1 - (P1 - P2) * (T - Tstop) / T0 'power during event
      Else
        P = P2 'power after event
      End If
    Else
        P = P1  'power prior to event
    End If
    F = 5000000000000# * 3600 * P

    D1 = (G1 * S * F - L1 * I) * T1                           'dI
    I = I + D1
    D2 = (L1 * I + G2 * S * F - L2 * X - X * A * F) * T1    'dXe
    X = X + D2
    R = -(2.65E-18 * X / S / 2.43 / 0.85 / 1.06) * 100000#  'dRho

    Cells(T + 4, Kolumn + 1).Value = -R      'reactivity
    Cells(T + 4, 1).Value = T                'time
    Cells(T + 4, Kolumn).Value = 100 * P     'relative power
Next T
```

Fig 4. Part of the VBA-code used for the simulation of xenon poisoning in a nuclear reactor. The results of the calculation are transferred to a worksheet using the Excel function Cells(Row #, Column #).Value.

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THE INSTITUTE FOR NUCLEAR RESEARCH PITESTI- AN IMPORTANT FACTOR FOR EDUCATION AND TRAINING IN ROMANIAN NUCLEAR FIELD

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ABSTRACT

Institute for Nuclear Research Pitesti, Romania, is a complex R&D centre with over 30 years of activity in the nuclear energy field, deeply involved in the management and execution of the R&D National Nuclear Power Program. The main activities cover a large spectrum of nuclear energy. Based on the accumulated experience in developing codes, performing analyses, designing and conducting experiments an important knowledge was obtained. Taking into account the historical relation with different organizations, INR acted as a promoter of nuclear methods and techniques, transferring experience and knowledge. Based on the experimental and computing infrastructure and on the experienced personnel the Institute may become an important factor in nuclear education and training. This paper is intended to highlight the Institute competences and facilities and also the REFIN network, a Romanian Educational Network in Nuclear Physics and Engineering, like a good example for the Institute involvement in the national education and training in nuclear field.

1. Introduction

In the whole nuclear domain, the recent trends are based on a sustainable development, both for the nuclear power and the nuclear applications. Starting from this reality, it is neccessary to admit that the success of all these applications of nuclear knowledge depends upon being sufficient competent and well-qualified personnel for their implementation and that depends in turn on knowledge management, /1/. The knowledge management has been most visibly implemented in the nuclear research and industry as a response to the aging nuclear domain workforce.

In Romania, the state of the art of the nuclear knowledge is similar with other European countries, but some specificities should be mentioned here. Romania is one of the few countries with a dynamic development of nuclear power in the last two decades. First CANDU unit became commercial in 1996, and the second unit in 2007. A political decision in order to sustain the building of two new CANDU units until 2015 exists. Moreover, at high decisional level there are discussions about the necessity and opportunity to built another NPP with 2-4 reactor units with a different location than actual CANDU NPP. In this context, important requirements for new personnel are expected for the next 5-10 years. But, on the other hand, as in other countries, the personnel ageing effect, both in nuclear industry, research, and other organizations is visible. Also, it was occurred an important loss of high qualified personnel by emigration and cancellation by employee (motivated by the temptation of a transfer in other economy sectors). In parallel with the loss of qualified personnel, a decreasing of the interest of the young generation for nuclear field is felt. The number of students in nuclear field has decreased, also the number of courses and universities with nuclear subjects, /2/.

From this prospective point of view and accordingly with the requirements of the Romanian Nuclear Programme regarding the education and training of the skilled personnel for the nuclear facilities, we consider that the Institute for Nuclear Research from Pitesti can be and must be an important factor for education and training in Romanian nuclear field and not

necessary. The affirmation is based on the reality that the Institute has both the experimental and computational infrastructure but also the experienced personnel.
In the followings, we try to argue this affirmation by a short presentation of the Institute and also one of the most important INR realization in the educational and training area, i.e. the REFIN network, /3/ and /4/.

2. The INR and Competences- short presentation

The **I**nstitute for **N**uclear **R**esearch (INR) Pitesti was founded in 1971 and with the mission to foster the peaceful utilization of nuclear power. The Institute developed technologies, methods, computer codes, its own experimental infrastructure, directed towards an end-product or service with applications in a nuclear power plant (NPP). The Institute continues to act as a technical support institute for the safe and economical operation of the NPP, in accordance with National Nuclear Programme and international agreements on the safety of nuclear installations.

In Figure 1 the INR's assets are presented:

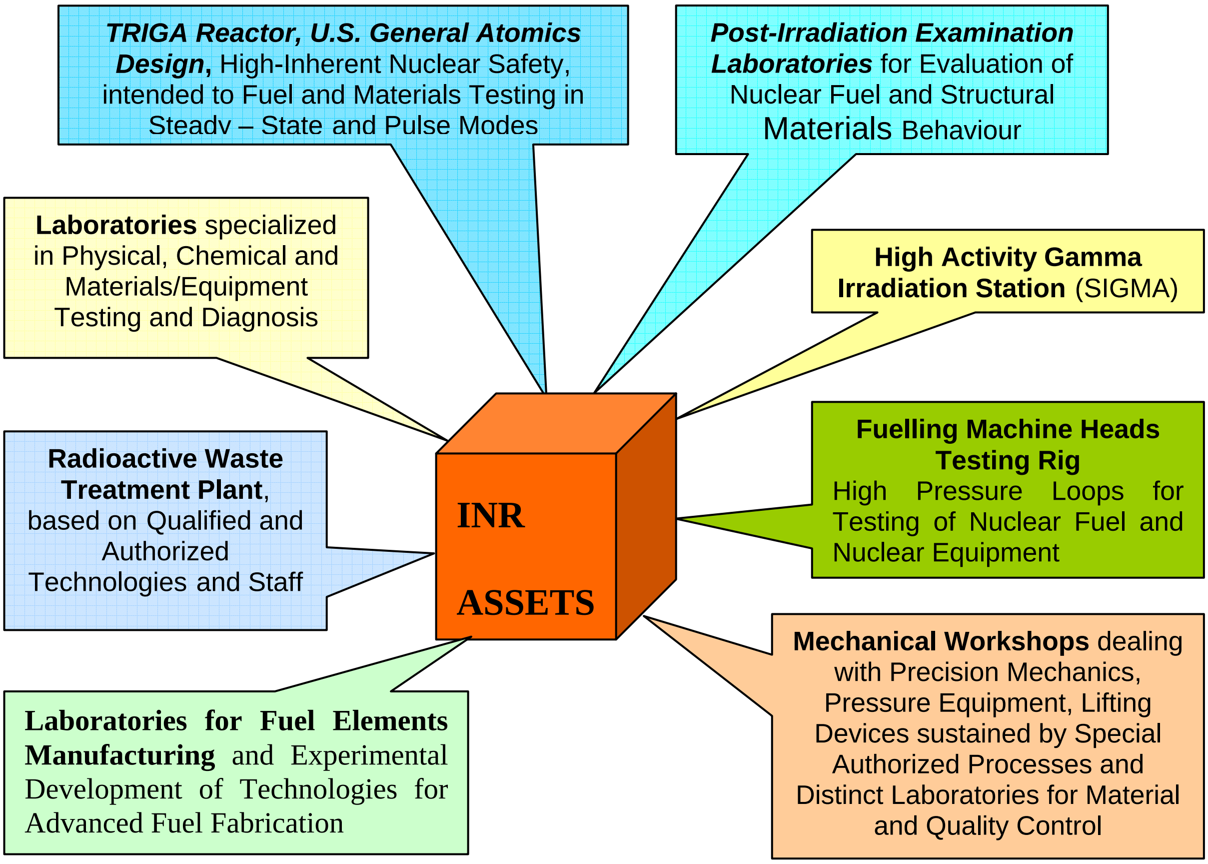

Fig. 1. The Institute for Nuclear Research assets

During the last 15 years, the research activity of the INR was mainly oriented towards applied and engineering research, within programmes with objectives connected to the CANDU NPP. To achieve these objectives, the Institute activities are oriented in the following main research areas:

- Reactor Physics and Nuclear Safety;
- Irradiation and Post-Irradiation Tests;

- Nuclear Fuel Cycles;
- Material Analysis and Evaluation;
- Out-of-Pile Testing;
- Radioactive Waste Management;
- Electronics, Instrumentation and Control;
- Radiation Protection, Environmental Protection and Civil Defence;
- Equipment Design, Development and Testing;
- Reliability and Testing;
- Quality Management.

The structure of the Institute research programmes is fully compliant with the research programmes engaged by the CANDU owners community. This also improves the ground of international scientific cooperation and exchanges throughout Europe and the whole nuclear world, which acknowledges the INR as a valuable partner.

The most known product of INR is the Romanian nuclear fuel technology. Most of the know-how was obtained in ‘80s. The pilot unit was designed, built and operated in INR. In 1992 the know-how, buildings, installations and people are transferred in the new company Nuclear Fuel Factory. That is a good example of knowledge transfer in our history.

3. REFIN- The Romanian Educational Network in Nuclear Physics and Engineering

In the last years, in INR were developed or are in progress some very important activities, related with the finding and implementation of the appropriate methods and tools for transfer and preservation of the relevant accumulated knowledge. On this way, in the following we present the Romanian Educational Network for Nuclear Physics and Engineering.

According to the requirements of the Romanian Nuclear Programme regarding the education and training of the skilled personnel for the nuclear facilities, a knowledge transfer network named REFIN (in Romanian: **R**etea **E**ducationala in **F**izica si **I**ngineria **N**ucleara) was developed since 2005. The knowledge target field is nuclear physics and engineering.

The Polytechnic University of Bucharest is the coordinator of this programme and other involved partners are University of Bucharest, University of Pitesti, University Babes Bolyai of Cluj-Napoca, University of Constanta, Institute for Nuclear Research Pitesti, Institute for Physics and Nuclear Engineering from Bucharest and the Training Center for Nuclear Units of Cernavoda NPP.

In Figure 2., the home page of the REFIN web-site in Romanian language is presented. The english version very soon will be in use.

REFIN

RETEA DE EXCELENTA PENTRU PREGATIREA IN DOMENIUL FIZICII SI INGINERIEI NUCLEARE

NEW! INTERNATIONAL COURSE ON RADIOACTIVE WASTE MANAGEMENT. 6-10 November 2006

Proiectul REFIN urmareste dezvoltarea unui sistem flexibil, eficient si modern de pregatire in domeniul nuclear, care sa raspunda cerintelor industriei nucleare (CNE, autoritati de reglementare, subcontractori, dezafectare, radioprotectie, depozitare deseuri), armonizat cu sistemele existente in tarile europene si in concordanta cu perspectivele ariei comune europene de cercetare (PC6, PC7, Euratom Nuctech). More... REFIN

MEMBRII CONSORTIULUI: Universitatea POLITEHNICA din Bucuresti (Departamentul Inginerie Nucleara din Facultatea de Energetica) , Universitatea BUCURESTI (Facultatea de Fizica) , Universitatea din Pitesti (Facultatea de Stiinte, Catedra de Fizica si Chimie) , Universitatea Ovidius din Constanta (Facultatea de Fizica, Chimie si Tehnologia petrolului si Facultatea de Inginerie mecanica, Industriala si Maritima) , Universitatea "Babes-Bolyai" CLUJ (Facultatea de Fizica) , Institutul de Fizica si Inginerie nucleara (Centrul de Pregatire si Specializare a Cadrelor din Domeniul Nuclear (CPSCDN-IFIN-HH)) , Departamentul de Pregatire a Personalului si de Autorizare a CNE Cernavoda DPAP, ICN-Pitesti

Contact: PETRE GHITESCU , Tel:021-4029511 ; E-mail: ppghites@hotmail.com; ILIE PRISECARU , Tel:021-4029828 ; E-mail: prisec@cne.pub.ro ; WebPage: www.cne.pub.ro

Figure 2. The home page of the REFIN

The main objective of this network is to develop an effective, flexible and modern educational system in the nuclear physics and engineering area, that could meet the requirements of all the known types of nuclear facility and therewith be redundant with the perspectives of the European Research Area (FP7, EURATOM).

The construction of a such network is an important step in the improving both knowledge transfer process and collaboration between the responsible factors in the education and training of future specialists. In this way the knowledge transfer is made at all the level: explicit, implicit and tacit, due both the methods (mentoring, tutoring, e-learning, etc.) and a higher usage of the material base (documentation, experimental devices, models, etc.).

The education and training strategy of this network is divided into several topics: university engineering, master, post-graduate, Ph.D. degree, post-doctor's degree, training for industry, improvement. Thus, at the Institute for Nuclear Research (INR) Pitesti the students prepare the engineering diploma, Ph.D. students preparing the thesis, mixed (simulations and experiments) training stages for students, joined participations at nuclear meetings and conferences involving students, professors and INR specialists.

One of the most important activity performed in the REFIN frame in 2007 was the elaboration of the manual „Numerical and Experimental methods in Reactors Physics" by some INR experts in experimental methods and in numerical methods used in the reactor physics, /5/. The novelty of this manual is the double ways approach of the reactor physics: both the experimental and theoretical maner.

Related with this manual, between 12 and 16 November 2007 in INR was organized the pilot module course on „Numerical and Experimental methods in Reactors Physics", /6/. This course was attended by 42 master students in nuclear area, from the Polytechnic University of Bucharest, University of Bucharest, and the University of Pitesti. The students were divided in 3 groups for a good involvement of everyone in the course deployment. The course was performed by the INR experts

The main goal of the course was to offer at the participants not only a theoretical course about the reactor physics, but also the opportunity to make some experiments and some neutronic calculations with transport codes. So, if in the first day was devoted to a theoretical introduction into the basic knowledge of reactor physics theory and a summary description of the experimental methods, in the next 4 days each students group performed experiments or neutronic calculations by codes based on transport methods. The experiments were dedicated to the neutronic measurements (mainly the work with the detectors) and electronic measurement chain. So, were presented the most used measurement and data acquisition methods. The transport calculations, based on deterministic transport codes, referred to macroscopic cross sections obtaining and neutronic parameters local and global calculations. At the end of the course, the students were tested and the results were evaluated.

The course was modularly structured in order to allow a rapid implementation in the next stage of the REFIN project i.e. the e-learning system. The general aim of the e-learning system is to offer a modern tool for education including long-distance education, especially continuous education for nuclear industry personnel and other nuclear organizations such as research, regulatory, agencies, etc.

The e-learning system is intended to introduce both theoretical aspects and application aspects, mainly based on computer code simulations. Of course, short stages in INR for using the experimental infrastructure and to enter in contact with the specific community of practice is needed.

The project, involving a great contribution of INR, should be extended with the participation of other research organizations and end-users in order to cover the diversity and the dynamics of nuclear power and nuclear applications in our country.

Also, the main results of developing the excellence network might attract all interested organizations in the Romanian nuclear field (both during and after the project) and thereby will permit its expansion to other areas related with the nuclear field.

4. Conclusions

(C1) The project REFIN have contributed to a real link of INR with Romanian universities and end-users interested in nuclear education. Starting with a general exploration of the present situation in Romania and in the Europe, the project has identified the needs for a modern nuclear education and the optimal allocation of resources by partnership and by knowledge transfer. An important activity consisted of the initiation of the modular course „Numerical and Experimental methods in Reactors Physics". Based on this, the INR and Polytechnic University of Bucharest have started to introduce the e-learning system for nuclear education.

(C2) INR has an important infrastructure and important human capabilities in order to help educational organization to improve the quality of their work. INR offers some experimental works, calculation methodologies, computer tools and more important a real community of practice in order to prepare the future personnell for nuclear organizations.

(C3) INR capabilities are able to harmonize the classical methosd and the 21st century educational methods for a better education in the nuclear field.

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UTILIZATION OF ICT-BASED TRAINING / LEARNING FOR CAPACITY BUILDING IN RESEARCH REACTOR UTILIZATION

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ABSTRACT

Research reactors are devices designed to initiate, control and sustain nuclear chain reactions at a steady rate. They serve primarily as a neutron source and are basically utilized for research and training, materials testing, production of isotopes in medicine and industry. They allow training to be given to students, physicists and engineer trainees in relevant fields.

ICT has made possible the development of e-learning and several Virtual Learning Environments (VLEs) which can support a wide range of capacity building requirements, ranging from under-graduate and post-graduate programmes, Continuing Professional Development (CPD) courses, right through to short subject-specific and research courses, thereby eliminating the problems of conventional forms of training / learning, some of which are: limited access, cost effectiveness and language / cultural barriers.

This paper focuses on the utilization of these ICT-based training / learning for capacity building in research reactor utilization and concludes with suggestions on implementation strategies.

1. Introduction

It is inevitable in this day and age to discuss capacity building in nuclear science and technology without making mention of research reactor utilization, with reference especially to the utilization of ICT-based training / learning for capacity building and manpower development.
This is because ICT has drastically changed the face of capacity building through training / learning, and has opened up quite a lot of opportunities and 'high-ways' for the delivery of knowledge and information at the speed of light.
It is therefore imperative to properly harness and exploit the potentials in ICT-based teaching / learning for capacity building in research reactor utilization.

2. Research Reactors

Nuclear reactors are devices designed to initiate, control and sustain nuclear chain reactions at a steady rate. They are designed to maintain a steady flow of neutrons generated by the fission of heavy nuclei.
Nuclear reactors are however, differentiated either by their purpose or by their design features. In terms of purpose, they are either research reactors or power reactors.
Research reactors are operated at universities and research centres in many countries, including some countries where no nuclear power reactors are operated.
For almost 60 years, research reactors have been centres of innovation and productivity for nuclear science and technology. To date, some 672 research reactors have been built, and of these, 274 reactors in 56 countries continue to operate. However, nearly two-thirds of the world's

operating research reactors are now over 30 years old. Many of them have been refurbished to meet today's technological standards and safety requirements. [1]

3. Research Reactor Utilization

Research reactors have a wide range of utilization including analysis and testing of materials, and production of radioisotopes. Their capabilities are applied in many fields, within the nuclear industry as well as in fusion research, environmental science, advanced materials development, drug design and nuclear medicine.

Practically speaking, a low-power research reactor allows training to be given to students and physicist, engineer trainees and operators in various areas and fields of nuclear science and technology, amongst which some of them are the following areas: nuclear radiation measurement and application such as activity, dose, half-life, and so on; reactor theory, neutron transport by using spectrometry, neutron chopping and so on; short-lived radioisotope production; studies of reactor characteristics; extracted beam (neutrons) utilization; instrumental neutron activity analysis (INAA); reactor kinetics and dynamics; reactor operation and control by using an associated computer to simulate the reactor operation and control; criticality and power increase; relative and absolute flux measurements; control rod calibration; poisoning effect measurement; void coefficient determination; temperature coefficient measurement; radioisotope determination; reactivity measurement; radiation protection and shields measurement.

Like power reactors, research reactors are covered by IAEA safety inspections and safeguards, because of their potential for making nuclear weapons. India's 1974 explosion was the result of plutonium production in a large, but internationally unsupervised, research reactor. [2]

4. ICT-Based Training / Learning

Information and communications technology (ICT) has transformed the means by which we inform ourselves, remain up to date with world events and areas of personal interest, and further our learning. For many, books and journals are no longer the first or primary source of information or learning. We now regularly rely on images, video, animations and sound to acquire information and to learn.

ICTs have fundamentally changed the way we learn and communicate. They have transformed the nature of capacity building – where and how training / learning takes place and the roles of students and tutors in the training / learning process.

4.1 Learning Platforms

A Learning Platform is software or a combination of software that sits on or is accessible from a network, and which supports training, teaching and learning for practitioners and learners.

Learning platforms offer one or more of:

- a place to store, find, access and use prepared materials;
- a platform on which to build and deliver learning activity;
- a common and consistent interface and way of working;
- secure and controlled (login) access for trainers and trainees to materials;
- a set of communications possibilities, ranging from transmission of static information (timetables, policies etc) and narrative (notes, videos), through to discussions, collaboration and exchange.

- tracking and monitoring of learners’ activity, performance and progress and, if linked to other business and information systems within the organisation, the potential to become the heart of a full managed learning environment.
- some learning platforms offer an offline facility, whereby content can be downloaded onto a laptop for use in sites without access to the network, then automatically updated when reconnected to the system.

Above all, it is an important point to realise that learning platforms are **not** about the technology, and do not provide quick technological fixes. They are about using technology, **where appropriate** (research reactor utilization in this case), to enhance training and learning.

4.1.1 Virtual Learning Environments (VLEs)

A virtual learning environment (VLE) is a set of teaching and learning tools designed to enhance a trainee’s / student's learning experience by including computers and the Internet in the learning process. It is a set of integrated Web-based tools that enable trainers / tutors to create and administer courses and allow trainees / learners to gain access to those courses A VLE will typically include most or all of the following features:

Content creation or upload tools:
There will be some mechanism to get materials into the VLE. Most will provide an upload facility so one can add files to the course that one has created elsewhere. In some cases the VLE will also provide an authoring tool allowing contents to be created; this authoring tool is likely to be more restrictive than a dedicated Web page authoring tool.

Course structure:
Having got the materials into the VLE, one can give them some structure within that module or course; the VLE will then provide a navigation toolbar to the learners so that they can view the learning materials in the intended order.

Navigation Structure:
Structured delivery of knowledge / information supported by a standard navigation toolbar. Most VLE software assumes that trainees / learners work their way through linear sequences of instructional material. Hence, in most cases, they allow only a linear navigation structure, but others can be much more flexible allowing for more complex structures. They can accommodate alternative knowledge / information structures, e.g. multi-path sequence navigation structures.

Communication tools:
These are tools such as email, discussion boards and chat rooms and can be used for exchanges between trainer / tutor and trainee / learner and between trainees / learner and trainees / learner. These communication tools can really add to the richness of the trainees’ / learners’ learning experience if used properly i.e. making sure that there is a clear purpose for which one is using them for. For example, if a discussion group is been made us of, the trainees / learners should have a specific topic to discuss.

Assessment tools:
VLEs can provide tools for assessment, both formative (self testing) and summative (assessed). Built in tools can be useful for keeping track of the trainees’ / learners’ progress and the VLE will record scores from these assessment activities.

Management tools:

These tools make it possible to set up user accounts and access levels. In most cases, the trainees' / learners' progress can be tracked through courses. Course marks can also be recorded here (even if the assessment did not occur online).

Delivery of learning resources and materials:
For example, through the provision of lecture notes and supporting materials, images and video clips, links to other resources, and so on.

Consistent and customizable look and feel:
In most cases, a standard user interface that is easy and friendly for trainees / students to understand and use. Courses can be individualized with colours, graphics and logs, but the essential mode of use remains constant.

Other tools:
There is a range of other tools your VLE may include. For example, a few VLEs include a tool that allows trainees / learners to add their own notes within the learning package. Some VLEs have a special area where learners can submit work where learners can view it and add comments about it.

4.1.2 Why use VLEs for capacity building (training/learning) in research reactor utilization?

VLEs can offer trainees / students and trainers / lecturers some support with flexible and widening access to materials and resources. This has particular advantages for trainees / students who are studying (under-graduate, post-graduate, continuing professional development courses, and short-specific subject courses) on a part-time basis. Engaging and motivating trainees / learners in research reactor utilization can also be a challenge. VLEs can help pull together up-to-date, interesting and interactive electronic resources as well as additional supporting materials. VLEs can open up opportunities for new ways of training / learning and communicating, and can support collaborative learning and independent learning. A VLE can help establish a community more quickly and 'integrate' trainees / students into the institution. However, the advantages of using VLEs need to be weighed against the disadvantages and these are summarized in Table 1.

ADVANTAGES	DISADVANTAGES
Easy online delivery of materials. VLEs provide a 'shell' for a course or programme, allowing one to: publish existing documents and presentations easily; link to online sources of data, news services, records and publications; link to online resources such as simulations and tutorials.	VLEs can become a 'dumping ground' for materials not designed to be delivered online. If materials are not integrated or linked in any way to face-to-face teaching, they may not be used properly, or at all. Issues of copyright and Intellectual Property Rights (IPR) of materials need to be considered.
They are easy to use for trainees / students and trainers / lecturers.	VLEs may be relatively easy to use, but generally the software is still in its infancy, with one having to bear in mind that standards are still emerging.
They widen trainee / student access on and off campus to learning materials and resources. Trainees / students should be able to access	On- and off-campus access to hardware, networks and printing facilities can be problematic for both students and lecturers,

these resources at any time, in any place.	and raises issues of equality. Disability legislation and accessibility to online materials also need to be considered.
They offer the potential of supporting large groups of trainees / students. Economies of scale can be gained, for example, by producing one set of online materials that can be used and updated each year, and assessing trainees / students online.	Populating a VLE with material and assessment questions is a front-loaded activity and requires considerable effort and time in the short run.
They offer new ways of training / learning and teaching, such as collaborative projects involving trainees / students at a distance. They can also support active and independent learning, where trainees / students are actively involved with studying ideas, solving problems and applying their training and what they've learnt.	Such independent learning still needs to be guided and supported. Appropriate training and ongoing support is still needed for both students and lecturers.
They offer flexible support for trainers / lecturers, who do not need to be in a fixed time or place to support and communicate with trainees / students.	Lecturers need to plan online support carefully to avoid overload.

Table 1: Advantages and disadvantages of using VLEs for capacity building (training / learning) in research reactor utilization

5. Conclusion / Suggestions:

In conclusion, it is worthwhile to know that ICT-based training / learning can support a wide range of capacity building requirements for research reactor utilization, ranging from under-graduate and post-graduate programmes, Continuing Professional Development (CPD) courses, right through to short subject-specific and research courses, thereby eliminating the problems of conventional forms of training / learning, some of which are: limited access, cost effectiveness and language / cultural barriers.

However, putting into consideration the peculiarity of the developing nations, where there is limited access to the internet and wide/convenient bandwidth, traditional storage media, which are also known as CD or DVD ROMs can be made use of in transferring the knowledge, training and expertise required for capacity building in research reactor utilization in form of software (for example, a research reactor utilization software), which will encapsulate the fundamentals and a wide range of capacity building requirements for research reactor utilization.

6. References / further resources

[1] http://www-naweb.iaea.org/napc/physics/ACTIVITIES/Foreword.htm

[2] http://www.uic.com.au/nip66.htm

Calculation of the neutron flux, fuel and moderator temperature transients for Research Reactors

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ABSTRACT

When withdrawing or inserting control rods in the core of a research reactor generally only the end values of the resulting neutron flux is calculated. This code offers a possibility to - in advance - depicture the whole course of the changes of the neutron flux, the fuel temperature and the moderator temperature. Used are the reactor kinetics equations with six delayed neutron groups, the fuel and moderator thermal dynamics equations, first in the form of Laplace transform with simple time delays and than as first degree differential equations. This set of nine differential equations coupled together is solved numerically.

1. Introduction

The classical reactor kinetic equations with six groups of delayed neutrons (point kinetics) are not solved analytically. In the presented program the fuel and the moderator thermal dynamic equations are coupled to the reactor kinetic equations. The equation system is solved numerically. This short program is suitable to be used by nuclear engineering students when practicing at research reactors. The parameters to be used are of course depending on the reactor design.

2. The simplified neutron kinetics equations

are

$$\frac{dN}{dt} = \frac{\delta k - \beta}{l} N + \sum_{i=1}^{6} \lambda_i c_i \qquad \frac{dc_i}{dt} = \frac{\beta_i}{l} N - \lambda_i c_i$$

Here

t	time (sec)
N	neutron flux (proportional to the reactor power)
δk	change of the effective neutron multiplication factor (k_{eff})
β	sum of the delayed neutron fractions (here 0.006502)
β_i	the i:th delayed neutron fraction
l	neutron mean lifetime (here 0.001 sec)
λ_i	i:th decay constant (sec^{-1})
c_i	concentration of the i:th fraction of the delayed neutrons' precursors,

At steady state, when time is zero t=0 all time derivatives are equal to zero, all d/dt=0 and the initial value of the relative power equals unity N(0)=1, and also no reactivity perturbation is present δk =0

$$N(0)=1 \quad \frac{dN}{dt} = 0 \quad \delta k = 0 \quad \sum_{i=1}^{6} \lambda_i c_i = \frac{\beta}{l} \quad \frac{dc_i}{dt} = 0 \quad c_i(0) = \frac{\beta_i}{l\,\lambda_i}$$

Table 1: Delayed neutron data for thermal fission in U^{235} is used

Group	1	2	3	4	5	6
Fraction β_i	0.000215	0.001424	0.001274	0.002568	0.000748	0.000273
Decay constant λ_i	0.0124	0.0305	0.111	0.301	1.14	3.01

Table 2: The initial values of the delayed neutrons' precursors are;

i	1	2	3	4	5	6
$c_i(0)$	17.3387	46.6885	11.4775	8.5316	0.6561	0.0907

Using the MATLAB notations; x(1)=N x(2)=c_1 ……….. x(7)=c_6

3. Fuel

The fuel temperature change (T_{Fuel}) follows after the power with a time delay (τ_{Fuel})

$$T_{Fuel} = \frac{c_{NF} N}{1 + p\tau_{\text{Fuel}}}$$

T_{Fuel} Fuel temperature change

N Relative neutron flux proportional to the relative power

c_{FN} fuel temperature proportionality constant to relative power

p Laplace operator d/dt, 1/sec

τ_{Fuel} thermal time constant of the fuel, here 5 sec

t time, sec

The differential equation form is

$$T_{Fuel} + \tau_{Fuel}\frac{dT_{Fuel}}{dt} = c_{NF}N \; ; \quad \frac{dT_{Fuel}}{dt} = \frac{c_{NF}}{\tau_{Fuel}}N - \frac{1}{\tau_{Fuel}}T_{Fuel}$$

At steady state (equilibrium) d/dt=0 N(0)=1
Suppose that at zero power the fuel temperature changes by 0.001 ^{0}C when N=1 and thereby c_{NF}=0.001

Suppose τ_{Fuel} =5 sec $\frac{1}{\tau_{Fuel}}$=0.2 $\frac{c_{NF}}{\tau_{Fuel}}$=0.0002^{0}C/sec
With the MATLAB notation x(8) = T_{Fuel}
and the neutron kinetics equations can be expanded to include the fuel dynamics
0.0002*x(1)-0.2*x(8)

3.1 The Doppler reactivity of the fuel is

$$\delta k_{Fuel} = k_{Fuel}(T_{Fuel} - T_{Fuel}(0))$$

Here

δk_{Fuel} the reactivity contribution of the fuel temperature change, at the initial phase (t=0), at steady state (equilibrium) is zero $\delta k(0)_{Fuel} = 0$

k_{Fuel} Fuel temperature coefficient (Doppler coefficient) here is -3.1pcm/^{0}C

The reactivity of the Fuel's Doppler effect is

$\delta k_{Fuel} = k_{Fuel} \cdot (T_{Fuel} - T(0)_{Fuel})$ = -3.1·10^{-5}·(T$_{Fuel}$ - 0.001)

with MATLAB notation; DeltaKfuel = – 3.1·10^{-5}*x(8) + 0.0031·10^{-5}

4. Moderator

The differential equation for the moderator is similar to that of the fuel, when the moderator thermal time constant is much bigger then the fuel thermal time constant $\tau_{Moderator} >> \tau$

$$T_{Moderator} + \tau_{Moderator} \frac{dT_{Moderator}}{dt} = c_{NM} N$$

$$\frac{dT_{Moderator}}{dt} = \frac{c_{NM}}{\tau_{Moderator}} N - \frac{1}{\tau_{Moderator}} T_{Moderator}$$

$T_{Moderator}$	Moderator temperature change
$\tau_{Moderator}$	Moderator thermal time constant, here 100 sec
c_{NM}	Moderator temperature proportionality constant to the relative power, suppose that at zero power operation the moderator temperature change is only 0.0005 ^{0}C when the relative power N=1. Then c_{NM}=0.0005

Suppose $\tau_{Moderator}$ =100sec $\frac{1}{\tau_{Moderator}}$ =0.01/sec $\frac{c_{NM}}{\tau_{Moderator}}$ = 0.0005·0.01 ^{0}C/sec = 0.000005

With the MATLAB notation x(9) = $T_{Moderatorl}$; and the neutron kinetics equations can be expanded to include the moderator dynamics too; 0.000005*x(1)-0.01*x(9)

4.1 Moderator reactivity contribution from temperature change

$$\delta k_{Moderator} = k_{Moderator} \left(T_{Moderator} - T(0)_{Moderator} \right)$$

Here

$\delta k_{Moderator}$ the reactivity contribution of the moderator temperature change at the initial phase (t=0), at steady state (equilibrium) is zero $\delta k(0)_{Moderator} = 0$

$k_{Moderator}$ Moderator temperature coefficient here is - 0.6pcm/^{0}C

The reactivity contribution from the changing moderator temperature is

$$\delta k_{Moderator} = k_{Moderator} \cdot (T_{Moderator} - T(0)_{Moderator}) = -0.6 \cdot 10^{-5} \cdot (T_{Moderator} - 0.0005)$$

with MATLAB notation; DeltaKmoderator=-0.6$\cdot$10^{-5}*x(9)+0.0003$\cdot$10^{-5}

5. Control Rods

δk_{CR} the reactivity contribution of the control rods' movement are here with two different maximum values; 50 pcm respectively 60 pcm
The movements of the rods and the corresponding reactivity changes are given in Figure 1

5.1 The reactivity balance with the control rods, the fuel's Doppler effect and the moderator's temperature effect

$$\delta k = \delta k_{CR} + \delta k_{Fuel} + \delta k_{Moderator}$$

The reactivity balance with MATLAB notation;
DeltaK = DeltaKcr + DeltaKfuel + DeltaKmoderator

6. Results of the Computation

In Figure 1 there is the schematic of the control rod reactivity used in the calculations
In Figure 2 the calculated relative neutron flux is displayed
In Figure 3 there are the characteristics of the fuel and moderator temperature increase. The values are very small as here the calculations are performed for zero power operation when practically no power is generated in the fuel and transferred into the moderator. However the curves clearly demonstrate that the fuel's thermal time constant is much smaller than that of the moderator's

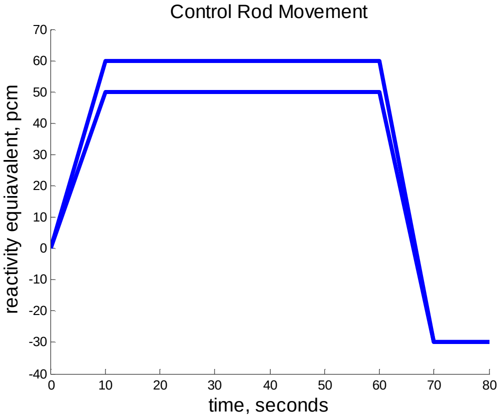

Figure 1, Schematic of the control rod reactivity

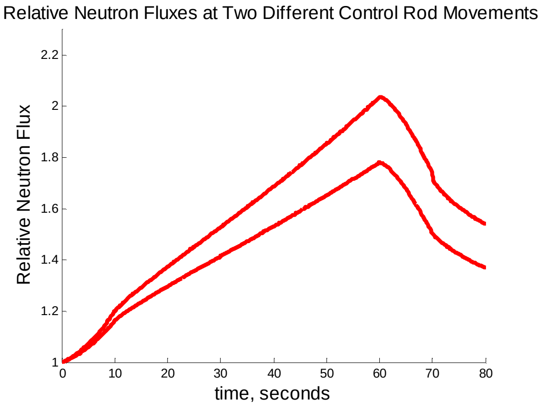

Figure 2, Relative neutron flux

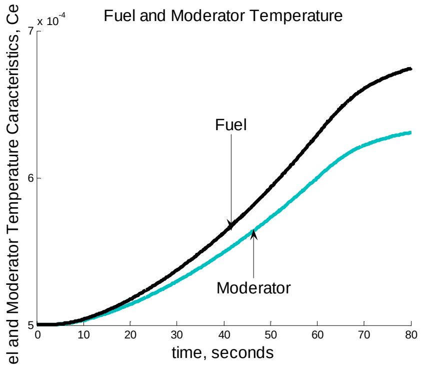

Figure 3, Characteristics of the fuel and moderator temperature increase

7. The Code

contains two parts

Part one

```
%Save as  xprim9FM.m

function xprim = xprim9FM(t,x,i)

DeltaKcr=i*10^-5;
DeltaKfuel=-3.1*10^-5*x(8)+0.0031*10^-5;
if t>=0 & t<10
    DeltaKcr=((i*10^-5)/10)*t;
end
if t>60 & t<70
DeltaKcr=(10^-5)*(i-8*(t-60));
end
if t>70
    DeltaKcr=-30*(10^-5);
end
DeltaKmoderator=-0.6*10^-5*x(9)+0.0003*10^-5;
DeltaK=DeltaKcr+DeltaKfuel+DeltaKmoderator;
xprim=[(DeltaK/0.001-
6.502)*x(1)+0.0124*x(2)+0.0305*x(3)+0.111*x(4)+0.301*x(5)+1.14*x(6)+3.01*x(
7);
0.21500*x(1)-0.0124*x(2);
1.424000*x(1)-0.0305*x(3);
1.274000*x(1)-0.1110*x(4);
2.568000*x(1)-0.3010*x(5);
```

```
0.748000*x(1)-1.1400*x(6);
0.273000*x(1)-3.0100*x(7);
0.000200*x(1)-0.2000*x(8);
0.000005*x(1)-0.0100*x(9)];
```

Part two

```
%Save as ReaktorKinFM.m

a=50;
b=10;
c=60;

figure
hold on
for i=a:b:c %i is the max Control Rod reactivity i pcm
[t,x]=ode45(@xprim9FM,[0 80],[1; 17.3387; 46.6885; 11.4775; 8.5316; 0.6561;
0.0907;0.001; 0.0005],[] ,i);
 plot(t,x(:,8))
 end
hold off

figure
hold on
for i=a:b:c %i is the max Control Rod reactivity i pcm
[t,x]=ode45(@xprim9FM,[0 80],[1; 17.3387; 46.6885; 11.4775; 8.5316; 0.6561;
0.0907;0.001; 0.0005],[] ,i);
 plot(t,x(:,9))
 end
hold off

figure
hold on
for i=a:b:c %i is the max Control Rod reactivity i pcm
[t,x]=ode45(@xprim9FM,[0 80],[1; 17.3387; 46.6885; 11.4775; 8.5316; 0.6561;
0.0907;0.001; 0.0005],[] ,i);
 plot(t,x(:,1))
 end
hold off

figure
hold on
for i=a:b:c
x=[0,10,60,70,80];
y=[0,i,i,-30,-30];
plot(x,y)
end
hold off
```

8. References

University textbooks on nuclear engineering, thermal dynamics and control engineering contain the applied equations. Textbooks on information technology and numerical analyses contain the applied method used to solve the differential equations..

INNOVATIVE APPROACH TO SIMULATE A RADIOACTIVE PLUME FOR TRAINING

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ABSTRACT

A new approach to simulate a radioactive plume was developed. The simulator is designed for Vehicle Monitoring System (VMS) training. It consists of a base station and several monitoring vehicles connected via limited band-pass cellular communication network. The simulator meets requirements such as running in real time with limited computer resources and generating well estimated radiation field. The simulator enables to generate time-depending plumes and simulate contamination fields generated on different weather stability and wind properties.

A function based on the Pasquill[1] Gaussian dispersion model has been adopted and expanded in order to simulate a plume generated by a wind characterized by altering direction and speed.

A simple, non-iterative mathematical algorithm to generate the simulator contamination field is presented in this work. The algorithm generates the plume according to parameters such as: sampling and eruption location, wind velocity, weather stability, time and eruption rate.

1. Introduction

A VMS has been lately developed by the NRCN Electronics Laboratories. The system, designed for radioactive radiation fields mapping, consists of a base station and a dozen monitoring vehicles, connected via cellular communication network. In order to enable operators' training, the VMS was designed with a special training mode. In this mode, the radiation field data received from the simulation software instead of the VMS radiation monitors. The parameters for this simulation software are received from the base station. This work presents an innovative simulation approach that enables to meet the requirements for the mentioned kind of system.

2. Discussion

A simulator for radioactive contamination field, used as a part of training system for the VMS operating teams, has to meet special requirements. Dispersion of radioactive material can occur in different locations, different types of weather stability and different static or dynamic wind parameters such as speed and direction. The new VMS adds additional limitations. All vehicles together with the base unit should operate at the same time. The trainer should be able to control all the above parameters in real time and transmit the data to all the stations via limited band pass cellular communication channel which is used to connect the stations. The computer resources designated for the simulator are limited; this means that a simple algorithm is needed to generate the field value at any vehicle location. Air pollution models are expected to simulate radioactive contamination dispersion and provide a realistic plume shape.

2.1. Air pollution dispersion models

A "box model" assumes that the contamination dispersion is in a box shape volume and that the contamination inside the box is homogeneously distributed. This model cannot be applied because the generated plume does not have a realistic shape which is needed to provide the trainee the necessary realistic contamination field feeling.

The "Particles Following" (PF) models are more efficient for estimating the plume shape. These models mathematically follow the trajectories of particles which are continually generated in large numbers by the simulation software. Particles course is simulated according to weather parameters, wind speed and wind direction. Lagrangian and Eulerian are examples for PF models. An example of particles distribution is demonstrated in figure 1.

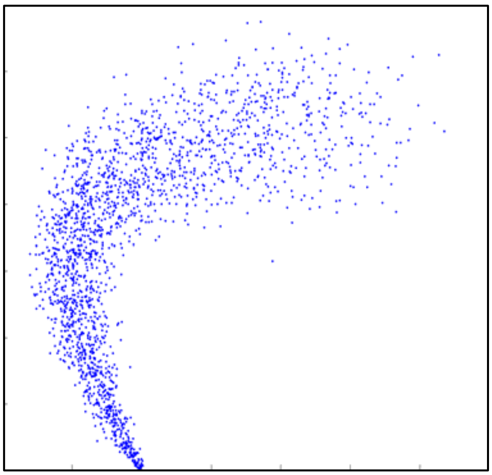

Figure 1: Example of a "particles following" models

Although the PF models generate a nice plume shape, they cannot be applied for the VMS simulation because of the limited computer resources available to implement the iterative function used to generate the plume.

The oldest and perhaps the most commonly used model type is the "Gaussian Model" (GM). This model states that the contamination perpendicular to the plume centerline has a normal probability distribution. Pasquill(1) model is an example to the GM. The basic function states that the contamination density C on [x,y,z] equals to:

(1) $$C(x,y,z)=\frac{Q}{2\pi\sigma_{y(x)}\sigma_{z(x)}u}Exp\left[-\frac{y^2}{2\sigma_{y(x)}{}^2}\right]\cdot\left\{Exp\left[-\frac{(z-H)^2}{2\sigma_{z(x)}{}^2}\right]+Exp\left[-\frac{(z+H)^2}{2\sigma_{z(x)}{}^2}\right]\right\}$$

Where:

Q – Contamination rate

U – Wind speed

$\sigma_{y(x)}$ – Y axis standard deviation (a function of the weather stability and location on X axis)

$\sigma_{z(x)}$ – Z axis standard deviation (a function of the weather stability and X location)

For $\sigma_{z(x)} << H$ the ground effect is negligible leaving a 2D Gaussian function.

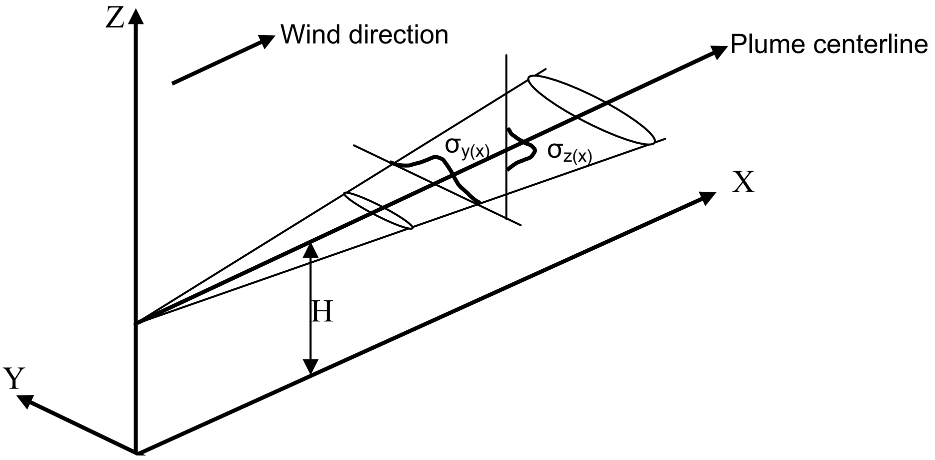

Figure 2: Plume simulation based on Gaussian dispersion model

The Gaussian Model meets most of the VMS simulator requirements. The model is based on a simple non iterative mathematical function that can be calculated using minimum computer resources; the trainer can control the function parameters in real time and transmit them via cellular channel. The model can simulate different types of weather stability and can give the trainee a realistic feeling of contamination field. The main disadvantage of the Gaussian

Model is that it cannot simulate a plume generated by a variable wind which changes its direction and speed in time.

3. Expanding the Gaussian Model

An expansion to the Gaussian model is suggested, to meet the VMS simulator requirements. The new model can simulate a plume generated by a wind with changing parameters, and keep the principle according to which the Gaussian distribution is perpendicular to the plume centerline.

A transformation to the XY plane is applied, so that instead of changing the plume state function, the plane is distorted. The assumption is that the wind direction changes linearly in time. The centerlines of contamination plumes are shown on figure 3. The figure demonstrates a 100 sec. eruption time at 1 m/s constant wind speed. These parameters generate a straight 100 meter plume centerline towards the wind course (figure 3a). In figure 3b wind direction is changed from the west at t=0 sec, to the south at t=100 sec, generating an arc shaped plume centerline. The constrains are the arc length and the angles. The free parameters are radius and circle center location.

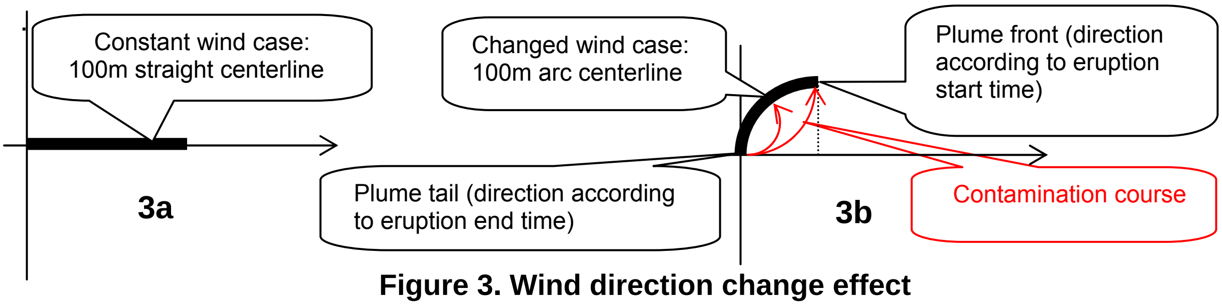

Figure 3. Wind direction change effect

Figure 4 shows a 120-degree (1/3 π) change in wind direction.
Where:

z – Angle change [rad]
α = π-z
L – Plume length [m]
R= L/z
X=R•Sin (α)
Y= R•Cos (α)

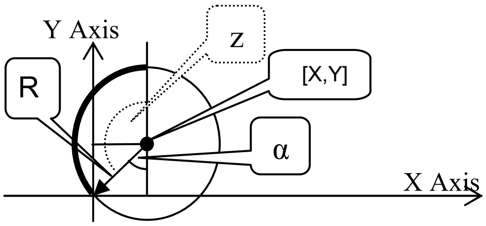

Figure 4: Arc parameters according to plume length and wind direction

For constant wind speed and effective plume width smaller than R (R>>$\sigma_y(x)$), it can be assumed that contamination intensity behaves as the Gaussian model. The intensity value is changed as a function of the distance from the plume axis. Hence, the distance between [x,y] point and X axis (plume axis without wind direction change) is transformed to the same distance between [x',y'] and the arc (wind direction change). The Gaussian distribution contamination that was perpendicular to the X axis is transformed to be perpendicular to the arc, at any point.

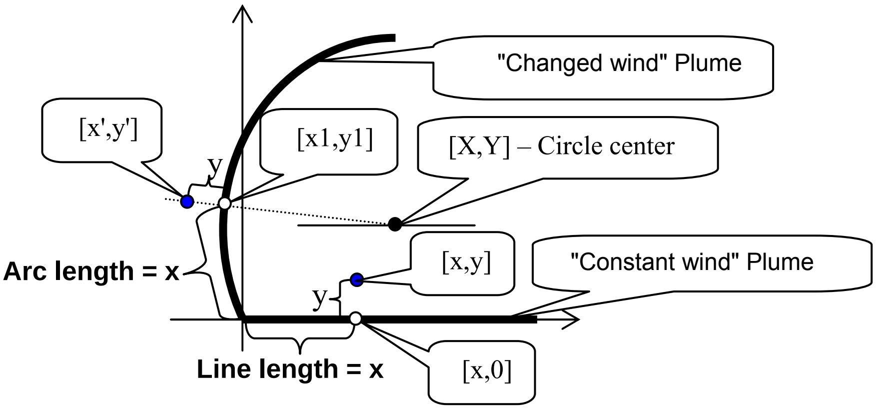

Figure 5. Gaussian distribution perpendicular to the plume center line

Figure 5 shows transformation of a point [x,0] on the X axis to [x1,y1] on the arc:

(2) $x1 = L/z(1 - Cos(x/L \cdot z - z + \pi/2)) - L/z \cdot (1 - Cos(z - \pi/2))$

(3) $y1 = L/z \cdot Sin(x/L \cdot z - z + \pi/2) + L/z \cdot Sin(z - \pi/2)$

The arbitrary [x,y] point transforms to [x',y']:

(4) $[x', y'] = [x1 - y \cdot Cos(\pi/2 - z \cdot (1 - x/L)), y1 + y \cdot Sin(\pi/2 + z \cdot (1 - x/L))]$

The result of the above is an algorithm to transfer any point [x,y] from a constant wind case to a new [x',y'] location on a changed wind case determined by the wind parameters.
(5)

$$[x, y] \Rightarrow \begin{matrix}[L/z(1 - Cos(x/L \cdot z - z + \pi/2)) - L/2(1 - Cos(z - \pi/2)) - y \cdot Cos(\pi/2 - z \cdot 1 - x/L)) \\ , \quad L/z \cdot Sin(x/L \cdot z - z + \pi/2) + L/z \cdot Sin(z - \pi/2) + y \cdot Sin(\pi/2 + z \cdot (1 - x/L))]\end{matrix}$$

4. Reverse Transform

In order to apply the above transformation to the VMS simulator, an inverse algorithm is required to obtain a contamination field value at any location [x',y'] on the transformed plane. The field value at [x',y'] (see figure 5) is calculated by finding the corresponding [x, y] point and placing it in the original contamination density function (at the pre-transformed plane). The algorithm includes five steps:

- Calculate the circle parameters, R,X and Y, based on the plume parameters L and z
- Find y - the distance between the circle and the field point [x',y']
- Find x – the arc length from origin to [x1,y1]
- Insert [x,y] value into the 2D distribution function to obtain the contamination field value
- Calculate the radiation field value based on the contamination density

<u>**Step 1** - Calculate the circle parameters</u>

(6) $R = L/z$

(7) $Cos(\pi - z) = Y/R \Rightarrow Y = R \cdot Cos(\pi - z)$

(8) $Sin(\pi - z) = X/R \Rightarrow X = R \cdot Sin(\pi - z)$

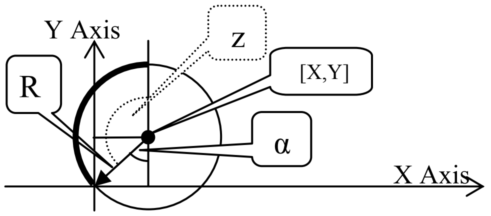

Figure 6. Circle parameters

<u>**Step 2 –** Calculate y - the distance between the circle and point [x',y']</u>

(9) $Cos(\alpha) = \dfrac{X - x'}{\sqrt{(X - x')^2 + (Y - y')^2}}$

(10) $x1 = R \cdot Cos(\alpha) + X$

(11) $a = \dfrac{y' - Y}{x' - X}, \qquad b = Y - a \cdot X$

(12) $y1 = a \cdot x1 + b$

(13) $y = \sqrt{(x' - x1)^2 + (y' - y1)^2}$

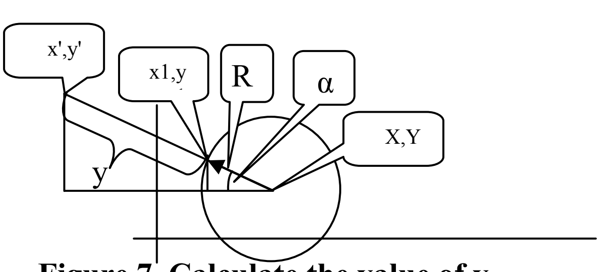

Figure 7. Calculate the value of y

<u>**Step 3** - Calculate x - the arc length</u>

The ratio between the arc length and the circle perimeter (2πR) is identical to the ratio between the angle corresponding to the arc and 2π. It is easier to find the dotted arc length-**d** (figure 8) that complements the arc length to L.

(14) $$Cos\,(\beta) = \frac{y1 - Y}{\sqrt{(x1 - X)^2 + (y1 - Y)^2}}$$

(15) $$\beta = Cos^{-1}(Cos(\beta))$$

(16) $$d = \beta \cdot R$$

(17) $$x = L - d$$

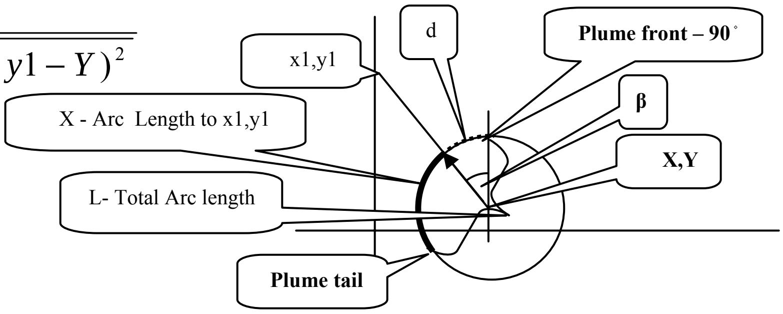

Figure 8. Calculating the x value

Step 4 - Calculate the contamination field

Placing $\sigma_y(x)$ and y on the 2D field function gives the required contamination value:

(18) $$F = C \cdot \frac{1}{\sigma_{y(x)} \cdot \sqrt{2\pi}} e^{-\left(\frac{y^2}{2\sigma_{y(x)}{}^2}\right)}$$

Step 5 - Calculate the radiation field

At any arbitrary point, the whole plume contributes to the radiation field. In a first order approximation, radiation field is proportional to a point source as $1/R^2$. Summing the radiation contribution from the proximity surrounding area to any point is satisfying for the training requirements.

5. Add speed change to the wind

When the wind continually changes its velocity and direction, the plume centerline shape changes to an arc with a radius that changes its length and origin (figure 9a,b and c). A reverse transform to this shape of plume is more complicated. For the VMS simulator, intermittent arc intervals with different radiuses are satisfying (Figure 9d).

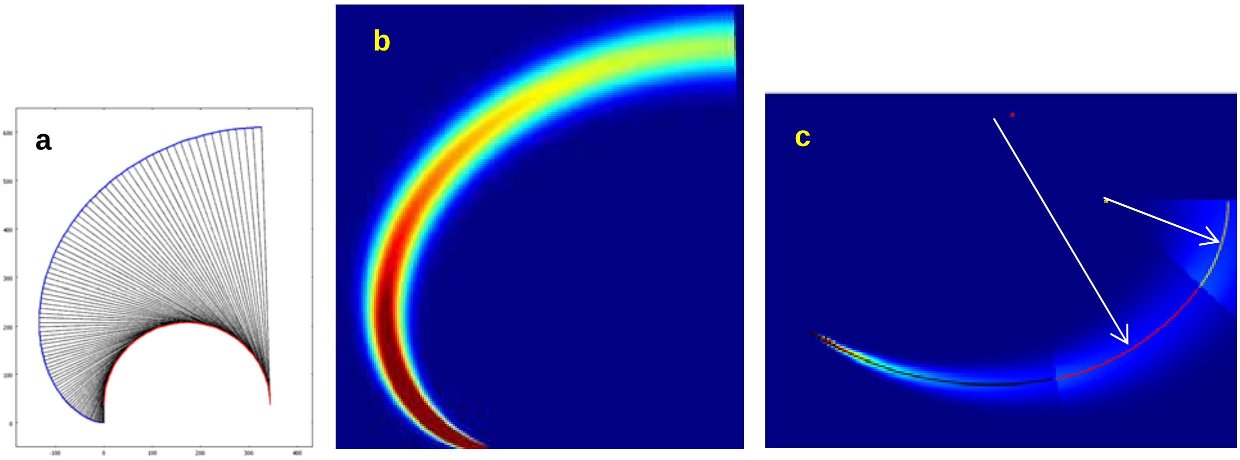

Figure 9 – Plume centerline generated from a wind that changes velocity and direction

6. Conclusion

A simple algorithm simulating a radioactive plume for training is presented. The algorithm uses small amount of computer resources that can be easily implemented on a standard mobile PC or microcontroller, to run in real time. The algorithm requires few parameters that can be easily spread through a limited band pass communication network. The plume dynamics is based on the Pasquill Gaussian atmospheric diffusion and is suitable to any weather stability class. The Pasquill model was expanded to be implemented in case of wind direction change.

7. Reference

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NUCLEAR TRAINING OPPORTUNITIES AT THE NEUTRON DATA MEASUREMENT FACILITIES OF THE JOINT RESEARCH CENTRE

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ABSTRACT

The Institute for Reference Materials and Measurements (IRMM) of the European Joint Research Centre (JRC) is equipped with a unique scientific infrastructure for highly accurate neutron cross-section measurements. It is a combination of a 150 MeV linear electron accelerator with neutron time-of-flight facility and a 7 MV light-ion Van de Graaff accelerator. The complementary research capabilities offered at the two accelerators create excellent opportunities for training. The institute hosts a number of PhD and post-doctoral fellows, visiting scientists and trainees every year. To respond to demands from the educational world the institute organises several hands-on training courses at university level. These regular training courses have the objective to initiate graduate or post-graduate students into the nuclear data field via exciting experiments at the appropriate level. This paper describes the neutron data facilities and nuclear training activities more in detail.

1. Introduction

The Institute for Reference Materials and Measurements (IRMM) in Geel, Belgium, operates two particle accelerator facilities: a 150 MeV linear electron accelerator (GELINA) with a high-resolution neutron time-of-flight (TOF) facility and a 7 MV light-ion Van de Graaff (VdG) facility used for the production of quasi-monoenergetic neutron fields. This research equipment is specially designed for the measurement of highly accurate neutron cross-section data. Measurements at these facilities provide data which form the basis for a wide range of evaluated neutron cross section data.

The development and improvement of a comprehensive neutron cross section database is essential for many areas of nuclear research and technology. For nuclear power production, neutron-induced reactions are definitely the most important interactions. Many reaction channels may occur in numerous isotopes. A precise knowledge of neutron cross sections, over a broad energy range, is of a great importance for a proper account of reaction rates and detailed neutron flux distributions in many nuclear applications [1]. Neutron cross sections are vital when evaluating the safety and risks related to the operation of nuclear power plants and to nuclear waste management. There is an increasing demand on the accuracy of the data for assessing criticality safety aspects and designing fuels for very high burn-up. Also the development of novel systems like accelerator-driven transmutation systems or new concepts for nuclear power production, as defined by the Generation IV International Forum (GIF), rely on accurate neutron cross section data [2].

The areas mentioned above demand for accurate high-resolution neutron data in the energy interval from thermal neutron energy up to the MeV-range. The neutron cross sections show resonance-type energy dependence in part of this energy domain. The resonance structure, which differs from isotope to isotope, cannot be calculated by theoretical models. Therefore, experiments with high energy resolution are required to resolve the resonance structure.

The energy domain of interest can be subdivided into two regions:

- resolved resonance region: to reveal the complicated cross-section resonance structure the extremely good energy resolution of a dedicated time-of-flight (TOF) facility as GELINA is required.
- unresolved resonance region and above: here the measured widths of the resonances are larger than the resonance spacing so that the resonances appear to be overlapping. In the energy domain of overlapping resonances and above, mono-energetic neutron beams, as produced with a Van de Graaff facility, are used.

Thanks to the combination of the GELINA white neutron TOF facility and the quasi mono-energetic neutron source at the VdG, the IRMM facilities cover the whole energy range from a few meV to about 24 MeV. As a result of this combination IRMM is one of the few laboratories in the world which is capable of producing the required accuracy of neutron data in the energy domains defined above. The extending of neutron cross section data and reducing the uncertainties will result in enhanced safety and efficiency of the present and future nuclear power systems. The neutron data measurement activities of IRMM fulfil one of the mandates of the EURATOM treaty, and follow the demands of nuclear industry and research laboratories for complete and evaluated data files on neutron induced nuclear reactions. Measurements carried out at GELINA and the Van de Graaff play a major role in establishing and improving the evaluated nuclear data file maintained at the OECD-NEA databank.

Attracting young people and passing on the best practices and experience is essential in this area. The complementary research capabilities offered at the two accelerators create excellent opportunities for training. The institute hosts a number of PhD and post-doctoral fellows, visiting scientists and trainees every year. To respond to several demands from the educational world the institute organises also hands-on training courses at university level. This paper describes the neutron data facilities and nuclear training activities more in detail.

2. Neutron Data measurement facilities

2.1 GELINA

The Geel Electron Linear Accelerator GELINA [3] is a white neutron source, where the TOF method is used to determine the energy of the interacting neutrons in the energy range covering 11 decades (1 meV – 20 MeV). Among the pulsed white spectrum neutron sources available in the world, GELINA is the one with the best time resolution. The resulting excellent neutron energy resolution is made possible by a combination of four specially designed and distinct units: a high-power pulsed linear electron accelerator, a post-accelerating beam compression magnet system, a mercury-cooled uranium target, and very long flight paths.

The GELINA neutron source is based on a linear electron accelerator producing electron beams with a typical beam operation mode characterised by 100 MeV average energy, 10 ns pulse length, 800 Hz repetition rate, 12 A peak and 100 μA average current. Using a unique post-acceleration pulse compression system, the electron pulse width can be reduced to approximately 1 ns (FWHM) while preserving the current, resulting in a peak current of 120 A. The accelerated electrons produce Bremsstrahlung in an uranium target which in turn, by photonuclear reactions, produces neutrons. Within a 1 ns pulse a peak neutron production of 4.3×10^{10} neutrons is achieved (average flux of 3.4×10^{13} neutrons/s).

The neutron energy distribution ranges from subthermal to about 20 MeV, with a peak at 1-2 MeV. In order to have a significant number of neutrons in the energy range below 100 keV, a hydrogen-rich moderator is added. The energy distribution of the partially moderated neutrons has approximate 1/E energy dependence plus a Maxwellian peak at thermal energy. By using collimators and shadow bars moderated or unmoderated neutron beams are selected. Further tailoring of the spectral shape is obtained with filters.

Fig.1. Aerial view of the GELINA time-of-flight facility

An aerial view of the GELINA facility is shown in figure 1. GELINA is a multi-user facility serving twelve completely independent flight paths and accordingly up to twelve different experiments can be carried out simultaneously. The up to 400 m long flight paths, which point radially to the uranium target, lead to experimental stations at distances of 10, 30, 50, 60, 100, 200, 300 and 400m. These experimental stations are equipped with a wide variety of sophisticated detectors, and data acquisition and analysis systems, especially designed for neutron-induced cross-section measurements with an exceptional precision and energy resolving power. Modern detection techniques such as advanced HPGe Compton-suppressed detectors and data acquisition systems based on fast signal digitisers are in use. The facility is operated in shift work on a 24-hours/day basis, for about 100 hours per week.

2.2 Van de Graaff facility

At the Van de Graaff (VdG) facility of IRMM quasi mono-energetic beams of neutrons are produced in the energy range up to 24 MeV [4]. Especially in the MeV neutron energy domain where the resonance structure of the cross-sections is averaged out, the high-resolution measurements at GELINA can be complemented by measurements at the VdG, where the experimental conditions are more favourable for weak cross sections and low sample quantities.

The Van de Graaff facility, shown in figure 2, is a 7 MV electrostatic accelerator for the production of continuous and pulsed proton-, deuteron- and helium ion beams. Ion beams can be produced with a current of up to 60 μA on target in DC mode and up to 5 μA in pulsed mode. The pulse repetition rates are 2.5, 1.25 or 0.625 MHz and the ion pulselengths are 2.50-1.25 ns FWHM depending on the ion energy. The energy of the mono-energetic neutrons is defined by using lithium, deuterium or tritium targets and choosing appropriate emission angles. Depending on the neutron energy up to 10^8 neutrons/s can be obtained.

At the VdG six beam lines with dedicated experimental set-ups for activation, fission and scattering experiments are attached to the accelerator. In contrast to GELINA, here, only one set-up can be used at a time. The facility is operated continuously for weeks without degraded performance.

Fig. 2. Van de Graaff accelerator

3. Nuclear training at the neutron data facilities

Within the seventh European Framework Programme (2007-2013), it is the objective of JRC to reinforce in the nuclear field its collaboration with the universities. Because JRC is a research centre, it is not its objective to play the role of a university. It will merely provide a contribution wherever its unique research facilities and in-field expertise can be an asset for university students. The working programme at the IRMM accelerator facilities is focussing on nuclear data for (1) nuclear waste transmutation, (2) innovative reactor systems, (3) basic research in nuclear physics and (4) nuclear standards. This forms an ideal background for the organisation of training activities at graduate and post-graduate level. It is the goal to attract young people, initiate them to the nuclear data domain and its technological context, to give them first working experience in a nuclear research environment and to transmit knowledge and best practices. The educational activities around the IRMM accelerator facilities can be subdivided in three major categories: (1) academic courses, (2) education of students as trainees and (3) training of PhD students and post-doctoral fellows.

To respond to several demands from the educational world the institute organises hands-on experimental training courses at university level. One course is organised within the framework of the Master of Science in Nuclear Engineering program of BNEN (Belgian Nuclear Education Network) [5]. This course is also recognised as an elective course in the ENEN programme [6] (2 ECTS points in the European Credit Transfer System) [7]. There are typically 10 students per course. Another course is part of the SPERANSA programme (Stimulation of Practical Expertise in Radiological and Nuclear Safety) of the CHERNE (European Collaboration for Higher Education and Research in Nuclear Engineering and Radiological Protection) network [8]. SPERANSA is a bi-annual ERASMUS intensive programme (IP) project for students of 6 European nuclear engineering institutions. For the SPERANSA courses there are typically 35 participating students. The following topics are covered during these two-days training courses: physics aspects of neutron cross-section measurements; neutron data for nuclear waste transmutation and design of advanced reactor systems and fuel cycles; data analysis techniques; physics of accelerators; safety aspects; radiation dosimetry. The experimental training part concentrates on time-of-flight neutron cross-section measurements and on neutron fluence spectrometry. A one week Summer School on Neutron Resonance Analysis, at a post-graduate level, will be organised in June 2008 [9]. This course is supported by the OECD/NEA and the Nuclear Data Section of the IAEA. Other courses are under discussion.

The JRC traineeship scheme opens a second channel of educational activities for graduate and post-graduate students. Traineeships in cross-section measurements and nuclear data research are offered at the accelerator facilities for graduate students preparing their thesis or for post-graduate students aiming at their first working experience in the nuclear field. There are two calls for traineeships per year. All trainees receive a standard living allowance. Details can be found in [10]. The duration of a traineeship at IRMM ranges typically from two to six months.

The neutron data facilities host also a number of PhD and post-doctoral fellows. PhD students and post-doctoral fellows work at IRMM during several years either with internal JRC grants [11] or with externally funded grants. It should be noted that JRC is hosting the PhD student but the PhD title can only be awarded by a university. Therefore usually a collaboration agreement with a university is established, so that the educational institution will survey that at the end of the research a PhD title can be awarded. In addition to these long-term PhDs and post-doc fellowships the neutron data facilities are hosting PhD students and post-docs for shorter periods of several weeks in the framework of the EURATOM Transnational Access projects NUDAME and EUFRAT [12].

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[12] http://www.irmm.jrc.be/html/homepage.htm

TRAINING COURSES ON ISIS REACTOR AT SACLAY RESEARCH CENTER

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ABSTRACT

ISIS is an open core pool type reactor with a thermal power of 700 kW. In 2003 the decision was taken to transfer educational and training activities carried out on ULYSSE reactor (Argonaut, 100 kW) on ISIS reactor. Thus, from 2004 till 2006, ISIS reactor went through a major refurbishment of the control system and control room to adapt it to these activities. The refurbishment was defined taking into account the pedagogic needs : ability to carry out specific operations, development of a software with specific supervision screens used to visualize the evolution of reactor parameters and definition of ergonomic adapted to the educational and training activities. We present here the definition of the reactor refurbishment made to adapt the reactor to training courses, as well as some insight into the experiments that are carried out on the reactor using the developed supervision screens.

1. Introduction

As a part of the French Atomic Energy Commission (CEA), the National Institute for Nuclear Science and Technology (INSTN) is a higher education institution that provide engineers and researchers a high level of scientific and technological qualification in all disciplines related to nuclear energy applications, including nuclear reactor theory and operation. Since 1956, the adopted strategy is to complete theoretical courses and training courses on simulators by experimental work carried out on experimental facilities. For this purpose, an Argonaut type reactor especially designed for training courses was constructed at the INSTN headquarter situated on the CEA Saclay centre. This reactor, so called ULYSSE with a nominal power of 100 kW, was operated from 1961 until 2007.

In 2003, when the decision was taken to shut down ULYSSE reactor after more than 40 years of operation, the leading strategy of completing theoretical courses with training courses was continued and it was decided to transfer the educational and training activities to another experimental reactor, so called ISIS and also located on the CEA Saclay centre. For this purpose, ISIS reactor had to go through a major refurbishment of the control system and control room to adapt it to these activities.

After an overview of the ISIS reactor characteristics, we present here the major steps of the reactor control system and control room modifications that were made to adapt the reactor to the educational and training activities. We then illustrate the use of the renewed control system, which include specifically developed supervision screens, with some experiments carried out in the frame of the courses organised by the INSTN.

2. ISIS reactor characteristics

ISIS is an open core pool type reactor with a thermal power of 700 kW. It is the neutron model of OSIRIS research reactor situated in the same building and which exhibits a thermal power of 70 MW. The reactor, that reached criticality in 1967, has mainly been used until 2004 for the test of new OSIRIS core configurations, for power cartography and gamma heating measurements, as well as to supply neutron and gamma fluxes for experiments in the core or its periphery.

ISIS core, shown in figure 1, contains 38 fuel elements (in red), 6 control rods (in dark green), 5 experimental cases (in light green, with 4 red disposals) and a wall of 7 Beryllium elements (in yellow) placed in a compact vessel. The core exhibits a section of 60 cm x 60 cm and a high of 90 cm. The fuel, in Silicide (U_3Si_2) form, is enriched at 19.75%. The fuel elements are made of 22 plates separated by a distance of about 2.5 mm where the water flows. The beryllium elements are used both as neutron reflector, to reduce neutron leakage on one side of the core, and as the starting neutron source though (γ, n) reactions. The experimental cases can be used to place experimental set ups (instrumentation, materials absorber material, test fuel, …).

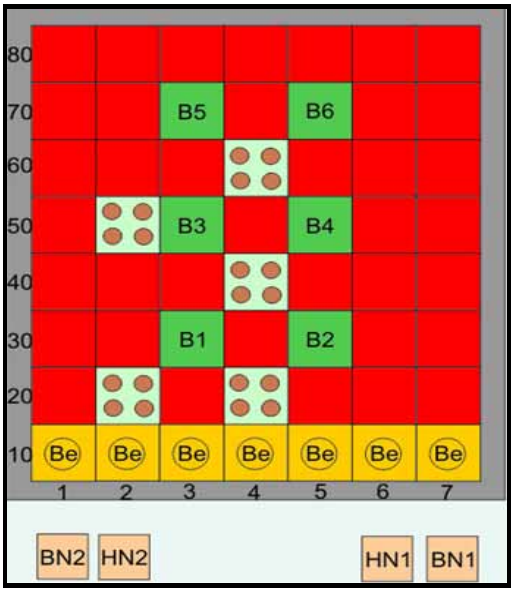


Figure 1: Core configuration.

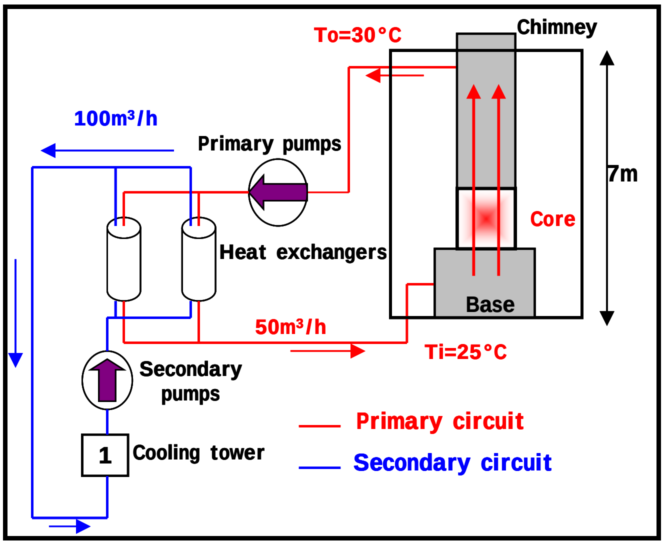


Figure 2 : Schematic of the cooling circuit.

The water circuit is shown in figure 2. The core is placed in a 7 meters deep pool, filled with light water that is used for moderation, cooling and biological protection. Once the water circuit is on, water flows from the bottom to the top of the vessel, between the plates of each element, and goes trough the chimney to reach the extraction pipe. The primary pump is used for the circulation of the water in the primary circuit ($50m^3/h$). Water flowing from the pump reaches the 2 heat exchangers in which the secondary circuit water is used to cool down the primary circuit. After being cooled down, the water is injected under the core, through a big metallic piece called “the base”, which support the structure of the core and the chimney deep inside the pool.

To measure the neutron density and to determinate the reactor power, ISIS is equipped with 4 detection systems, BN1 and BN2 (shown in figure 1) used in the counting mode at low power level (< 40 W) and HN1 and HN2 (shown in figure 1), typically used in the current mode above 10 W. These systems give a signal proportional to the neutron density.

3. Reactor refurbishment

From 1961, ULYSSE reactor located at the INSTN was operated for education and training courses. The reactor had been especially designed in 1960 for this application and latter on, in 1974, the reactor went through a major refurbishment of the control system to improve its control system. ULYSSE reactor was used for 46 years and an important background on the use of an experimental reactor for education and training activities had been gained. When transferring the activity on ISIS reactor this background was used to define the refurbishment programme of the reactor control system and control room. A committee that joined together the project managers, ISIS operators as well as the teachers and operators from ULYSSE reactor was formed.

The first step in the activity transfer was to evaluate the ability to reproduce or to adapt the experiments carried out on ULYSSE, as well as to found new experiments that can be carried out on ISIS taking advantage of its characteristics. The output of this work was used to define the specific modifications of the control system for the education and training activities, which came in addition to the "standard" refurbishment of ISIS control system that was operated since 1967. The modifications concerned control system equipments, the logic of the safety system, control system hardware, the ergonomic of the control board and control room, as well as of the development of a supervision software.

For example, the following modifications have been introduced. Thermocouples were added in the core to study the temperature effects. The logic of the safety system was modified to be able to individually drop each rod during standard reactor operation. Three operation modes were defined depending on the reactor configuration (natural convection or forced water circulation) and utilisation (education, experiments), the education mode being limited to a maximum power of 50 kW. The measured signals during reactor operation were extracted to be used in the supervision software that displays different screens showing the evolution of chosen reactor parameters for each type of experiment done on the reactor. Figure 3 and 4 show, respectively the control board and the major screen used to follow the operating (rod state and position, …) and measured parameters (signal of the detection system, doubling time, power, …).

All the modifications had to be approved by the French safety authority and needed an update of the operating licence obtained in 2006. The refurbishment programme was accomplished between 2003 and 2006, for a total cost of 2,2 M€. ULYSSE reactor was then definitively shut down in February 2007 and the training activities were transferred on ISIS reactor in March 2007. We present in the following paragraph three examples of experiments carried out on ISIS in the frame of INSTN educational and training courses.

Figure 3 : ISIS control board.

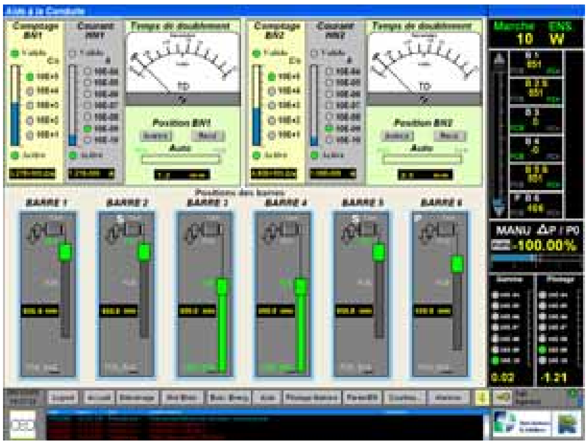
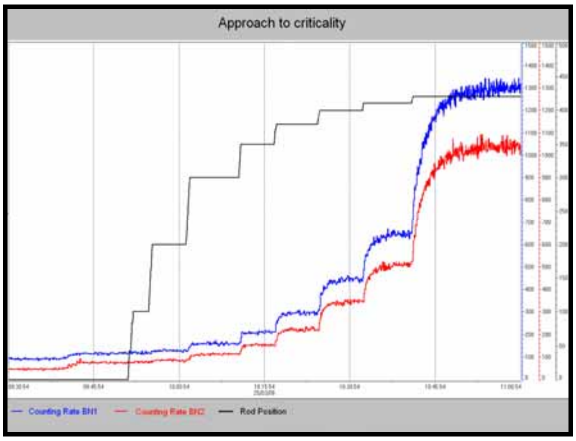


Figure 4 : Screen used for reactor operation.

4. Approach to criticality

Before reactor start up, it is necessary to safely determine a critical configuration of the control rods of the reactor. This is done by an approach to criticality through the removal of one of the control rods (rod B6) for a given configuration of the other rods. Figure 5 shows the supervision screen displayed to follow the evolution of BN1 and BN2 counting rates as well as B6 rod position as a function of the time during the approach. For each stabilisation of the counting rate for a given rod position, the measured counting rate N is extracted and used to draw the 1/N versus rod position curve, shown in figure 6. The position of B6 associated to criticality is established by extrapolation and can then be used to start up the reactor using the Nordheim curve and the calibration curve of the rod B6.



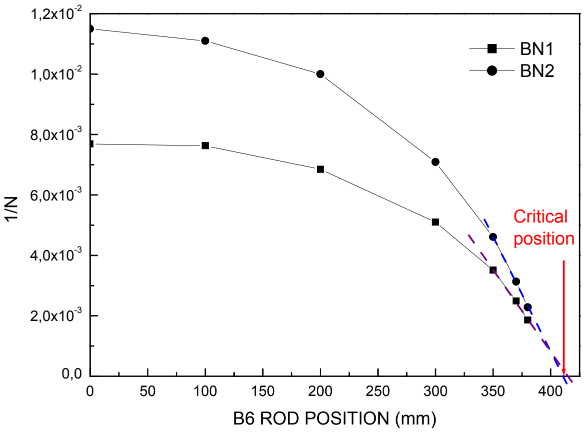


Figure 5 : Screen during approach to criticality.

Figure 6 : Search for critical position

5. Temperature effects

When a reactor is operated at appreciable power, the energy produced by the fission reaction induces the increase in temperature of the fuel, the moderator and other material present in the core of the reactor. This, in turn, leads to a modification of the core reactivity ρ. In order to study the temperature effects, the following experiment is carried out. The reactor being stabilised at 500 W, the critical position of B6 and the water temperature are recorded. The reactor power is then increased and stabilised at 50 kW. The reactor is then switched to automatic control to maintain the power constant, i.e. the rod B6 is automatically moved to maintain the reactor critical. After a certain time at 50 kW, the new critical position of B6 and core temperature are recorded. Then the reactor is switched to manual control without any modification of the rod position, i.e. the evolution of the core temperature and thus core reactivity is no more compensated by the automatic move of B6. Figure 7 shows the evolution of rod position, reactor power and core temperature as a function of time during the experiment.

The figure shows that when reaching 50 kW, while there is not yet water temperature increase, the critical position of rod B6 has changed from 405 to 423 mm. This corresponds to a variation in core reactivity of about 120 pcm that can be attributed to the Doppler effect. The power being kept constant at 50 kW with the automatic control, the figure shows that the critical position increases with the water temperature. This corresponds to a decrease in core reactivity attributed to dilatation effect. Thus, the overall temperature coefficient is negative, i.e. the reactor is sub-moderated. After switching to manual control (at t = 16:02:30), we observe the self-stabilisation of the reactor whose power decrease by itself due to temperature effects. Finally, from the recorder critical position of rod B6 at 500 W and at 50 kW, the overall temperature coefficient is calculated : -17 pcm/°C.

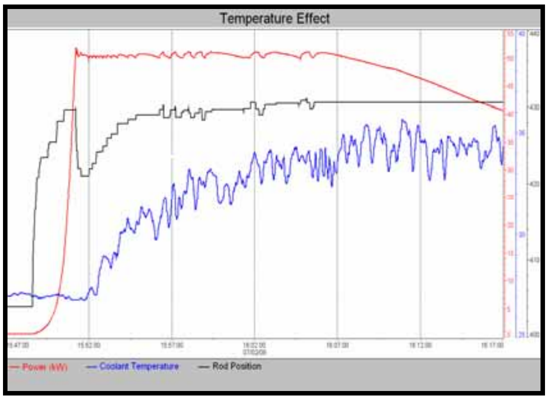


Figure 7: Screen during the study of temperature effects

5. Reactivity effect of experimental samples and set ups

ISIS reactor is equipped with 5 experimental cases that can be used to place experimental set ups. Each case is normally occupied by an aluminium box that contains four holes filled by aluminium cylinders (see position 64 in figure 1). In order to study the potential effect of experimental samples or set-ups on the core reactivity, the reactor being stable at 500 W, three of the four aluminium cylinders are successively removed from the box in position 64. Before and after each cylinder removal, the critical positions of rod B6 are recorded and reported in Table 1. Using the calibration curve of the rod, the variation in core reactivity associated with the removal of the cylinders is calculated and also reported in table 1.

Cylinder removed	Rod position (mm)	Reactivity effect on the core (pcm)
none	406	0
1	405	+ 8 pcm
1,2	394	+ 96 pcm
1, 2, 3	383	+ 184 pcm

Table 1 : Reactivity effect induced by aluminium cylinder removal.

It is shown that the removal of the aluminium cylinders increases the reactivity of the core through the replacement of aluminium by water, which increases the moderation factor. The different values in reactivity variation associated with the cylinder number are directly related to their relative position to B2 (completely extracted), B4 (completely inserted) and B6 (in intermediate position).

5. Conclusion

As a part of CEA, the INSTN provide engineers and researchers with a high level of scientific and technological qualification in nuclear reactor theory and operation. Since 1956, the adopted strategy is to complete theoretical courses and training courses on simulators by experimental work carried out on experimental facilities. For this purpose, ISIS reactor went through a major refurbishment to transfer the educational and training activities previously carried out on ULYSSE reactor. This transfer took advantages of the 46 years background on the use of an experimental reactor for education and training activities. This leaded to the use of a supervision software that displays specific screens showing the evolution of chosen reactor parameters for each type of experiment done on the reactor.

TRAINING POSSIBILITIES AT THE BELGIAN NUCLEAR RESEARCH CENTRE SCK•CEN

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ABSTRACT

Thanks to its thorough experience in the field of peaceful applications of nuclear science and technology, the Belgian Nuclear Research Centre SCK•CEN has garnered a reputation as an outstanding centre of not only research, but also education and training (E&T). The E&T activities at SCK•CEN cover among others nuclear engineering, reactor physics and operation, radiation protection, decommissioning and waste management. This paper gives an overview of the education and training possibilities at SCK•CEN.

1. Introduction

The Belgian Nuclear Research Centre SCK•CEN was created in 1952 in order to give the Belgian academic and industrial world access to the worldwide development of nuclear energy. It is a Foundation of Public Utility, with a legal status according to private law, under the tutorial of the Belgian Federal Minister in charge of energy. Since 1991, the statutory mission gives priority to research on issues of societal concern such as safety of nuclear installations, radiation protection, safe treatment and disposal of radioactive waste, fight against uncontrolled proliferation of fissile materials and fight against terrorism. The Centre also develops, gathers and disseminates the necessary knowledge through education and communication, and provides all services asked for in the nuclear domain (by the medical sector, the nuclear industry and the government). Today, about 600 employees advance the peaceful industrial and medical applications of nuclear energy, and realise a turn-over of about 80 M EURO.

SCK•CEN is also an important partner for training projects in Belgium (to the nuclear sector, the medical and non-nuclear sector), as well as at the international level (IAEA, EC, …). The Centre's know-how and infrastructure are also available for training purposes.

Our courses are directed to the nuclear industry, the medical and the non-nuclear industry, national and international policy organizations, the academic world and the general public. E&T programmes are also organised in cooperation with universities, technical universities, nuclear power plants and public and private health services. In addition, SCK•CEN is involved in international E&T research networks and programmes such as ENETRAP, EUTERP, EUNDETRAF, CETRAD, BNEN and ENEN.

2. Training topics

SCK•CEN provides courses on a wide range of nuclear topics. Following paragraphs highlight the principal areas of training.

2.1. Master of nuclear engineering (BNEN)

In collaboration with the major Belgian universities, SCK•CEN organises a one-year programme (60 ECTS) on nuclear engineering. The objective of this master is to offer present and future professionals and researchers a solid background in the different disciplines of nuclear engineering. The programme is taught in English. Its high modularity allows for optimal time management for teachers and students, it facilitates individual participation in selected courses e.g. advanced courses in the context of continuous professional development and it also facilitates foreign students participation in blocs of courses.

2.2 Nuclear reactor physics and reactor operation training

To guarantee the safe operation of present and future nuclear reactors the initial and continuous training of reactor operators has proven to be indispensable. In most countries, such training also results from the direct request from the safety authorities to assure the high level of competence of the staff in nuclear reactors. SCK•CEN organises such courses for, amongst others, reactor operators of the BR2-reactor at the SCK•CEN site, for the reactor operators and operation team heads of the PWR's situated at the DOEL-site (Belgium), and recently also for the new recruits of Suez in Belgium. The course covers nuclear reactor statics and kinetics. In addition to the theoretical courses, practical sessions on the BR1 research reactor are organised. Training courses on reactor operation are also organised on service basis for nuclear engineering students of various Belgian and foreign universities and technical universities.

Fig 1. Training of reactor pilots at SCK•CEN

2.3 Radiation protection

SCK•CEN's isRP (international school for Radiological Protection) coordinates and organises courses which deal with all aspects of radiation protection. The series "background and basic knowledge" consists of seven modules (nuclear physics, interaction of radiation with matter, radiation and dose measurements, biological effects, gamma spectrometry, legislation and ALARA and safety culture) and provides the theoretical and practical knowledge required for implementing radiation protection aspects in an industrial, medical or research working environment, both in daily practice and in long-term management. A course programme can be extended with one or more modules from the "nuclear and radiological expertise" series (covering topics such as: radon and natural occurring radioactivity, nuclear transport, on-site accident management, organization of emergency planning, radiochemistry, ethical aspects of the radiological risk, …), depending on the specific working environment of the students. On-site practical training exercises are organised and visits to different SCK•CEN installations and laboratories can be included. More information can be found on www.sckcen.be/isrp.

2.4 VISIPLAN 3D ALARA planning tool

The application of ALARA and the dose assessment for work in complex environments is a complicated task. Dose values are influenced by the geometry of the installation, the source distribution, the shielding configuration and the work organization. VISIPLAN 3D ALARA planning tool is a PC-based programme developed for the ALARA analyst or the person responsible for the assessment of the dose uptake of the workers. It allows to assess the radiation doses in a 3D environment and to compare different work scenarios. Typically, a three day course explains the VISIPLAN features.

2.5 Nuclear emergency management

Off-site nuclear emergency management concepts have been reviewed in-depth after the Chernobyl accident. SCK•CEN transmits its know-how in this field by a one-week European training course on "Preparedness and response for nuclear or radiological emergencies". The course aims at giving a comprehensive overview of off-site nuclear emergency management, its principles and their application to those involved in emergency planning and response, e.g. health physicists, technical and radiological advisors, civil and environmental protection officers. It covers the following major topics: principles of intervention, radiological evaluations, decision-aiding techniques and the decision-making process leading to optimised management options. The European and international dimension of the subject is treated (e.g. Community legislation, ECURIE and EURDEP). Other topics such as health effects, economic consequences and psycho/social aspects are also included.

Fig 2. Nuclear emergency management course

2.6 Decommissioning of nuclear installations

With the decommissioning of the BR3 reactor, a European pilot project, SCK•CEN succeeded at developing the best approaches for the optimization of dismantling, decontamination and decommissioning techniques and processes (including the restoration of nuclear sites to so-called 'green fields') Experience also includes the realistic assessment of costs, and the development of techniques for minimization of secondary waste and minimization of radiation doses to the personnel. The course on dismantling and decommissioning is based on this know-how and is primarily intended for dismantling project managers, safety engineers, health physicists, decontamination and dismantling operators. The course is also of interest to governmental and regulatory bodies dealing with decommissioning.

2.7 Radioactive waste disposal

Customised training courses are offered in the field of long-term radioactive waste management. The courses focus on final disposal as the preferred option to long-term radwaste management. Waste disposal requires selection and thorough characterization of a site, characterization of waste packages, and finally demonstration of long-term safety by means of performance and safety assessment. Courses are generally organised in three areas that are very closely linked, i.e.

- Characterization of radioactive waste packages in relation with its disposal;
- Site selection and site characterization;
- Integrated safety assessment modelling.

Training courses typically last for one up to two weeks and generally include hands-on computer sessions, technical workshops or field visits. The courses are directed to individuals having a controlling or supervising role within radwaste agencies or nuclear control bodies, or for technical experts who carry out the characterization of an existing or new site, characterise waste packages, or perform post-close assessments.

3. Approach

Except for the Master in nuclear engineering, all course programmes are tailored to the needs of the students and are available to fit into a larger modular programme.

The courses can be taught at the premises of the customer or at SCK•CEN's Conference Centre, offering fully equipped lecture rooms or at the venue of the customer. The Conference Centre is located next to the technical domain of SCK•CEN, allowing easy access for the practical training sessions. Several laboratories and installations are available and open to national and foreign students.

Fig 3. SCK•CEN's Conference Centre

The team of lecturers includes engineers, physicists, technicians, biologists, occupational physicians and social scientists who all bring insights and ideas from their specific background into the course programmes. As SCK•CEN staff members they have a solid knowledge and experience in their field, and can thus directly transfer their theoretical knowledge and practical experience to the various courses.

4. Graduate thesis, PhD and post-doc research

Next to courses SCK•CEN also offers students the possibility to perform their research work at its laboratories, at several levels.

On a regular basis, final-year bachelor or master students visit SCK•CEN and are guided by our researchers in their dissertation work.

In a conscious desire to increase its pool of highly specialised young researchers and to tighten its cooperation with the universities, SCK•CEN embarked in 1992 on a bold programme to hire about 10 PhD candidates and post-doctoral researchers every year. These early-stage researchers are recruited in the research domains that reflect the priority programmes and R&D topics of our institute.

COMPETENCE BASED APPROACH FOR EDUCATION AND TRAINING OF NUCLEAR ENGINEERS

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ABSTRACT

The Russian higher education standard prescribes that a university graduate should be capable to make the decisions, to take the responsibilities, to find the effective way for solving a non-standard task and the non-standard way for solving a typical task – the features related to so-called competences. Competences represent a combination of attributes – with respect to knowledge and its application, attitudes, skills and responsibilities – that are especially important for nuclear industry where a human error may lead to serious national or even international socio-economic consequences. This paper presents the competence based approach to education being developed in Moscow Engineering and Physics Institute, which is one of the most important suppliers of scientists and engineers for Russian nuclear industry.

1. Introduction

In the time of heightened international interest to the development of atomic engineering the process of preservation and management of nuclear knowledge acquires strategic value. Nowadays the enterprises of this field introduce various training aids, including simulators, systems of remote training, computer training systems and other technical means on the basis of information systems. However in order to maintain the efficiency of this process we need a clear methodological concept allowing to objectively estimate the level of the experts working at atomic power stations.

From the theoretical point of view such a concept can and should be based on modern pedagogical achievements, and from the technical point of view it has to be supported by rapidly developing information technologies. And it is necessary to consider the rates of progress in this area and a fast change of platforms of software products development that, certainly, creates difficulties in the realization of scale projects and causes their reorganization even in the process of their realization. On the other hand, a problem of the staff for new power units, the necessity to reduce the training duration of the staff, the requirement to maintain the flexibility and adaptation of the educational content to the current needs of the field demand fast response to the changes, both in a subject domain, and in a technical part of the realization of the training program for the experts in nuclear sphere.

2. Current trends in Russian higher education

Now in Russia it is possible to refer to the following tendencies in terms of data support of work with the staff and professional trainings, typical of specialized educational institutions and the educational centers at the enterprises of the field:

- increase of the application of IT solutions in the staff training;
- inclusion of "heavy" means of training (such as an analyzer for the research of emergency situations) into the university educational process in order to improve the

quality of the preparation of students;
- application of remote training technologies;
- expanded application of the Internet technologies both for the preparation of students, and for the tasks of the management of the staff qualification.

There are some problems of application and development of the information technologies (IT) in terms of staff training, like university budget constrains, insufficient coordination between universities and enterprises in IT area, unclear mechanism of collection, analysis and dissemination of software products, etc.

So we can speak about the necessity to formalize the process of knowledge management in the nuclear field. The international practice supported by the IAEA (International Atomic Energy Agency) indicates that this problem is considered in all the countries, especially in those where the nuclear power plant construction was postponed or in those where the accelerated implementation of nuclear power is planned. Not to lag behind, first of all, it is necessary to equip the Russian key higher educational institutions with computer training systems, simulators, including simulators of emergencies. It will allow improving the quality of senior students training.

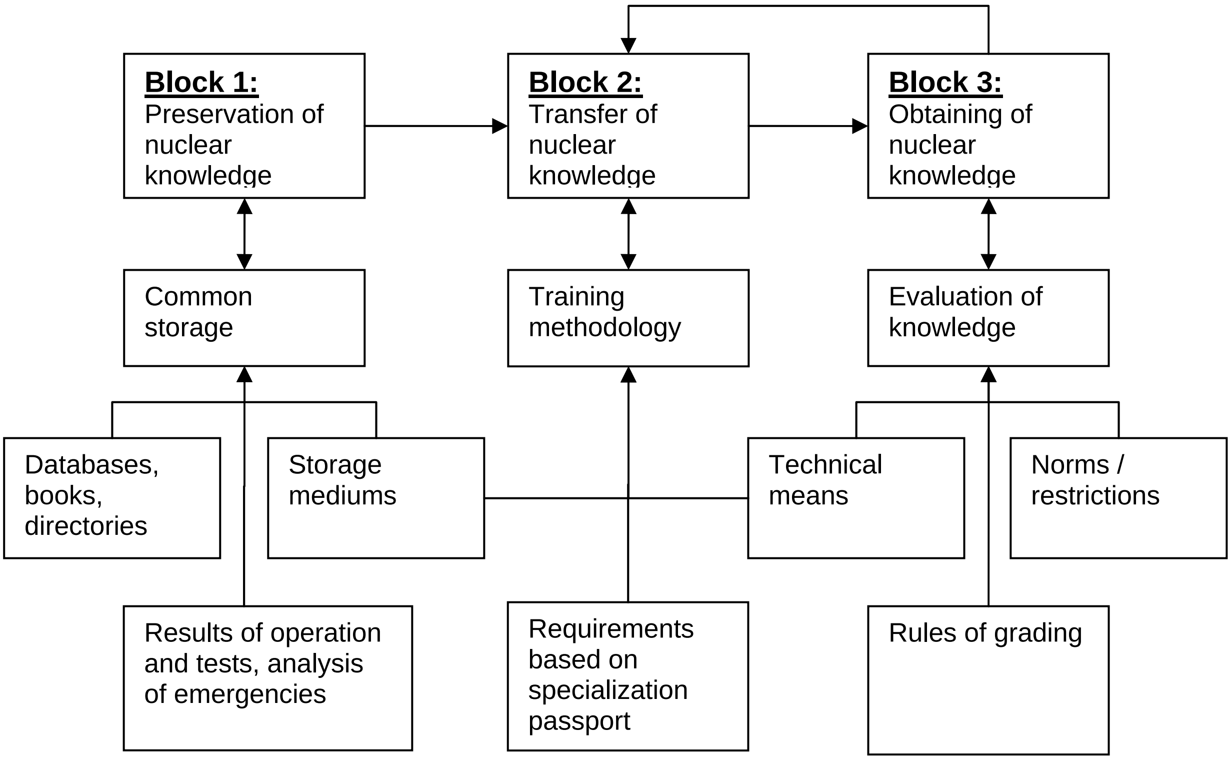

Fig. 1 Model of staff education for nuclear industry

The methodological concept of staff training includes three blocks (Fig. 1):

1. Formation of the well structured common information storerage and organization of its constant updating (preservation of nuclear knowledge).
2. Development of the training techniques based on pedagogical standards and modern training aids considering the possible restrictions such as training terms, economic and organizational factors (transfer of nuclear knowledge).
3. Development of full-function techniques of adequate and comprehensive evaluation of the training process and its results with the obligatory feedback, allowing to adjust the education process (obtaining of nuclear knowledge).

Today the active development of education and nuclear knowledge control methodologies (blocks 2 and 3 above) is being carried out in Moscow Engineering and Physics Institute.

3. Model of competences

The modern view at the methodology of the evaluation of the training results is specially focused on such priorities as free development of the person, formation of the creative initiative, independence, competitiveness and mobility of the future expert. One of the ways of fixing such skills and acquired abilities is the competence-based approach to the estimation of the training results. The competence based approach in education is the implementation of such educational programs that are directed on the formation of the ability to apply the received knowledge and skills independently in a certain context. And the approach covers all the spectrum of personal features, not just those that are purposefully formed through the training of certain disciplines (Fig. 2). Such important factor as the type of the person making critical decisions plays a huge role in the course of functioning of complicated technical systems, in the sphere of high technologies and innovative economy.

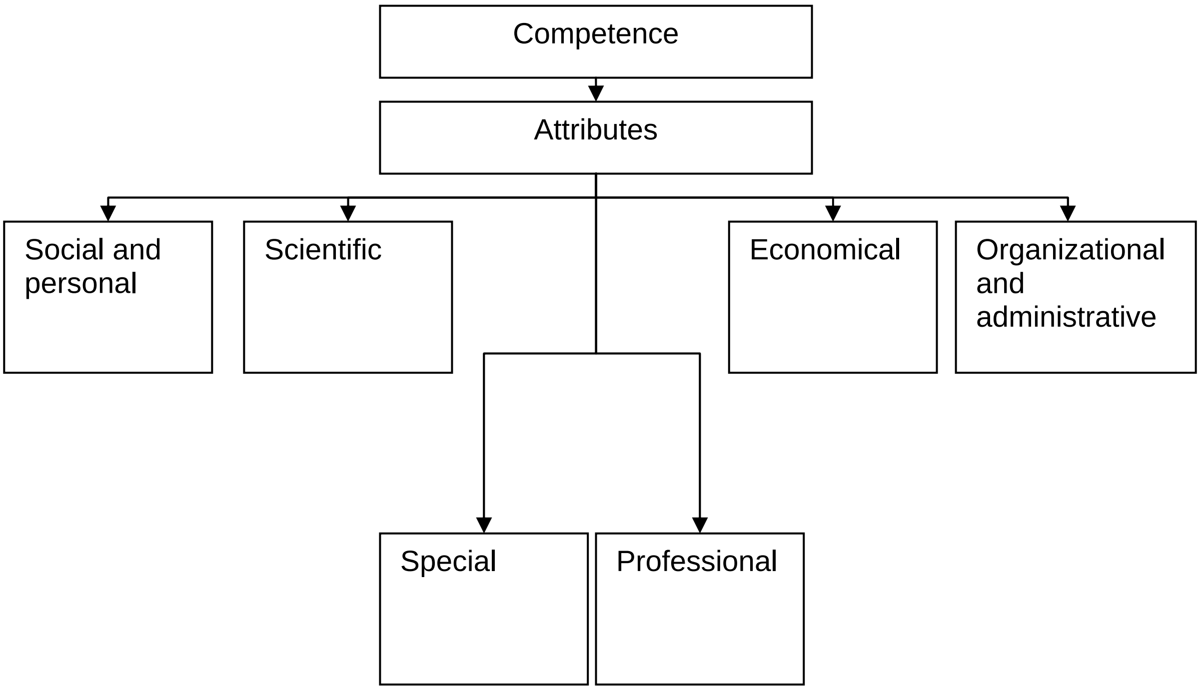

Fig. 2 Classification of competences in Russian education standard

It is necessary to note that the most actual are the techniques developed to deal with the disciplines that are highly critical in respect of cumulative cost of the error committed by the expert. Such disciplines are nuclear physics, nuclear engineering, medicine, transportation, governance and many other spheres of human activity.

Implementation of modern information technologies allows to solve a number of problems providing the students not only with a full-scale access to the necessary knowledge in hypertext, graphic, audio and video formats, but also to the modern systems of information search, and the possibility to model the future activity by means of special software. All that fully corresponds to the ideology of the formation of the expert who not only knows (what) but as well can (how), and the ability to expand the sphere of knowledge and to develop the set of skills independently is being built throughout the whole cycle of the training thus forming general, professional and educational competences (Fig. 3).

Thus using the competence based approach, the quality of the training can be evaluated by means of the model of competences by performing the following three steps:

- Step 1. To develop the global model of competences of a student including general and educational competences and to define the importance of these competences.
- Step 2. To evaluate a level of responsibility for the decisions made in the course of studying of the specialized disciplines.
- Step 3. To develop the specialized model of specific competences and to integrate it into the global model.

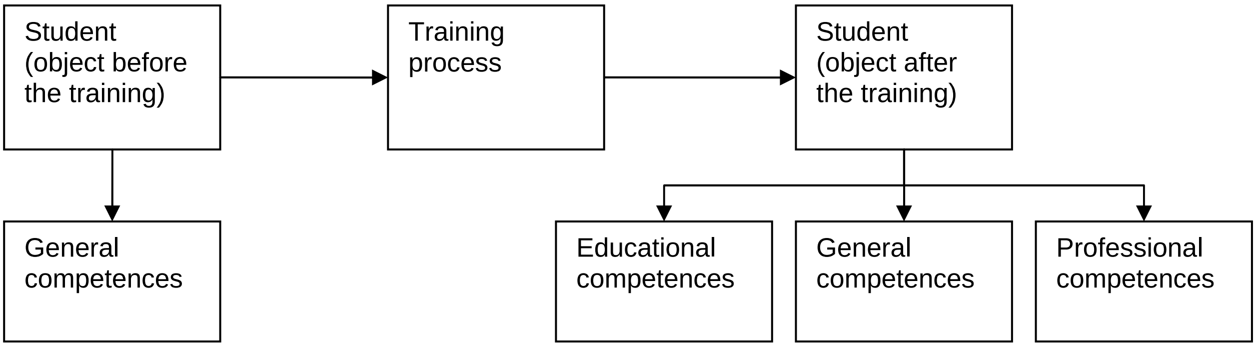

Fig. 3 Model of competences prior and after the training

Steps 2 and 3 are to be performed in accordance with the specific discipline being studied with the strong orientation on its purpose, tasks, detailed content and timetable, as well as on the set of economical and administrative constrains. Under this approach, Step 1 includes the processing of large volume of information and remains independent upon the specific discipline.

4. Results of education

The staff training in nuclear and adjacent matters requires a special attention and systematic approach. The evaluation of the training results depends on a set of various qualities of the individual (psychological, intellectual and personal character). The necessity to evaluate a graduate not just as a professional but also as a person is extremely important in the nuclear field for an error here might cost also human lives and serious environmental problems.

From the pedagogic point of view it is more difficult to develop the skills than to transfer the knowledge because it demands more time and resources. Formation of competences requires special attention according to the state educational standard of the third generation accepted in Russia and bearing in mind the specific of nuclear engineering. It is supposed that the new competence based methodology of the third generation will correspond to the concepts being developed in the frame of the Bologna process which Russia joined in September 2003 at the Berlin meeting of European Ministers of Education.

According to such concepts, the competences are interpreted as the common (coordinated) language to describe the academic and professional profiles and levels of higher education. In the frame of the competence model, a student has to be evaluated in 3 various directions:

- *Knowledge* and *understanding* (theoretical knowledge in the academic area, ability to learn and understand);
- *Knowledge how to do* (practical and operative application of knowledge to concrete situations);
- *Knowledge how to be* (values as an integral part of a way of perception and life with others in a social context).

The main objective of knowledge evaluation is to get the feedback. It is possible because the training is initially conducted on the basis of the constructed interrelations between educational modules and the competences to be formed in the training process. Therefore if the evaluation of a certain competence is out of the allowed range, it would be possible to define educational modules connected with this competence and to change them properly.

5. Conceptual model of knowledge management

According to the competence-based approach it is possible to allocate the basic stages of planning of the training in highly critical spheres. The methodical part (priorities and restrictions):

- Allocation of the target competences that should be developed or improved directly in the course of reception of the corresponding knowledge;
- Developing the hierarchy of competences;
- Attraction of the experts in a subject domain in order to define the priorities of each competence within the frame of the hierarchy;
- Control of judgments of the experts in terms of coordination and if necessary – their adjustment;
- Definition of a vector of the target competences scales to each group and to the hierarchy in general;
- Development of adequate scales and corresponding recommendations about the estimation of competences;
- Setting the restrictions for the minimum level of competence of the expert in general and on the certain competences in particular.

The subject part (cross communications between the information and competences):

- Decomposition of the training course into a set of sections, topics, blocks;
- Setting of a binary vector for the blocks formed as a result of decomposition and creating the list of competences for each of them;
- Resultant definition of the capacity of each block, characterizing the number of included competences and the level of importance of a given block in the creation of the curriculum considering the general estimation of the training results;
- Construction of a corresponding binary vector for each competence helping to define which block influences the given competence;
- Resultant definition of capacity of each competence, characterizing the number of blocks that influence the formation of the given competence and accordingly the number of the resources of various character that should be involved in the creation of the curriculum considering the general estimation of the training results;

The functional part (testing and receiving the feedback):

- Definition of the student’s initial level (entrance testing) and socio-psychological portrait of an individual;
- Definition of the student’s level in the course of training in several control points (intermediate testing), formation of a vector of changes of socio-psychological portrait of individual and accumulation of statistics on mastering thematic material, and formation of skills and abilities.
- Definition of the final level upon the graduating of the training course (final testing), with monitoring of a trajectory of the changes of the results in terms both of knowledge and socio-psychological portrait of the individual;
- Analysis of the results and formation of methodical instructions on modifications of techniques, format, subjects, and duration of the training course in order to achieve required level of separate competences and competence as a whole.

6. Conclusion

The methodology described above is being developed with a focus, first of all, on the creation of the curricula for the universities specializing in the nuclear field. But the basic elements of this methodology can be also used to manage the nuclear knowledge in scientific research institutions, regulatory bodies, and design and utility organizations of the nuclear power complex.

RAPHAEL EUROCOURSE: AN E-LEARNING APPROACH FOR TIMELY DISTRIBUTED COURSES

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ABSTRACT

Following the philosophy of the sixth framework program (FP-6) to produce structured knowledge a new approach of knowledge dissemination has been developed which fits the needs of the EUROCOURSE organised in the scope of the RAPHAEL project on Very High Temperature Reactors. The main challenges which have to be tackled are the timely distribution of the several EUROCOURSE seminars as well as the different scientific background of the participants. This new approach combines classical class based teaching with e-learning components. It is derived from the concept of blended learning and modified to fulfil the needs and boundary conditions introduced by the RAPHAEL project. The experiences from the first seminars show that this approach is usable and well accepted by the participants.

1 Introduction

Since 2004, the RAPHAEL Integrated Project [1] addresses the viability and performance issues of an innovative system for the next generation of nuclear power plants, the Very High Temperature Reactor (V/HTR), which can supply both electricity and heat for industrial applications, including hydrogen production.

In the frame of the Education & Training activities of RAPHAEL, an EUROCOURSE will be organised to disseminate basic knowledge as well as the latest developments to students and young researchers and engineers. The goals of the education and training activities in RAPHAEL are, on the one hand, to attract students to study High Temperature Reactor (HTR) technology and, on the other hand, to bring together experts and students. To establish long term connections between students and experts, and to allow the participants to follow the progress of the project, the EUROCOURSE consists of three seminars distributed over the lifetime of the RAPHAEL project.

In the frame of the RAPHAEL EUROCOURSE concepts have been introduced to fulfil the diverse challenges caused by the different types of participants and their distribution all over Europe. To meet these challenges, EUROCOURSE uses a mixture of classical teaching and e-learning components based on the concept of “Blended learning”.

This paper describes how e-learning concepts can be adapted to timely distributed courses and focuses on a new approach for preserving and extending knowledge in the domain of nuclear science.

2 RAPHAEL EUROCOURSE

The main challenge is that the course is intended for students and young engineers. It has to be taken into account that these groups have a different scientific background. The first group, the students, come from universities all over Europe. They have general but not specific knowledge of nuclear engineering. The latter group, the young engineers, have an extended and more specific and detailed knowledge of V/HTR technology, depending on the task they have to perform at their companies. Another challenge is the timely distribution of the EURCOURSE over the lifetime of the RAPHAEL project, where the time between the course seminars is approximately nine months. Additionally, it has to be taken into account that not all students and young engineers will be able to attend all EUROCOURSE seminars.

The main goal of the RAPHAEL EUROCOURSE is to introduce HTR technology, the historical background of this technology and the reasons why this technology can play an important role in the energy supply in Europe. The course is divided into three seminars, each 3-4 days long and taking place at different locations in Europe. There is an introduction and allows enough time for direct contact between students and experts.

The first seminar aimed to provide a basic overview of HTR technology, discuss different designs, as well as the role of HTR and V/HTR in the scope of Generation IV Reactors and other FP6 projects. Additionally, the inherent safety features of HTR technology, the main phenomena of core physics, and thermal hydraulics in the core were topics of discussion.

The second seminar covered two major topics: The first one was dedicated to fuel elements, their characteristics, and fabrication. The second topic was waste management, especially regarding results of the Plutonium and Minor Actinides (PUMA) [2] project.
This seminar was also supported by IAEA by providing lecturers from outside of EUROPE as well as fund for students from none EURATOM countries.

The third, and last seminar, will address the remaining aspects of an entire HTR plant, such as materials, system, and components, possible applications and processes as well as safety and the results of the subproject system integration.

The topics of all EUROCOURSE seminars consist of

- Core physics
- Thermal hydraulics
- Fuel
- Waste
- Material and components
- Safety
- System integration.

They cover all main aspects of the V/HTR technology and represent the research performed in the RAPHAEL project.

The first seminar was attended by 64 participants from 18 different countries and 32 universities, research centres, and companies. The second one by 54 participants from 14 countries and 26 universities, research centres and companies.

3 Preservation and Extension of Knowledge

To tackle the challenges mentioned above requires a concept how the single seminar can be structured to achieve at the end an integrated knowledge on V/HTR technology. The distribution in time and place requires modern approaches like e-learning concepts, web based technologies, and the combination of the two.

The most convincing e-learning concept for timely distributed courses is the concept called blended learning [3]. Blended learning is an approach quite common in the engineering sciences (e.g. we blend course work, exercises, practical training in various stages, excursions, seminars, and conferences, etc. to improve our own knowledge and that of our students).

3.1 How to select e-learning components for a special course

Blended learning is well organised and continuously monitored. The different learning forms are combined in a way that helps best to reach the goals. It is well known from pedagogical theory that best learning results can be achieved through a mix of methods and media which takes into account both the group of learners and the content of the course to be given. Therefore, to select components for a specific course requires a didactic concept which treats these questions in view of the actual knowledge situation of the learners. This can be reached hardly in conventional teaching but also seems to be impossible to achieve by e-learning methods solely. A mixture is necessary where the teacher takes over all the tasks which require human interaction and the computer gives support in those areas where pure information transfer has to be provided.

3.2 Blended learning course

The following describes a new approach for blended learning courses. They have a typical structure where presence and e-learning phases follow each other (Fig. 1). This course structure can be refined iterative.

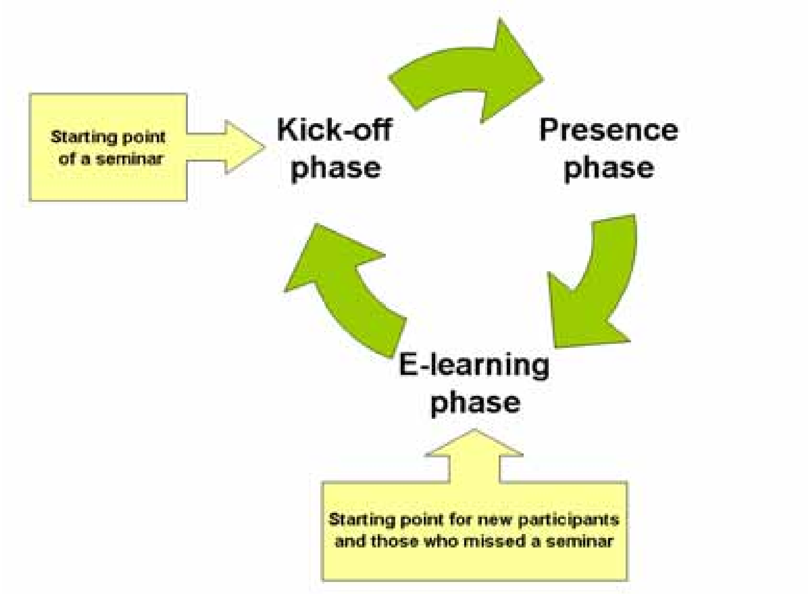

Fig. 1: Blended Learning Cycle

1. **Kick-off phase**
   The Kick-off phase is characterized by providing information about the seminar content and by an introductory session at the beginning of a seminar.

2. **Presence phase**
   The presence phase always starts with the introductory session (Kick-off phase) followed by lectures given by experts of the specific field.

   a. **Training phase**
      Depending on the seminar topics simulation based training will deepen the understanding of the lectures. Technical visits are another option for the training phase to combine theory and practice.

   b. **Evaluation phase**
      Each presentation phase is completed by an evaluation which gives feedback to the organisers how to improve further seminars and courses.

3. **E-learning phase**
   During the e-learning phase the learners can exchange documents and share files among each other. The teacher can provide PowerPoint presentations including audio, video, and animations. They can define exercises which students are able to use to deepen their understanding.

4 Best Practice – Adapting E-Learning Concepts

The blended learning concept fits well to meet the challenges of timely distributed courses. Changes of the concept have been necessary mainly in the production of the e-learning material, because the production of e-learning modules is very time consuming. The lecturers for this EUROCOURSE are selected from the partners of the RAPHAEL project. They do not have this time due to their normal research work. To provide the participants with more than just the presentations all lectures are electronically recorded, so both the presentations themselves and the explanations of the lecturers are available for the e-learning phase.

To bring all participants to nearly the same level of knowledge each seminar starts with the kick off phase by providing the participants with the abstracts and the preliminary presentations as well as useful links to web pages for further information on the seminar topics. To provide this information to all participants a dedicated web server is set up which acts as content provider for all content collected during the seminars.

A dedicated introductory session at the first seminar covering the basics of HTR technology also contributes to bring the participants to nearly the same level of knowledge.

The seminar itself is identical to class based teaching of blended learning, extended by either exercises, for example by simulating the behaviour of an HTR or by technical visits. The information provided serves as basis for the final phase of the seminar, the e-learning phase which allows the participants to work up the content of the seminar. This information also serves as material for the kick off phase of the next seminar together with new abstract and preliminary presentations. This information can also be used by those who could not attend a seminar.

After having completed the EUROCOURSE a set of documents will be available covering nearly all aspects of V/HTR technology which can be reused for further educational and training purposes.

4.1 Tools

Mainly three tools were used during the EUROCOUSE, a web server, a recording tool, and the Sinter Simulation Environment for simulation based training:

The Apache Web Server
A Web server, developed by the Apache Software Foundation, is freely available under the licenses conditions of the Apache Software Foundation [4].

Camtasia Studio
Camtasia Studio [5] is a commercial tool to record presentations. It integrates itself into Microsoft PowerPoint to make recording facile, and is also able to record all actions on a computer screen. It includes an editor, to edit recorded presentation, as well as a tool to convert the recorded presentation in different web based formats like flash.

Sinter Simulation Environment - Simulation based training
One example of simulation based training was included in the first seminar of the EUROCOURSE in Stuttgart.

Fig. 3: Sinter Simulation Laboratory

It was an exercise on the transient behaviour of an HTR core. The Sinter Simulation Environment [6], developed at IKE, offered the participants the opportunity to improve the memorization by training. This web-based tool (Fig. 3) was provided to simulate the withdrawal of the control rods at different velocities. In optimized views, forms for the input data of the most important core parameters were offered and the results were displayed (e.g. neutron flux, and temperature distribution in the core).

5 Conclusions

Until now, two of the three courses have been carried out, with approximately 90 participants and lecturers from Europe and, due to the collaboration with IAEA, from all over the world. The feedback from the participants, after these seminars, was very positive and the high number of participants shows the demand for more courses of this type. Getting a complete overview on HTR technology, as well as having all presentations available online, meets the needs of the participants, and those interested in this technology.

The new approach of blended learning fulfils the demands described above very well. Therefore, it could serve as an example for other timely distributed courses. The tools used to implement the concept are easy to use and do not require a complex and expensive technical infrastructure.

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NUCLEAR EDUCATION FOR A RESTART

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ABSTRACT

The last two decades have been a tremendous waste of opportunities in the nuclear field in our country squandering a relatively advanced position with the first operating nuclear power plant in Latin America. The present scenario imposed by the nuclear renaissance presses strongly on the human resource basis. The principal challenge is to cope simultaneously with the urgent need of prepared personnel and the quality of training required. In this aspect the University is playing an increasingly important role covering knowledge areas which were formerly limited to CNEA. An important campaign is necessary in order to deliver the correct message related to nuclear. It is of paramount importance to improve the public understanding on this technology and the role it can play in solving the increasing energy demand in a world of decreasing energetic resources.

1. Introduction

The last two decades have been a tremendous waste of opportunities in the nuclear field in our country squandering a relatively advanced position with the first operating nuclear power plant in Latin America. Atucha II Nuclear Project is a clear example: halted during almost the same period at 80% completion it has been a sink of funds dedicated almost exclusively to the maintenance of relevant parts waiting for better times to come...

Recently the government has announced and started completion of the plant and the amount of necessary human resources is not there. The scenario is further complicated for two reasons: nuclear is not an attractive choice for students nowadays and the staff of experts with sound experience in previous projects is retired or about to.

The first reason is partly due to the Chernobyl accident and the distorted and unfortunate picture that it draw about nuclear for the general public. Also important has been the inability of the nuclear sector (public and private) in transmitting a clear and credible message about the benefits of nuclear technology in different fields of human life. The second is associated to the lack of funding for nuclear projects for a long period of time and the corresponding gap in training activities.

In the previous context the “Instituto de Tecnología Nuclear Dan Beninson” (IDB) was created associating the Atomic Energy Commission (CNEA) with a Public University, Universidad de San Martín (UNSAM), in order to bring to the academic area training and research activities formerly reserved almost exclusively to the scientific institution. The main subjects involved are:

Nuclear Reactors and their Fuel Cycle
Radiochemistry and Nuclear Applications
Dosimetry and Physics of Radiotherapy
Methodology and Applications of Radioisotopes

These topics in the form of postgrade careers and courses are the core of our academic offer and we point to graduates in engineering, physics, chemistry and related areas. Simultaneously we train personnel for the nuclear sector companies “at demand” and we established a correspondence between both activities in order to optimize the agenda of the Institute personnel (mainly professors) due to the scarcity of senior experts, specially in selected areas.

2. Academic Offer

The Institute was created in december 2006 with a frame agreement between the involved institutions (1) and the academic offer was organized around activities of strong tradition in CNEA and not specifically covered by the other two academic Institutes of CNEA: Instituto Balseiro and Instituto Sábato. These are:

Careers

Specialization in Radiochemistry and Nuclear Applications (2):

It is a one year postgrade career (700 classroom hours). The objective is to provide students with high level knowledge in basic radiochemistry and expertise in the use of installations and equipment necessary for nuclear applications. This career has two orientations: general and radiofarmacy

Specialization in Nuclear Reactors and their Fuel Cycle (3):

It is a one year postgrade career (630 classroom hours). The objective is to provide the students with a general knowledge about the technology of nuclear reactors, the nuclear fuel cycle and the main disciplines involved. This allows an insertion in the professional area in basic or applied work.

Courses

Methodology and Applications of Radionuclides:

This 200 hours course provides the necessary knowledge -theoretical and practical-, for the use of radioactive substances taking into account the due precautions for the radiological protection of the involved personnel, technicians and public. It fulfils one of the basic requirements to get from the regulatory authority, the individual authorization for the manipulation of radionuclides.

Dosimetry in Radiotherapy:

This 200 hours course provides the necessary knowledge for the dose control in patients at a radiotherapy institution, fulfiling one of the basic requirements to get the licence as a Technician in Radiotherapy from the regulatory authority.

Physics in Radiotherapy:

This 360 hours course provides the necessary knowledge for the performance of a physicist in a radiotherapy institution. It is one of the requirements for a physicist to apply for a licence as a Specialist in Radiotherapy to the regulatory authority.

3. Brief historical background

In 1951 Dr . Walter Seelmann Eggebert created the first ***radiochemistry*** group in CNEA. After the installation of the first Phillips cyclotron in 1954 twenty new isotopes were discovered and characterized in few years, after fast radiochemical separations.

From that time radiochemistry applications has diversified enormously from basic science to uncountable industrial applications. Worth mentioning its role in nuclear medicine, and nuclear fuel cycle specially radioactive waste.

The formal training in the area intended to restore an integral vision in the professional career and it began in 1999 with the Master in Radiochemistry (in agreement CNEA-National Technological University) which was discontinued in 2005.

At present the academic activity is concentrated under the frame of CNEA-UNSAM agreement.

With respect to ***nuclear reactors*** the first course was organizad in 1952 briefly after "Nuclear Reactor Theory" from Glasstone Edlund was first published.

Many annual courses followed, always in CNEA, and they were the principal source of professional staff for the nuclear reactor projects, excelling Atucha I and Embalse Nuclear Power Plants. This activity had the academic endorsement of Buenos Aires University-Engineering faculty from 1981 to 1994.

As in the case of radiochemistry the Master in Nuclear Reactors followed (in agreement CNEA-National Technological University) from 1999 to 2005 and at present the preparation of human resources is focused in the career previously described under the frame of CNEA-UNSAM agreement.

As for the ***use of radionuclides*** (4), the first course was delivered in 1958 and since then other 95 followed. Some of them were hosted by different provinces. Up to now more than 1900 professionals graduated among physicians, chemists, physicists, engineers, etc. Recently and due to the high demand we admit technicians who can demonstrate at least five years experience in a nuclear medicine center.

Related to the use of ionizing radiation in human health, ***radiotherapy*** (5) is the application that uses the highest doses and thus requires great precision.

The Dosimetry and Physics of Radiotherapy courses handle these topics and have been doing so since long time.

Once again CNEA has been pioneer in the area preparing human resources with specific courses on radioprotection and nuclear medicine (1958) and radiotherapy (1964). 22 dosimetry courses have been recorded since 1964 with increasing participation of physicists and technicians. Physics of Radiotherapy records 21 courses. In both courses there is a limitation in the number of admissions, beyond the necessary background knowledge, imposed by the hospital practice.

4. Other Activities

A series of activities complementary of the main academic ones are performed at the Institute:

Our activities in the nuclear medicine field are being expanded incorporating short training courses for physicians, physicists and technicians. These courses aim to the use of Proton Emission Tomography combined with Computed Tomography (PET/CT) and the production of the necessary radiofarmacy compounds for diagnosis. This activity is performed with the “Fundación Centro Diagnóstico Nuclear” at Buenos Aires which is provided with the adequate equipment.

Special courses “at request”. As example we can mention the four months full time courses on *“Basic training for operators of nuclear reactors-professional level”* and *“Basic training for operators of nuclear reactors-technician level”*

We are studying the implementation of a career related to energy, all forms of energy, covering technological, economic and political issues. Of course nuclear energy is included but we consider relevant to place it in the adequate context.

Other topics related to nuclear technology are the object of a regular programme of open seminars.

5. Final Remarks

The scenario imposed by the nuclear renaissance in Argentina presses strongly on the human resource basis. The principal challenge is to cope simultaneously with the urgent need of prepared personnel and the quality of training required. In this aspect the University is playing an increasingly important role covering knowledge areas which were formerly limited to CNEA.

The medical and industrial applications of nuclear technology have a predictable demand and there is a regular quantity of professionals willing to orient their careers in these directions.

A very different situation appears related to nuclear power. Here the demand of engineers founds difficulties related with public perception against nuclear and also a competing demand of engineers from other areas were big projects are underway with higher salaries and less public aversion.

An important campaign is necessary in order to deliver the correct message related to nuclear. It is of paramount importance to improve the public understanding on this technology and the role it can play in solving the increasing energy demand in a world of decreasing energetic resources. Also further precisions about the future national priorities in the area will create the conditions and enthusiast the students to enter into the fascinating and challenging world of nuclear technology.

References

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