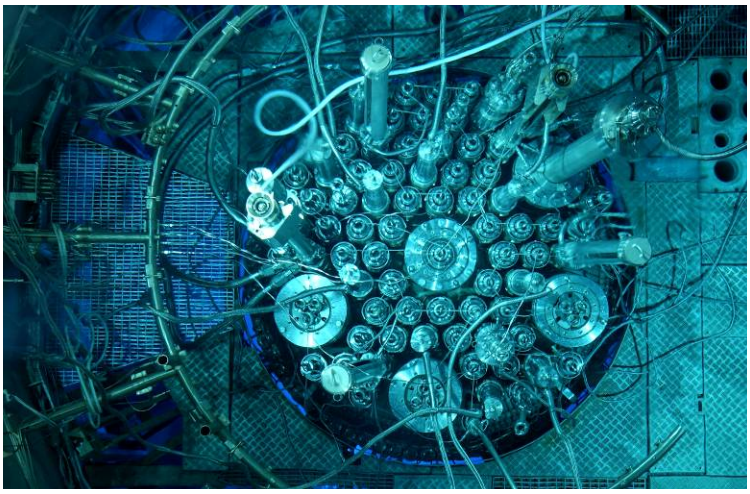
BNEN

Belgian Nuclear higher Education Network – *Boeretang 200, BE-2400 MOL*

Interuniversity programme on nuclear engineering

Your way to the European Master in Nuclear Engineering!



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BNEN is an active member of ENEN,
the European Nuclear higher Education Network
http://www.sckcen.be/ENEN

Table of contents

Introduction

BNEN, the Belgian Nuclear higher Education Network has been created in 2001 by five Belgian universities and the Belgian nuclear research centre (SCK•CEN) as a joint effort to maintain and further develop a high quality programme in nuclear engineering in Belgium. In a country where a substantial part of the electricity generation will remain of nuclear origin for a number of years, there is a need for well-educated and well trained engineers in this area. Public authorities, regulators and industry brought their support to this initiative. In the framework of the new architecture of higher education in Europe, the English name for this 60 ECTS programme is “Master of Science in Nuclear Engineering”. To be admitted to this programme, students must already hold an university degree in engineering or equivalent. For students not fully satisfying this requirement, special entrance consideration apply as explained further in the brochure.

During the preparation of this new “master after master” programme, all partners agreed to strive for top quality goals. Linked with university research, benefiting from the human resources and infrastructure of SCK•CEN, encouraged and supported by the partners of the nuclear sector, this programme should be offered not only to Belgian students, but also more widely throughout Europe and the world. This is why parallel efforts were made to create a European network of academic institutions active in nuclear engineering education, to establish links with the International Atomic Energy Agency (IAEA), with the Nuclear Energy Agency of the OECD (NEA), and other international bodies like the World Nuclear University (WNU).

Today, the European network has been established as an international association of about twenty universities cooperating with the European stakeholders (industry, regulators, research centres), and is strongly supported by the European Commission. Its name is ENEN (European Nuclear Education Network). It is legally based at the premises of the "Institut National Supérieur des Sciences et Techniques Nucléaires" (INSTN) at Saclay, and BNEN is the Belgian pole of this network. Students registering to any of the participating institutions are offered the opportunity to coherently take a part of their basic nuclear education at different places in Europe while cumulating credit units. Practical laboratory sessions and advanced subjects taught in a modular way are also offered to enrich the programmes. A special qualification of “European master” is planned to be awarded in the future to the students who will have obtained their degree with a substantial effort of mobility. The ENEN Association is taking care of the quality of the programmes including their professional relevance, the links with the research world and with the practical training organisations.

Thanks to ENEN, several courses organised by the BNEN consortium are taken by a significant number of foreign students. Their presence gives our lectures an international atmosphere of friendship and competition. The master programme is a demanding programme where students with different high level backgrounds in engineering have to go through highly theoretical subjects like neutron physics, fluid flow and heat transfer modelling, and apply them to reactor design, nuclear safety and plant operation & control. As a more interdisciplinary level, the programme includes some important chapters of material science, with a particular interest for the fuel cycle. Radiation protection belongs also to the backbone of the programme. All subjects are taught by academics appointed by the partner universities, whereas the practical exercises and laboratory sessions are supervised by researchers of SCK•CEN. The final thesis offers an opportunity for internship in industry or in a research laboratory.

The programme structure includes the possibility to spread it over two years, especially to accommodate young engineers working already in the nuclear sector. All students are strongly encouraged to include a period of training abroad, to benefit from the multiple opportunities created by ENEN.

We are conscious that this challenging programme will be able to deliver a considerable number of highly qualified engineers required for the safe and economic operation of the nuclear power plants, not only in Belgium, but also in the world.

Prof. Dr. Ir. Michel GIOT
Chairman of BNEN 2002 - 2004

BNEN Steering Committee

For the academic years 2010-2011 / 2011-2012

Université Catholique de Louvain

Prof. Yann Bartosiewicz Yann.Bartosiewicz@uclouvain.be	Proxy	**Prof. Hamid Aït Abderrahim** hamid.ait.abderrahim@sckcen.be

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Belgian Nuclear Research Centre (SCK•CEN)

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Secretary
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BNEN Agreement

Interuniversity programme in Nuclear Engineering organised within the Framework of the Belgian Nuclear Higher Education Network (BNEN)

This Agreement is made between

1. **Vrije Universiteit Brussel, VUB,**
   represented by, Rector Van Camp

2. **Universiteit Gent, UGent,**
   represented by, Rector Van Cauwenberge

3. **Katholieke Universiteit Leuven, KULeuven,**
   represented by, Rector Vervenne

4. **Université de Liège, ULg,**
   represented by, Rector Rentier

5. **Université Catholique de Louvain, UCL,**
   represented by, Rector Coulie

6. **Université Libre de Bruxelles, ULB,**
   represented by Rector Vincke

and in collaboration with:

Studiecentrum voor Kernenergie/Centre d'Etude de l'Energie Nucléaire, SCK•CEN, a public utility centre, whose registered office is situated at Herrmann Debrouxlaan 40, BE-1160 Brussels, Belgium and laboratories at Boeretang 200, BE-2400 Mol, represented for the purpose of the signature of this Agreement by Prof. Eric van Walle, General Manager and Prof. Frank DECONINCK, Chairman of the Board of Governors.

It replaces the agreement of 2005, which was the continuation of an agreement of 2002.

The partners 1-6 are further called "the Universities". The universities and the SCK•CEN are called Consortium BNEN and partners of BNEN. Further on they will be referred to as “partners”.
Whereas

- the partners are aware that on the European level and in view of the European Research Area a problem exists to keep up the expertise in the nuclear field and that the many efforts from the European Commission and the international agencies, such as the

OECD/Nuclear Energy Agency (NEA), to obtain international collaborative programmes in nuclear science, have to be supported in Belgium;
- in 2000, contacts with European colleagues have resulted in the creation of ENEN, the European Nuclear Education Network that became a non profit international organisation established on September 22, 2003. This organisation is currently receiving the support of the European Commission through several successive projects aiming at the preservation and further development of higher nuclear education and expertise. In particular, through ENEN, locally coordinated teaching activities such as those developed by BNEN receive a European support and an international recognition. For this purpose, ENEN organises among others quality assessments, specialised seminars linked to research, mobility actions of teachers and students, as well as studies around the improvement of teaching and training. In 2005-2006, the quality of the education offered under the BNEN agreement, considered as a pilot internuniversity project, has been externally assessed. The results of this assessement are very positive;
- it has been agreed upon by all Belgian universities that it is of utmost importance for the nuclear safety and the energy provisions of our country, that all academic expertise should be joined in one effort to establish one unique academic programme preparing the personnel for its future functioning in the nuclear industry;
- the partners have since 2002 worked together in a joint programme on nuclear science and technology, named “the Belgian Nuclear Higher Education Network – BNEN”, and have successfully cooperated up till now, hence their belief that this cooperation should be continued and strengthened as follows.

In view of:

On behalf of the Flemish universities :

- the Decree of June 12th 1991 concerning the Universities of the Flemish Community, amendments included, and particularly of the possibilities of interuniversity co-operation such as stated in article 125 of this Decree;

- the Decree of April 4th 2003 concerning the structure of Higher Education in the Flemish Community; and particularly articles 94 and 95 concerning multiple and joint degree programmes;

- the Decree of April 30th 2004 concerning the 'flexibilisation' of Higher Education in the Flemish Community;

On behalf of the French speaking Académies :

- the Decree of the French Community of March 31th 2004 concerning the definition of higher education and its integration in the European higher education system and refinancing the universities.

BNEN Admission Criteria

This programme is open for students:

1. On the basis of their diploma: holders of the degree of:

   - “Burgerlijk ingenieur” and “Bio-ingenieur” from the Flemish Community (Master in Engineering Sciences)
   - “Ingénieur civil” and “Bio-Ingénieur” from the French Community
   - “Burgerlijk ingenieur polytechnicus” from the “Koninklijke Militaire School” at Brussels
   - “Ingénieur civil polytechnique” from the “Ecole Royale Militaire” at Brussels.

2. On the basis of a decision taken by the Teaching Committee based on the evaluation of previous studies and experiences of the candidates and subject to an entrance exam: candidates holding a different higher education degree of the second cycle of a university or a diploma of the second cycle of a non-university higher education from the Flemish or the French community (i.e. Master in de wetenschappen, Master en Sciences, 4 year Master in Engineering,…).

3. Candidates holding a foreign degree of higher education can be admitted within the limits stipulated by the above mentioned Decrees, after evaluation and approval of the Teaching Committee and with observance of the procedural rules of the respective participating universities.

BNEN "entrance-exam" scope for 4 year Master in Engineering and Master in Sciences

Master in Engineering and Master in Sciences (with a degree from a Belgian institute) can only be admitted to the BNEN programme if “they successfully pass an entrance exam”. The material covered by the entrance exam is that of the courses specified below. Practically speaking, the students are encouraged to follow a set of courses (in principle covering the study of 30 ECTS points) as approved by the Teaching Committee of BNEN, as “free student” and take the exams. Upon successfully passing the exams, the student will be admitted to the BNEN programme.

Depending on the university of choice, the make-up courses may be different. Hereunder, an example for the KULeuven is given. As a guideline, the “bridge year” followed by industrial engineers to become ir is taken as a basis. However, some freedom of choice should/may be built in.

Master in Engineering

In total at least 30 ECTS points are to be taken. The emphasis is on math, physics and fundamental engineering. If the students wish so, they can take courses from different universities if that suits them.
For the KULeuven the choice is as follows. The courses 5 and 6 are obligatory.

From the bridge year Master in Engineering to ir
1. - (Aanvullingen) Differentiaalvergelijkingen met inbegrip van de variatierekening (*differential equations and variational calculus*), 6 ECTS
2. - Numerieke wiskunde (*Numerical Analysis*), 5 ECTS
3. - Statistiek en waarschijnlijkheidsleer (*Statistics and probability*), 4 ECTS
4. - (Aanvullingen) Algemene Natuurkunde (*Complements to physics*), 4 ECTS
5. - Thermodynamica en Turbomachines (*Thermodynamics and turbomachines*), 7 ECTS - partim Thermodynamica, 4 ECTS
6. - Warmteoverdracht en vloeistoffenmechanica (*Heat transfer and fluidum mechanics*), 7 ECTS

From the first Master in Science - Physics, 1st lic
7. - Wiskundige Natuurkunde (*Mathematical physics*), 5 ECTS
8. - Kwantummechanica (*Quantummechanics*), 5 ECTS

Master in Sciences

In total at least 30 ECTS points are to be taken. The emphasis is on basic engineering.
If the students wish so, they can take courses from different universities if that suits them.
For the KULeuven the choice is as follows. The courses 5 and 6 are obligatory.

From the bridge year Master in Engineering to ir
1. - Elektrotechniek en elektrische energie (*Electrical engineering and energy*, 6 ECTS
2. - Numerieke wiskunde (*Numerical analysis*), 5 ECTS – not for lic math.
3. - Systeemtheorie en regeltechniek (*System analysis and control theory*), 6 ECTS
4. - Materiaalkunde, deel 2 (*Material science part 2*), 6 ECTS
5. - Thermodynamica en Turbomachines (*Thermodynamics and turbomachines*), 7 ECTS
6. - Warmteoverdracht en vloeistoffenmechanica (*Heat transfer and fluidum mechanics*), 7 ECTS
7. - Ingenieursmechanica (*Mechanics for engineers*), 5 ECTS

The English titles of the course are only for general information. These courses are not taught in English (the handbooks usually are).

For a list of reference books on BNEN prerequisites: http://www.sckcen.be/BNEN

Belgian Nuclear higher Education Network

ID Picture

Academic Year 2011 - 2012

☐ *Unique year* ☐ *Unique year bis* ☐ *Part I* ☐ *Part I bis* ☐ *Part II* ☐ *Part II bis*

Registration form

TO SEND BACK NOT LATER THAN FIRST OF SEPTEMBER 2011
Please complete this form and send it to
Thomas Berkvens / Kris Pennemans:
SCK•CEN, Boeretang 200, B-2400 Mol,
Fax: +32 14 33 25 84 or E-mail: bnen@sckcen.be

APPLICANTS DATA

Private data

Last Name: _____ **First Name:** _____ ❑ **Prof.** ❑ **Dr.** ❑ **Mr.** ❑ **Ms.**

Private address: _____

Zip: _____ **Town:** _____ **Country:** _____

Place of birth: _____ **Date of birth:** _____ **Nationality:**_

Passportnumber: _____ **Date of Issue:** _____ **Valid till:** _____

National register no.:_____________

Professional data

Company: _____ **Address:** ______________________________

Position at company:_______________

Zip: _____ **Town:** _____ **Country:** _____

Phone: _____ **Fax:** _____ **E-mail:** _____

University in which you intend to enroll

○ **K.U.Leuven** ○ **UCL** ○ **ULg** ○ **UGent** ○ **VUB** ○ **ULB**

Please use capitals.

Hereby I apply for registration in the BNEN "Belgian Nuclear higher Education Network". I accept that my application is subject of a selection procedure, and may be refused, if the steering committee decides so, due to any reason. I understand that my travels to Mol (Belgium) and back, my accommodation, my insurances, and the acquisition of the necessary visa have to be arranged and paid individually if I will be selected for participation.

The following documents are attached to my application:
1) A Curriculum Vitae (English knowledge must be stated).
2) A list of courses followed during the university studies. A short description of the content of the following courses: mathematics and physics.
3) A statement about the way of the coverage of the costs of my participation (own sources, home university, grant, fellowship, etc.).
4) A copy of your degree(s).
5) We advise students to provide us a GRE (Graduate Record Evaluation) score. It will help us to make a decision about your application.
6) Proof of registration at the university

Date: Signature: N/A (electronic)

After signing this document the candidate acknowledges that:

- *After acceptance of the application by the BNEN Steering Committee, the candidate is authorised to enrol at one of the partner universities for the 'Master of Nuclear Engineering' (KULeuven, UGent, VUB) or for the 'Master Complémentaire en Génie Nucléaire' (UCL, ULg, ULB).*
- *The acceptance notification only is <u>not</u> sufficient for non-EU candidates to apply for a student visa. Proof of registration in one of the partner universities is needed.*
- *Registration for isolated courses only is <u>not</u> sufficient for non-EU candidates to apply for a student visa.*

BNEN Detailed share of teaching responsibilities

	Total ECTS	KUL	RUG	VUB	UCL	ULB	ULg	Titular
Nuclear energy: introduction	3	3						William D'HAESELEER
Introduction to nuclear physics	3			3				Peter BAETEN
Nuclear reactor theory	8	2	3		3			William D'HAESELEER Jean-Marie NOTERDAEME Hamid Aït ABDERRAHIM
Nuclear thermal-hydraulics	6				6			Yann BARTOSIEWICZ
Operation and control	3		3					NN Greet JANSSENS-MAENHOUT
Reliability and safety	3	3						André POUCET
Nuclear fuel cycle and applied radiochemistry	3						3	Hubert DRUENNE Pierre VAN ISEGHEM
Nuclear materials I	3						3	Jacqueline LECOMTE-BECKERS
Nuclear materials II	3	3						Walter BOGAERTS Eric VAN WALLE
Radiation protection and nuclear measurements	6		4			2		Hubert THIERENS Nicolas PAULY Klaus BACHER
Advanced courses	4					4		Pierre-Etienne LABEAU
Project and internship:	15							
Total:	**60**							

A menu of advanced courses is offered to the students. Students can select from this list, or propose a new course themselves, up to 4 ECTS worth of courses and communicate their choice to Professor P. E. Labeau (pelabeau@ulb.ac.be) in due time.

BNEN Academic Calendar

- Start: Monday 26th of September
- 24 weeks of courses
- 11 weeks for project work and examinations

For a detailed calendar: consult http://www.sckcen.be/BNEN

What are ECTS credits?

ECTS credits are a value allocated to course units to describe the average student workload required to complete them successfully. They reflect the quantity of work each course requires in relation to the total quantity of work required to complete a full year of academic study at the institution, that is, lectures, practical work, seminars, private work – in the laboratory, library or at home – and examinations and other assessment activities.

In ECTS, 60 credits represent one year of study (in terms of workload); normally 30 credits are given for six months (a semester) and 20 credits for a term (a trimester).

ECTS credits are also allocated to practical placements and to thesis preparation when these activities form part of the regular programme of study at both the home and host institutions.

ECTS credits are allocated to courses and are awarded to students who successfully complete those courses by passing the examinations or other assessments.

Ref.: http://ec.europa.eu./education/programmes/socrates/ects/index_en.html

How to translate ECTS in work load - hours?

60 ECTS – 1 year workload or 40 weeks x 45 hours/week = 1 800 hours.

3 ECTS credits represent an estimated work load for the student of 90 hours.
Typically 3 ECTS = 1 teaching module = 20 hours of lectures + 10 hours e.l.s.
e.l.s. = exercises, laboratory sessions, seminars.

For a 3 ECTS course, these 90 hours might be rated as:

- 20 hours lectures x 3.5 = 70 hours. Factor 3.5 or the standard student needs another 2.5 hours to assimilate what has been taught in one hour. This factor also depends on the teaching pace. Some universities foresee more contact hours, go thus somewhat slower, integrate more examples/exercises and apply a factor of 2.5 or 3.
- 10 hours els x 1.5 = 15 hours. Laboratory sessions and/or exercises, without to much of reporting, get a factor 1. With reporting: 1.5.
- 5 hours additional independent reading/study.
- in summary: 70 hours + 15 hours + 5 hours = 90 hours.

A different 3 ECTS course might be rated as:

- 20 hours lectures x 4 = 80 hours
- 10 hours els x 1 = 10 hours
- in summary: 80 hours + 10 hours = 90 hours

An elective/advanced course e.g. a topical day of 1 ECTS or 30 hours:

- 8 hours lectures x 1.5 = 12 hours
- 12 hours report preparation = 12 hours
- 6 hours report writing = 6 hours
- in summary: 12 hours + 12 hours + 6 hours = 30 hours
- remark: reports of 10 to 20 pages, to be handed in two weeks after the event.

Exemptions

Students can ask for an exemption for a particular course or a part of the course.
This request should be submitted in time to the BNEN Steering Committee.
Prior to a formal positive decision from the Steering Committee concerning the requested exemption, students must assume they have to take the course(s).

Note that a maximum of 6 ECTS (credits) can be accepted.

BNEN Laboratory sessions

- Most courses include exercises, lab sessions and/or seminars (els).

- **Attendance to exercises, lab sessions, seminars is compulsory** (2nd teaching committee meeting dd. October 22, 2002). It is strongly recommended to take the els with the course. However in case of motivated "non-possimus", an els attendance might be shifted to another occasion a.o. to the next year.

- The academic responsible for the course, decides on the reporting (number of pages, deadline) as well as on the weight of the els in the final quotation of the overall course.

Costs

Academic students pay the enrolment fee at the respective university.
For continuous professional development programmes, please contact the secretariat.

Communication

Most correspondence concerning the programme goes through the BNEN secretariat (bnen@sckcen.be). However we would also like to ask our students to check their e-mail account of the university on a regular basis.

BNEN Master thesis – project work/internship

General

- The master thesis is an essential part of the post-graduate program for Master of Science in Nuclear Engineering.
- The master thesis is rated about 25% of the students work load or about 10 to 11weeks.
- For more details, consult the specific on http://www.sckcen.be/BNEN
- Thesis guidelines are available on the BNEN website.

Submitting the thesis

- Students are not allowed to submit their master thesis before **the promoter has read and approved the preliminary thesis version by signing the thesis abstract page** (see BNEN website, Thesis section). This preliminary version should not be a rough electronic draft but a complete paper version with pictures, references, etc.

Plagiarism

- Plagiarism is the act of using any part (text, graphs, pictures, …) of a written document authored by a third party, without properly referencing it.

  Students guilty of plagiarism in any course report or in the thesis report of their BNEN programme put themselves at the risk of penalties, which can range from a nil mark for the concerned course to an adjournment.

Prizes on final year thesis (for information only)

- SCK•CEN allots annually a prize of € 1500 to the best university thesis carried out in its laboratories. http://www.sckcen.be
- The Belgian Nuclear Society – Young generation allots a prize of € 1250 to a thesis in the field of nuclear sciences. http://www.bns-org.be
- The Belgian Physical Society awards annually three scientific prizes, € 250 each, to reward the best master thesis in the field of physics. http://www.belgianphysicalsociety.be

BNEN Grants

Denomination

The grants are called BNEN grants, eventually BNEN-XXXX grant, where XXXX stands for the sponsoring company.

Selection

- Grants are awarded on basis of a selection made by the BNEN steering committee.
- Ranking is according to the best academic results.

Admission criteria

- enrolment for the interuniversity program in Nuclear Engineering at a BNEN university (KULeuven, UCL, UGent, ULiège, VUB,ULB)
- applicants are available full time for the studies (60 ECTS in one academic year) or at least half time (60 ECTS spread over two academic years)
- students with a full time employment are not eligible for the grant
- applications are sent to the BNEN administration before August 1.

Application file

An application file consists of, at least:

- a motivated application for a grant
- a curriculum vitae
- transcripts of academic results
- evidence of enrolment for the interuniversity program in Nuclear Engineering
- a declaration on the (non-) employment situation

Grants

- depending on the BNEN financial reach, up to five BNEN grants a year might be given
- the gross grant amounts to € 10.000. The steering committee might decide to increase the gross grant to € 20.000 e.g. to compensate for (higher) travel costs.
- due to administrative reasons, grant instalment may be rather late in the academic year" (the objective: January 15: first payment, April 15: second payment)
-

Advice

Applicants are advised to consult a BNEN professor at their university as soon as possible.

Deliberation Rules

Common criteria for passing course units and for succeeding the BNEN year of study

Article 1 (criteria for passing course units)

A student shall be deemed to have succeeded in a course unit if **at least 10 out of 20 points** or a 'pass' assessment has been awarded.
In both cases a **credit certificate** shall be delivered to the student, unless the enrolment fee was not paid on time or fraud has been established.

Article 2 (weighting)

In order to establish the **percentage** obtained for the BNEN year of study, the individual course results are weighted by the number of ECTS characteristic of that course and/or master project work or thesis.
The BNEN Teaching Committee, at its discretion, can decide to adjust or modify the ECTS allocation of the particular courses and master project work or thesis in general, or for individual students in case those students request credit transfer from earlier course work or from exchange courses. If changes have occurred compared to the previous year, the new arrangement shall be made public at the start of the academic year.
The course units that are only assessed by means of the 'pass/no pass' system are excluded from the calculation of the (weighted or unweighted) percentage.

Article 3 (criteria for succeeding the BNEN year of study)

All courses are graded with marks out of 20; i.e., each result is expressed as x/20 with 0. le. x .le. 20. A grade less than 10/20 is referred to as a 'failing grade'.

Definition:
For each failing grade for a course, the number of 'fail points' is defined as the number of points below 10/20. E.g., a score of 08/20 amounts to two 'fail points'.
If applicable, the number of 'fail points' for several courses is added together to obtain the total number of 'fail points'. E.g., a score of 08/20 for one course and 09/20 for another course amounts to three 'fail points'.

A student shall be deemed to have passed the complete BNEN year of study when one of the following two conditions has been met:

a) s/he has passed all courses of the year of study (10/20 or 'pass'); i.e., a **percentage of 50%** suffices if all courses have been passed successfully.

b) in case of course failure (other than the master thesis/project), a maximum of two scores of 09/20 can be 'pardoned' by the Examination Board, on the condition that every 'fail point' is 'overcompensated' by 2 %-pts in the average percentage score. This means that the Examination Board is willing to award the degree even in the following cases:
student has one 09/20 but at least 52 % on average;
student has two 09/20 but at least 54 % on average.

c) in case of course failure (other than the master thesis/project), a maximum of one score of 08/20 can be 'pardoned' by the Examination Board, on the condition that every 'fail point' is 'overcompensated' by 2 %-pts in the average percentage score. This means that the Examination Board is willing to award the degree even in the following case:
student has one 08/20 but at least 54 % on average.

d) as a rule, in case of a total of more than 2 'fail points' (i.e., the accumulation of all marks short of 10), students will not be 'pardoned'.

e) for the master project/thesis a minimum score of 10/20 is always required.

In exceptional circumstances the Examination Board may decide to award a pass to a student who failed to meet the criteria set forth in the present examination regulation. Each member of the Examination Board or the ombudsperson may request a secret vote. If the Examination Board decides (whether by secret vote or not) to award a pass to the student in such a case, it shall justify its decision by citing the special circumstances that prompted the decision.

In the case of students who follow a part-time or personalized itinerary arranged according to a program of several study years, the Examination Board shall only take a decision on whether a student has passed or succeeded if the latter has obtained results for all the course units of one year of study.

For students not satisfying the requirements to pass as laid down in this Article 3, the decision will be recorded as '*adjourned*', except for an incomplete submission as explained in Article 4.

<u>Article 4</u> (special examination board decisions)

The BNEN examination board may establish that a student:

- is guilty of irregular conduct and decide to impose one of the sanctions as described in the examination regulation of the university of registration.

- has not participated in all exams and has therefore submitted an **incomplete result**, in which case a decision is made to postpone a final judgement on said student. On the transcript, the decision will be recorded as '*incomplete*'.

<u>Article 5</u> (criteria to obtain a Master's degree and levels of achievement)

The student who has passed the BNEN year of study obtains the degree of Master in Nuclear Engineering.
Students who have a reduced study load and whose program of study is divided differently in time, shall obtain the degree of Master when they have passed each of the course units of their program of study, albeit taking into account the conditions set out in Article 3.

A student obtaining the degree of Master shall be awarded with the following levels of achievement:

- *satisfaction* (cum fructum), if the student passes according to the rules laid down in Article 3;

- *distinction* (cum laude), on condition that 68% of the marks have been obtained and that all course units received a mark of at least 10/20;

- *great distinction* (magna cum laude), on condition that 77% of the marks have been obtained and that all course units received a mark of at least 10/20;

- *greatest distinction* (summa cum laude), on condition that 86% of the marks have been obtained and that all course units received a mark of at least 10/20;

- *greatest distinction* (summa cum laude) *with the congratulations of Examination Board*, on condition that 90% of the marks have been obtained and that all course units received a mark of at least 10/20.

For each 9/20 or in case of an 8/20; two and four percentage points, respectively, are added to the above mentioned requirements for levels of achievement. The mention “Congratulations” can not be awarded if there are marks below 10/20.

William D'haeseleer
September 30, 2006

Accepted by the BNEN Steering Committee Meeting nr. 28

Presentation of the BNEN courses and teaching staff

INTRODUCTION TO NUCLEAR PHYSICS

Peter BAETEN peter.baeten@sckcen.be
Professor at the Vrije Universiteit Brussel (VUB – Brussels)
PhD in Nuclear Engineering (1995)
Research field: Reactor Operations, Nuclear Reactor Measurements, Innovative Reactor Systems, Design & Safety.

Teaching duties in BNEN: Introduction to Nuclear Physics
Other Duties:
- Director of the Institute for Advanced Nuclear Systemsat SCK•CEN
- Vice-chair of ESNII (European Sustainable Nuclear Industrial Initiative)
- Lectures "Nuclear Reactor Physics" at the Faculty of Engineering, Department of Electrical Engineering & Energy Technology of the Vrije Universiteit Brussel

OBJECTIVES

- To learn and understand the basic properties of a nucleus
- To understand the role of conservation laws in decay processes and reactions
- To learn the principles of neutron physics related to nuclear fission reaction.

CONTENT

- Nuclear properties (nuclear radius; mass and abundance of nuclides; nuclear binding energy; nuclear exited states)
- Elementary introduction to nuclear models (drop & shell)
- Radioactive decay: radioactive decay law, radioactive mother-daughter chains, natural radioactive chains, types of radioactive decay, units of radioactivity
- Alpha decay
- Beta decay
- Gamma decay
- Types of nuclear reactions: compound nucleus, threshold reactions, concept of cross section
- Interaction of neutrons with matter; general considerations (elastic & inelastic scattering; thermalisation, radiative capture, …)
- Theory of nuclear fission, controlled chain reaction, physical principles of fission reactors
- Thermal and fast reactors: what can be learned from the differences in cross sections

REFERENCE BOOKS ON THE CONTENT

- Krane, K.S. “Introductory Nuclear Physics”, John Wiley, 1987.

PRE-ASSUMED KNOWLEDGE OR PREREQUISITES

Bachelor level lectures on physics, mechanics, mathematics.

REFERENCE BOOKS ON PREREQUISITE

See website www.sckcen.be/bnen → Brochures and Info →
Background books W. D’haeseleer (mathematics)

TEACHING LOAD AND METHODS

- 1 t.m. (3 ECTS ; 24h contact)
- SCK•CEN guidance: 8 hours seminar and laboratory sessions

WAY OF EXAMINATION

Written examination (closed book)

SCK•CEN REFERENCE PERSON

Lucia-Ana Popescu: lucia-ana.popescu@sckcen.be
Jan Wagemans: jan.wagemans@sckcen.be

INTRODUCTION TO NUCLEAR ENERGY

William D'HAESELEER william.dhaeseleer@mech.kuleuven.ac.be

Professor at the Katholieke Universiteit Leuven (KULeuven - Louvain).
Director of the KULeuven Energy Institute
University graduated electro-mechanical engineer - option energy (Burgerlijk Elektrotechnisch-Werktuigkundig
Ingenieur, optie energie); KULeuven, 1980
University graduated Nuclear Engineer (Burgerlijk Ingenieur Kernwetenschappen); KULeuven, 1982
Master of Science in Electrical Engineering; University of Winconsin-Madison, USA, Dec 1983

Doctor of Philosophy (PhD) in Engineering – Transport Phenomena in Plasmas; University of Winconsin-Madison,

USA, May 1988

Professional Record

1982 – 1988 Research Assistant at the University of Wisconsin-Madison, USA
1988 – 1993 Postdoctoral Euratom Fellow at the NET Team, Max-Planck-Institut für Plasmaphysik, Garching-bei-München, Germany
1993 – 1996 Mechanical Design Section Manager, and R&D Manager Nuclear Department, Tractebel Energy Engineering, Brussels
1996 – present Professor at the KULeuven

Research field

Energy system analysis, including rational use of energy, CO_2-emissions due to energy conversion, energy
conversion technologies ranging from combustion-related technologies to nuclear fission and fusion, renewables
and fuel cells; energy policy.

Teaching duties in BNEN

- Introduction to Nuclear Energy
- Nuclear Reactor Physics (partim)

Other activities: member of the Scientific Advisory Committee on Reactor Safety Fuel and Materials and Fuels of SCK•CEN, chairman of the External Advisory Committee on Thermonuclear Fusion of the European Commission, chairman of the division Energy of the Royal Flemish Association of Engineers (KVIV-TI), chairman of Cogen-Vlaanderen.

OBJECTIVES

- To place the world and the Belgian nuclear energy production in its economic, social, technical and cultural context
- To give a first overview of nuclear electricity generation and an overall introduction to reactor and plant engineering.

CONTENT

- Global energy issue: world energy needs (developing world), greenhouse effect, liberalisation of the energy markets, strategic independence of the EU.
- Environmental issues
- Birds-eye view of nuclear power generation: principle of generating electricity by nuclear means (fission; chain reaction; heat transfer to coolant; turbine; alternator); fissile & fertile materials; burn up; production of fission products; breeding; current types of power plants (PWR, BWR,…); future types of power plants (LWR-type, gas cooled, ADS, …); introduction to the fuel cycle; front end, back end; introduction to safety aspects of nuclear reactors (criticality; core melt); engineered safety systems; risk; difference with research reactors & fusion reactors; proliferation issues & safeguards
- Economics of nuclear power generation: European Utility Requirements; life time of existing NPP's; cost of nuclear kWh; investment costs of new types NPP's; construction time and licensing process; decommissioning costs; internalisation of waste management; external costs

- Public perception & communication (media, general public, public authorities).

REFERENCE BOOKS ON THE CONTENT

Textbook followed:

- John R. Lamarsh & Anthony J. Baratta, “Introduction to Nuclear Engineering”; 3-rd Ed., Prentice Hall, Upper Saddle River, NJ, 2001 (ISBN 0-201-82498-1)

Other interesting books:

- Ronald Allen Knief, “Nuclear Engineering; Theory and Technology of Commercial Nucler Power”; 2-nd Ed., Taylor & Francis, Washington DC, 1992
  (ISBN 1-56032-089-3)
- David Bodansky, “Nuclear Energy; Principles, Practices, and Prospects”; 2-nd Ed., Springer, Berlin/New York, 2004 (ISBN 0-387-20778-3)

PRE-ASSUMED KNOWLEDGE OR PREREQUISITES

Students are supposed to have a solid knowledge in basis engineering sciences such as thermodynamics, fluid mechanics, heat transfer, material science etc. (Level of electro-mechanical university graduated engineers is optimal.

REFERENCE BOOKS ON PREREQUISITE

See website www.sckcen.be/bnen → Brochures and Info → Background books W. D’haeseleer

TEACHING LOAD AND METHODS

- 1 t.m.
- It includes an introduction to SCK•CEN activities and a visit to SCK•CEN library.

WAY OF EXAMINATION

Open book preparation of two or three (generally overview) questions. Students can take notes during the 30 min preparation. Using the just made notes, students will then be interrogated orally to check whether they have thoroughly understood the study material. Questions are oriented towards understanding and insight.

SCK•CEN REFERENCE PERSON

Gert Van den Eynde: gert.van.den.eynde@sckcen.be

NUCLEAR THERMAL HYDRAULICS

Yann BARTOSIEWICZ yann.bartosiewicz@uclouvain.be
Professor at the Université Catholique de Louvain (UCL – Louvain-la-Neuve)
Master in Turbulence modeling and Transfer Phenomena, Ecole Nationale Polytechnique de Grenoble, France, 1998.
PhD in Mechanical engineering, Université de Sherbrooke, Canada, 2003: Modeling of supersonic plasma jets in non-Local Thermodynamics Equilibrium

Research fields: Fluid mechanics, heat transfer, compressible flows, two-phase flows, thermodynamics, computational fluid dynamics

Teaching duties in BNEN: Nuclear Thermal Hydraulics

Other research activities: scientific leader for UCL in European projects in nuclear thermal-hydraulics:

NURESIM: CFD Simulation of instabilities in a stratified two-phase flows relevant to PTS scenario
NURISP: Simulation of two-phase chocked flows during LOCA: implementation of non-equilibrium models in CATHARE 3

THINS: Direct and Large Eddy Simulation (DNS/LES) of convective heat transfer for low Prandtl fluids (Liquid metals)

UCL Promotor of other projects in energy

Other duties: Member of the CFD group at OECD, Member of the European Nuclear Engineering Network (ENEN)

OBJECTIVES

- To be familiarised with various reactor types and their main design and operational characteristics
- To learn how to estimate the volumetric heat generation rate in fission reactor cores under normal operation and shutdown conditions
- To learn how to analyse the thermal performance of nuclear fuel elements
- To learn the basic fluid mechanics of single phase reactor cooling systems
- To learn to calculate pressure drop in reactor systems, including tube bundles, and spacer grids
- To learn to analyse the heat transfer characteristics of single phase reactor cooling systems
- To learn the basic fluid mechanics of two-phase systems, including flow regime maps, void-quality relations, pressure drop, and critical flow
- To learn the fundamentals of boiling heat transfer, and its implications for reactor design
- To learn the fundamentals of core thermal design, with attention to design uncertainty analysis and hot channel factors.

CONTENT

- Reactor heat generation
- Transport equations (single-phase & two-phase flow)
- Thermal analysis of fuel elements
- (Single-phase fluid mechanics and heat transfer)—usually already known
- Two-phase flow dynamics
- Two-phase heat transfer
- Single heated channel; steady state analysis
- Single heated channel; transient analysis
- Flow loops
- Utilisation of established codes and introduction to advanced topics (modelling and thermalhydraulics for GEN4 reactors)

REFERENCE BOOKS ON THE CONTENT

- Todreas, N.E. and Kazimi, M.S. Nuclear System I: Thermal Hydraulic Fundamentals, Hemisphere Publishing Corp., New York, 1990.
- Todreas, N. E. and Kazimi, M.S. Nuclear Systems II: Elements of Thermal Hydraulic Design, Hemisphere Publishing Corp., New York, 1990.

TEACHING LOAD AND REFRENCE

- 2 t.m.: 40h teaching + seminar and 15h practical works in classroom
- SCK•CEN guidance for demonstrations with codes
- SCK•CEN + UCL TA for practical works

WAY OF EXAMINATION

Closed book - oral

SCK REFERENCE PERSONS

Simon Vanmaercke: simon.vanmaercke@sckcen.be

NUCLEAR REACTOR THEORY

William D'HAESELEER william.dhaeseleer@mech.kuleuven.ac.be

(Cf. Nuclear energy introduction)

Jean-Marie NOTERDAEME jmn@ipp.mpg.de

Professor at the Universiteit Gent (UGent - Ghent)
Head, ICRF Group of the Max-Planck Institut für Plasmaphysik, Garching, Germany
Burgerlijk Werktuigkundig-electrotechnisch Ingenieur (UGent, 1977)
Master of Science in Nuclear Engineering, Massachusetts Institute of Technology, 1978
Ph.D. in Nuclear Engineering, Massachusetts Institute of Technology, 1983

Research Field: Heating and Control of thermonuclear plasmas with electromagnetic waves

Teaching Duties in BNEN: Nuclear Reactor Theory (II)

Other duties: Chairman of the UGent Educational commission on Nuclear Engineering, member in the board of governors of ENEN, member of the European Coordinating Committee on Fast Wave, Coordinator of EnTicE (European network for Training ion cyclotron Engineers – a European Fusion Training Scheme), member of the executive board of FUSENET

Hamid AÏT ABDERRAHIM hamid.abderrahim@term.ucl.ac.be or haitabde@sckcen.be

Professor at the Université Catholique de Louvain
(UCL – Louvain-la-Neuve)
Director of the Institute of Advanced Nuclear Systems (SCK•CEN)
Ingénieur Industriel énergie nucléaire (ISIB,1983),
DEA en Physique des Réacteurs (Université d'Orsay Paris XI / INSTN-Saclay, 1984),
Docteur en sciences (Université d'Orsay Paris XI, 1990).

Research field: nuclear reactor engineering & design, Accelerator Driven Systems modeling & design,

Experimental core physics, Reactor Dosimetry, Reactor theory.
Author of approximately 50 papers on these topics.

Teaching duties in BNEN: Nuclear Reactor Theory (III)

Other duties: member of the Scientific Advisory Committee of GEDEPEON French Research Association,
Member of the FP6 EUROTRANS Project Coordination Committee,
Coordinator of the FP6 PATEROS Project (Partitioning and Transmutation European Roadmap for Sustainable nuclear energy).

OBJECTIVES

- To understand the physical processes involved in a nuclear reactor
- To understand and be able to write down and solve the basic equations
- To be able to simulate a reactor/source configuration as appropriate depending on:
  - number of dimensions;
  - steady state or transient;
  - number of groups;
  - delayed neutron precursors;
  - space dependent properties and grid spacing.
- To learn how to measure neutron distributions and parameters relevant for nuclear reactors, in particular reactivity and reactivity coefficients

CONTENT

- Physics of nuclear reactors
- Transport and diffusion
- Spatial dependence
- Slowing down theory
- Resonance integrals

- Cell calculations
- Neutron thermalisation
- Multigroup equations
- Reactivity and control
- Reactor dynamics
- Reactor codes
- Neutron sources and detectors
- Basic measurements: source strength, neutron flux (activation analysis, neutron counting), neutron spectrum (time of flight methods, unfolding methods), reaction rates
- Activity, dose and cross-section measurement
- Measurement of neutron transport parameters: stationary methods, pulsed neutron experiments
- Measurement of reactivities (and reactivity coefficients): survey, static methods, dynamic measurements, inverse kineticsStatistical fluctuation method: reactor noise, mathematical analysis, applications (Rossi-alpha, sign correlations, zero crossings)

REFERENCE BOOKS ON THE CONTENT

- J.J. Duderstadt and L.J. Hamilton, “Nuclear Reactor Analysis”, 1976 (Wiley & Sons)
- Lamarsh, J.R., “Introduction to Nuclear Reactor Theory”, Addison-Wesley, Reading, Mass., 1966
- Profio, A.E., Experimental Reactor Physics, J. Wiley, 1976

PRE-ASSUMED KNOWLEDGE OR PREREQUISITES

Mathematics as discussed in the list of background books by W. D'haeseleer (differential equations, taylor expansions, fourier expansions, bessel functions)

REFERENCE BOOKS ON PREREQUISITE

- See website www.sckcen.be/bnen → Brochures and Info → Background books W. D’haeseleer (mathematics)
- A further good book is : Advanced Calculus for Applications, F.B. Hildebrand, Prentice Hall

TEACHING LOAD AND METHODS

- 2.5 t.m. , 45 hours lectures, 45 hours lab. sessions, 15 hours independent study
- SCK•CEN guidance: use of codes: 1 day
- Use of a critical assembly at SCK•CEN

WAY OF EXAMINATION

Open book, written examination

SCK•CEN REFERENCE PERSON

Guido Vittiglio: guido.vittiglio@sckcen.be

Gert Van den Eynde: gert.van.den.eynde@sckcen.be

Geert Van den Branden: geert.van.den.branden@sckcen.be

RADIATION PROTECTION AND NUCLEAR MEASUREMENTS

Hubert THIERENS hubert.thierens@ugent.be

Professor at the Universiteit Gent (UGent - Ghent)
Ph.D. in radiation physics
Special doctorate in radiation physics
Research field: Dosimetry and radiation protection issues in applications of radiation in industry and medicine
Teaching duties in BNEN: Radiation Protection and Nuclear Measurements (part-time)
Certificates: Expert class I
Other duties: department head radiation protection UGent, member of the national health council, member of the medical jury ionising radiations, referee for different international journals.

Nicolas PAULY nipauly@ulb.ac.be

Klaus BACHER klaus.bacher@ugent.be

OBJECTIVES

The aim of the course is:

- to introduce the student to the physical principles of the interaction of subatomic particles and high-energy radiation with matter
- to learn how to apply the concepts of external/internal radiation dosimetry
- to introduce the student to the biologic effects of ionising radiation
- to learn how to apply dispersion models
- to be able to calculate the effects of shielding materials
- to know the concepts and legislation of radiation protection
- to give an overview of the different methods for detecting and quantifying the presence of such particles and radiation
- to give an introduction to the principles of particle acceleration

CONTENT

Part N. Pauly

- Introduction to subatomic physics
- Reminder on special relativity
- Reminder on probability theory
- Interactions of charged particles in matter
- Interactions of X and gamma rays in matter
- Neutrino interactions
- Detectors based on ionisation in gases
- Detectors based on ionisation in semiconductors
- Detectors based on scintillation
- Neutron detectors
- Electronics for nuclear detectors

Part H. Thierens and K. Bacher

1: Radiological quantities and units

1.1 : Exposure and kerma
1.2 : Absorbed dose
1.3 : Equivalent dose

1.4 : Effective dose
1.5 : Operational dose quantities

2: External dosimetry
- 2.1 : Ionometry of low energy photon fields
- 2.2 : High energy photon fields: the Bragg Gray relation
- 2.3 : Dosimetry of neutron fields

3: Internal dosimetry
- 3.1 : Concept of committed dose equivalent
- 3.2 : Concept of specific effective energy
- 3.3 : Compartmental model analysis
- 3.4 : Dosimetric model for the respiratory system
- 3.5 : Dosimetric model for the gastrointestinal tract
- 3.6 : Dosimetric model for bone
- 3.7 : Metabolic data of important fission products and actinides

4: Biological effects of ionizing radiation
- 4.1 : Deterministic and stochastic effects
- 4.2 : Overview of direct effects including utero
- 4.3 : Overview of late effects: the UNSCEAR report
- 4.4 : Biological effect models used in radiation protection

5: Engineering aspects of radiation shielding
- 5.1 : Build up factors
- 5.2 : Shielding of photon fields
- 5.3 : Shielding of combined neutron-photon fields

6: Dispersion of effluents from nuclear facilities
- 6.1 : Meteorology of dispersion
- 6.2 : Diffusion of effluents-Pasquill conditions
- 6.3 : External dose from plume
- 6.4 : Internal dose from inhalation

7: Legislation and regulations
- 7.1 : The ICRP 103 publication
- 7.2 : The conceptual framework of radiological protection
- 7.3 : The system of protection in occupational and public exposures
- 7.4 : The system of protection in interventions, accidents and emergencies

8: Measurement techniques in radiation protection
- 8.1 : Ionometry
- 8.2 : Film dosimetry
- 8.3: TLD dosimetry
- 8.4: OSL dosimetry

REFERENCE BOOKS ON THE CONTENT

- The PowerPoint presentations of the lectures, and extensive lecture notes, are available on the BNEN website.

Other useful references:

- Stefaan Tavernier, Experimental techniques in Nuclear and Particle Physics, Springer Verlag, 2010
- Glenn Knoll, Radiation detection and measurement, John Wiley & Sons, 2000

- N.M. Schaeffer, "Reactor Shielding for Nuclear Engineering", Atomic Energy Commission, USA, 1973
- A.E. Profio, "Radiation Shielding and Dosimetry", Wiley, NY, 1979
- J. Wood, "Computational Methods in reactor Shielding", Pergamon Press, Oxford, 1982
- Herman Cember, Thomas Edward Johnson, "Introduction to health physics', The McGraw-Hill Companies, 2008
- ICRP, "Publication 103: Recommendations of the ICRP", Elsevier, 2008

PRE-ASSUMED KNOWLEDGE OR PREREQUISITES

It is assumed that the students have a good background in basic physics as is usually part of the curriculum of the first two years of engineering, physics or mathematics. More in particular they should be familiar with classical theory of electromagnetism and classical mechanics.

An introductory level knowledge to electronics and circuit theory is also assumed.

Students should preferably also have an elementary knowledge of special relativity.

The course contains a short reminder of this subject, but this is probably difficult to comprehend for students who never had an introduction to special relativity. A basic knowledge of quantum mechanics is helpful but not essential.

REFERENCE BOOKS ON PREREQUISITE

- University physics, Hugh D. Young, Roger A. Freedman
- The art of electronics, Paul Horowitz, Winfield Hill, Cambridge University press

TEACHING LOAD AND METHODS

- 2 t.m. ; 36 hours of lectures, 5 lab sessions of ½ day
- laboratory work (SCK•CEN)

WAY OF EXAMINATION

Written examination. Exercise part: "open book", theoretical part "closed book".

Report of lab sessions account for 20% in the total mark.

SCK•CEN REFERENCE PERSON

Robbie Nijs: robby.nijs@sckcen.be

OPERATION AND CONTROL

NN

Greet JANSSENS-MAENHOUT greet.maenhout@jrc.it

Professor at the Universiteit Gent (UGent - Ghent)
Researcher at the Joint Research Centre Ispra (Italy),
Burgerlijk ingenieur natuurkunde (UGent, 1993), Doktors der Ingenieurswissenschaften (Maschinenbau, University Karlsruhe, 1998)

Research field: Nuclear safety and safeguards: (a) numerical modelling and experimental investigation of two-phase flow with heat transfer, (b) description of interfacial effects in micro-fluid dynamics.

Teaching duties in BNEN: Operation and control

Other duties: member in the “exzellenten Nachwuchsförderprogramm” of the Karlsruhe Research Centre, active member in the European Multiphase Sciences Institute.

OBJECTIVES

- To learn how to operate a nuclear reactor
- To seek the safe limits of operation of a nuclear reactor
- To study specific problems of measurement and control in nuclear reactors
- To obtain knowledge on nuclear reactor safety under accidental conditions emphasis is on PWR technology

CONTENT

- Fuel burnup and the basic principles of core reloading
- Variation of reactivity during a normal operating cycle of the reactor (burnup, moderator effect, Doppler effect, poisoning)
- Power distributions, Xe effect, Xe oscillations
- Operating modes, operating limits and protection diagram
- Measurement systems and their specific problems in the nuclear reactor
- Automatic control systems and their performance in transient and steady-state operation
- Safety requirements and advanced safety features of NPP
- An overview of the major Design Base Accidents, consequences and mitigation
- Visit of a Nuclear Power Plant (NPP)
- Seminar on reload calculations: tools used and economic considerations

REFERENCE BOOKS ON THE CONTENT

Collection Génie Atomique
"La chaudière des réacteurs à eau sous pression"
Ed. EDP Sciences, 2004
(No dedicated reference book in English has been identified at present.)

Pre-assumed knowledge or prerequisites

- It is advised that this course is taken after the following ones, because a number of topics in these courses are assumed known to the student:
- Nuclear Energy: introduction (must)
- Introduction to Nuclear Physics (advised)
- Nuclear Reactor Theory (advised)
- Nuclear Thermal-hydraulics (advised)

Reference Books on prerequisite

- See the recommended reference books for these courses
- See also www.sckcen.be/bnen → Brochures and Info → Background books W. D'haeseleer

Teaching load and methods

- 1 t.m. / 20 hours of lectures
- Visit of a NPP
- Two 1/2 day seminars on reload calculations

Way of examination

- Individual oral exam, closed book, no written preparation

NUCLEAR MATERIALS Part I

Jacqueline LECOMTE-BECKERS jacqueline.lecomte@ulg.ac.be
Professor at the Université de Liège (ULg - Liège)
Ingénieur Civil Physicien, 1978, ULg
Dr en Sciences appliquées, 1985, ULg

Research field: Specialization: metallurgy and materials science
Main field: metallography, phase transformation, metallic materials, thermo physical properties, microscopy.
Current research interest: phase transformation in high alloyed steels, iron and non-ferrous materials, determination of thermo physical properties, effect of inclusions in high alloyed steels.

Teaching duties in BNEN: Nuclear Materials I

Editorial duties: Referee for the journal Physica status solidi.

Other duties: Belgian representative in European Cost Committee: Cost 504, Cost 503, Cost 517, Cost 522 and Cost 541, CostMP0 903; member of Société Belge de Microscopie; member of American Society for Metals; member of Iron and Steel Society; member of Société française de Matériaux;
Vice-chairman and editor of the 6th, 7th Liège and 8th international conference on advanced materials for power Engineering (2002-2006-2010). Member of the scientific committee of the international conference on carbon-free power generation (2012)

OBJECTIVES

- To familarise students with the basic aspects of material science as they apply to nuclear systems
- To learn the basic processes of material degradation and ageing due to the nuclear environment (esp. radiation effects and fatigue).

CONTENT

- Brief review of most important mechanical properties of materials
  - stress-strain relationship
  - ductile and brittle fracture; ductile-brittle transition
  - fatigue failure
  - creep
- Stress analysis: stress intensity, thermal stresses
- Functional requirements of materials in a nuclear environment
  - “nuclear” materials: fuel, fuel cladding, moderator/reflector, coolant
  - structural materials: reactor internals and vessel, piping, valves
- Degradation mechanisms of materials in a nuclear environment
  - radiation effects: general principles, atomic displacements, embrittlement, swelling fatigue: due to thermal stresses and stratification
  - corrosion: p.m. (to be developed in course “Nuclear Materials II”)
- Introduction on treatment of important materials in a nuclear environment (especially nuclear-mechanical interactions and relationships)
  - fuel and cladding
  - moderator/reflector
  - structural materials (incl reactor internals, reactor vessel).

REFERENCE BOOKS ON THE CONTENT

- Benjamin, M., Nuclear Reactor Materials and Applications, Van Nostrand Reinhold, 1983.
- Glasstone, S. & A. Sesonske, Nuclear Reactor Engineering, 4-th Ed, Vol 1, Chapman & Hall, New York, 1994 (Chapter 7: Reactor Materials, pp 406-462).

PRE-ASSUMED KNOWLEDGE OR PREREQUISITES

Basic chemistry, material behaviour.

REFERENCE BOOKS ON PREREQUISITE

See website www.sckcen.be/bnen → Brochures and Info → Background books
W. D'haeseleer

TEACHING LOAD AND METHODS

- 1 t.m.
- Visits to SCK•CEN laboratories

WAY OF EXAMINATION

Oral examination; written preparation.

SCK•CEN REFERENCE PERSON

Eric van Walle: eric.van.walle@sckcen.be

NUCLEAR FUEL CYCLE AND APPLIED RADIOCHEMISTRY

Hubert DRUENNE hubert.druenne@gdfsuez.com

Lecturer at the University of Liège (ULg – Liège).
Ingénieur Civil Mécanicien (FPMons – 1981).
Principal Engineer at TE – Tractebel Engineering, Nuclear Department.
Major assignment at TEE: Cycle safety evaluation, fuel design, nuclear fuel management strategy for GDF DUEZ group. Teaching for the new comer (Core Reactivity Control) and in the frame of Suez Nuclear Trainees Program (The fuel cycle).
Teaching duties in BNEN: The fuel cycle: Front end and in-core management.
Other duties: member of the TWGFPT – Technical Working Group for Fuel Performances and Technology, IAEA, Vienna
Author of several papers for international conferences, about the fuel recycling: technical and economic analyses.

Pierre VAN ISEGHEM pierre.van.iseghem@sckcen.be

Invited lecturer at the University of Liège (ULg – Liège).
Burgerlijk ingenieur Metaalkunde (KULeuven, 1973).
Teaching duty in BNEN: the back-end of the fuel cycle.
Coordinator of the Research on Waste & Disposal at SCK•CEN since 2004. Before he was project leader and section manager of the waste package studies section at SCK•CEN.
Research field: chemical durability of different nuclear waste forms in disposal conditions; characterization of radioactive waste and waste packages; general R&D on the immobilisation and disposal of radioactive waste.
Other duties: member of the Steering Committee of ENTRAP (European Network of Testing Facilities for the quality checking or Radioactive Waste Packages).
Authored or co-authored over 100 papers in scientific journals or proceedings, member of various international expert committees, organized various international workshops or conferences.

OBJECTIVES

The objective is to provide students an overall view of the fuel cycle, from cradle to grave:

- The front-end of the fuel cycle: ore extraction, conversion and enrichment, fuel fabrication and use in the power plant, spent fuel reprocessing and recycling of re-enriched reprocessed U and Pu as MOX in PWR.
- The back-end of the fuel cycle: the radioactive waste management, ranging from waste characteristics, waste treatment technologies, disposal technologies, safety assessment of geologic disposal.

CONTENT

First part – The front-end of the fuel cycle (H Druenne)

- Uranium extraction and treatment of ores; worldwide resources and needs; costs
- Conversion of concentrated ores
- U enrichment: Basic principles of isotopic separation.Various techniques (gaseous diffusion, ultra-centrifugation, photo-excitation and ionisation with lasers, others). Theory of the cascade (for a symmetrical cascade) ; world capacities.
- Description of the current fuel types and Fabrication
- Basics of the in-core fuel management
- Residual heat
- Reprocessing of UO_2 fuel elements: Technology of the PUREX process
- Recycling of U and Pu: technology and industrial limits, MOX neutronic design.
- Exercises.

Second part – The back-end of the fuel cycle (P. Van Iseghem)

- Categories, inventory of radioactive waste

- Conditioning and immobilisation of radioactive waste
- Characterization of radioactive waste (general; scaling factors; destructive analysis; non-destructive analysis)
- Assessment of the safety of geological disposal (methodology; some typical results from the safety assessment)
- Impact of new fuel cycles on radioactive waste disposal
- Geological repositories: key criteria for designing a disposal concept, overview of ongoing international programmes, and discussion of the Belgian supercontainer concept.
- Technical visits to the Belgoprocess facility and to the ESV underground research laboratory in clay on the SCK•CEN site

PRE-ASSUMED KNOWLEDGE OR PREREQUISITES

Basic chemistry.

REFERENCE BOOKS ON PREREQUISITE

See website www.sckcen.be/bnen → Brochures and Info → Background books W. D'haeseleer

TEACHING LOAD AND METHODS

- 3ECTS = 30h; 1 t.m.
- visits of half a day:
  - Visit of the ESV laboratory on the SCK•CEN site
  - Visit of the facilities of Belgoprocess (CILVA, Isotopolis, decommissioning and decontamination)

WAY OF EXAMINATION

Oral examination; written preparation

SCK•CEN REFERENCE PERSON

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NUCLEAR MATERIALS Part II

Walter BOGAERTS walter.bogaerts@mtm.kuleuven.ac.be

Professor of Corrosion & Materials Engineering at the University of Leuven (KULeuven, Belgium). M.Sc. and Ph.D. in chemical engineering (KULeuven, 1977 & 1981). Training courses in nuclear engineering (KULeuven, 1978).

Vice-chairman of NACE-Benelux, Benelux section of the International Association of Corrosion Engineers (NACE-International). Member of EFC-STAC, the Science & Technology Advisory Committee of the European Federation of Corrosion (EFC).

Professional Record

Research fellow at the University of Cambridge (GB - British Council Fellowship) and at SRI International (USA - Fulbright/Hays fellowship, NATO Fellowship). Several years of nuclear corrosion research experience, along with over twenty years of work in the chemical & materials engineering field. Since many years, national representative in various working parties of the European Federation of Corrosion. Co-founder of 2 university spin-off companies.

Research field: Materials engineering, electrochemistry, corrosion and corrosion protection, water treatment, applications of advanced information technologies and artificial intelligence in the field of corrosion and materials engineering.

Teaching duties in BNEN: Nuclear Materials II.

Editorial duties: Prof. Bogaerts published over 170 peer-reviewed papers and 3 (electronic) books in the areas of materials science and advanced information processing technologies. He is a former member of the editorial board of the journal "Modelling and Simulation in Materials Science and Engineering", and is a current member of the editorial board of "Corrosion Engineering Science & Technology" .

Other duties: Chief technical advisor Technologica Group – European Technical Joint Venture; consultant to
various companies and international organizations (UNIDO, UNDP, NATO, MTI, EPRI, etc...); project manager
in a number of European R&D programs.

Eric VAN WALLE eric.van.walle@sckcen.be

Professor at the Katholieke Universiteit Leuven (KULeuven - Louvain) - Doctor in Science, Ph.D. in Nuclear Physics (KULeuven 1985), General manager of the Belgian Nuclear Research Centre (SCK•CEN),

Research field: Nuclear material degradation, specialised in Nuclear Reactor Pressure Vessel Steel (RPVS)

Teaching duties in BNEN: Nuclear Materials II

Other duties: Belgian representative in IAEA expert groups on RPVS degradation; chairman of the Technical Advisory
Committee on Metallurgical and Environmental Degradation in the International Working Group on Radiation Damage
IGRDM, active member of the European Working Group AMES on ageing mechanisms, active member on the ASTM
committee E10 on Nuclear Material Integrity, Relation Officer Belgium – USNRC.

OBJECTIVES

To provide the students with a comprehensive treatment of the corrosion and embrittlement degradation mechanisms of materials in nuclear environment.

CONTENT

The *ex cathedra* part of the course covers the following main topics:

- Corrosion phenomena: description and occurrence
- Electrochemical and chemical study of corrosion problems: basic equations, user diagrams and practical examples

- Detailed study of frequently occurring corrosion types (e.g. pitting, IGA, SCC, ...): setting and context, explanation, influences of the environment and material properties
- Methods of corrosion prevention and protection (design aspects, coatings, water treatment and inhibitors, electrochemical methods)
- Effects of radiation on corrosion (e.g., irradiation assisted corrosion)
- Corrosion problems in nuclear reactors: material behaviour and material requirements, technological aspects and environment-sensitive damage, with emphasis on light water reactors, in general, and steam generators, in particular
- Reactor pressure vessel life management: material degradation issues, legal context, advanced analysis and mitigation
- Fuel cladding and stainless steel degradation under irradiation
- Advanced treatment of irradiation effects in materials: radiation damage mechanisms at microscopic level

Some of these topics are further elaborated during seminars and visits to the SCK•CEN laboratories (incl. hot cells).

- Basic measurements: source strength, neutron flux (activation analysis, neutron counting), neutron spectrum (time of flight methods, unfolding methods), reaction rates
- Activity, dose and cross-section measurement
- Measurement of neutron transport parameters: stationary methods, pulsed neutron experiments
- Measurement of reactivities (and reactivity coefficients): survey, static methods, dynamic measurements, inverse kineticsStatistical fluctuation method: reactor noise, mathematical analysis, applications (Rossi-alpha, sign correlations, zero crossings)

Reference books on the content

- Fontana, M.G., Corrosion Engineering, 3rd Ed., McGraw-Hill, 1986.
- Bogaerts, W.F., Active Library on Corrosion (CD-ROM), 2nd Ed., Elsevier, 1998.
- Benjamin, M., Nuclear Reactor Materials and Applications, Van Nostrand Reinhold, 1983.
- Glasstone, S. & A. Sesonske, Nuclear Reactor Engineering, 4-th Ed, Vol 1, Chapman & Hall, New York, 1994 (Chapter 7: Reactor Materials, pp 406-462).
- Cahn, R.W., Haasen, P., Kramer, E.J., Materials Science and Technology, Volume 10 B, Volume editor Frost B.R.T. , Chapters 7-9

Pre-assumed knowledge or prerequisites

Basic knowledge of materials science, chemistry and electrochemistry.

Reference Books on prerequisite

- See website www.sckcen.be/bnen → Brochures and Info → Background books W. D'haeseleer (mathematics)
- see introductory chapters in references above;
- see also: Roberge, P.R., Handbook of Corrosion Engineering, McGraw-Hill, 1999.

Teaching load and methods

- 1 t.m.
- Visits to SCK•CEN laboratories (especially hot cells)

Way of examination

Oral exam, written preparation.

SCK•CEN reference person

Eric van Walle: eric.van.walle@sckcen.be

RELIABILITY AND SAFETY

André POUCET Andre.poucet@ec.europa.eu

Professor at the Katholieke Universiteit Leuven (KULeuven - Louvain)
Head of the Unit "Traceability and vulnerability assessment" at the European Commission Joint Research Centre
Burg. Electro Werktuigkundig ir. (KUL 1976), Doctor in de Toegepaste Wetenschappen (KUL 1983)
Research fields: Risk assessment methodology, fusion reactor safety assessment, measurement systems and information technologies applied to verification of non-proliferation regimes
Teaching duties in BNEN: Safety and reliability
Editorial duties: Member of the editorial board of the international journal "Reliability Engineering and System Safety" (1986-1996)
Other duties: former General Secretary of the European Safety and Reliability Research and Development Association ESRRDA (1988-1991).

OBJECTIVES

- To present elements of nuclear safety philosophy
- To present the approach for embedding safety in design of nuclear facilities and to perform safety analysis (both deterministic and probabilistic)
- To learn the basic notions and techniques of system reliability engineering
- To understand the fundamentals of probabilistic safety analysis (PSA).
- To be able to assess the overall quality of the PSA methodology.

CONTENT

- Introduction to nuclear safety: hazard sources, safety functions, safety systems, defence in depth, line of defence method
- Safety goals and risk based criteria: the concept of risk, individual and societal risk criteria, release limits, core damage frequency limit, safety goals at function or system level
- The safety design cycle: (conservative) deterministic analysis based on design basis accidents and (best estimate) analysis of beyond design basis events; probabilistic analysis as a review of the safety design;
- Overall process of probabilistic safety assessment (PSA): PSA level 1, 2 and 3
- Qualitative analysis: hazard and scenario identification methods (FMEA, HAZOP, Event trees..)
- Component reliability: basic RAMS concepts, failure and repair time distributions, estimation of parameters from real life data, uncertainty bounds, Bayesian estimation of parameters
- Systems reliability:
    - Fault tree analysis: fault tree construction, coherence of fault trees, logical and probabilistic analysis of fault trees, system unavailability, expected number of failures, criticality of events and minimal cut sets,
    - Markov analysis: state diagrams, transition matrices, determination of system unavailability and system
- Common cause failure analysis: type of dependencies, qualitative and quantitative analysis of common cause failures
- Elements of human reliability analysis
- Accident sequence analysis: event trees, determination of sequence frequencies and plant response
- Elements of PSA level 2 and level 3 methodology
- Exploitation of PSA results

REFERENCE BOOKS ON THE CONTENT

- *McCormick, N., Reliability and Risk Analysis – Methods and Nuclear Power Applications, Academic Press, New York, 1981.*
- *Henley, E.J. and Kumamoto, H., Reliability Engineering and Risk Analysis, Prentice Hall, Englewood Cliffs, 1981.*
- *Modarres, M., What Every Engineer Should Know about Reliability and Risk Analysis, Dekker Inc., New York, 1993.*
- *Kumamoto, H., and Henley, E.J., Probabilistic Risk Assessment and Management for Engineers and Scientists, 2nd Edition, John Wiley & Sons, New York, 2001.*
- *Bedford, T. and Cooke, R., Probabilistic Risk Analysis, Foundations and Methods, Cambridge University Press, New York, 2001.*

PRE-ASSUMED KNOWLEDGE OR PREREQUISITES

REFERENCE BOOKS ON PREREQUISITE

See www.sckcen.be/bnen → Brochures and Info → Background books W. D'haeseleer

TEACHING LOAD AND METHODS

- 1 t.m.
- Practical exercises: exercise on fault trees with ASTRA, Risk-Spectrum or Aralia-Simtree in SCK•CEN

WAY OF EXAMINATION

Two parts each counting for half of the quotation marks:

- A practical exercise to be prepared by the student covering the subject of reliability assessment and to be sent in to the teacher;
- An oral examination (open book) on the understanding of the concepts treated in the course

ADVANCED COURSES

Pierre-Etienne LABEAU pelabeau@ulb.ac.be

Professor of reliability engineering and nuclear engineering at the Université Libre de Bruxelles (ULB)
Ingénieur civil physicien (ULB 1992), Docteur en Sciences Appliquées (ULB 1996)

Research fields: probabilistic safety analysis methodology for nuclear power plants and transmission power systems, reliability and maintenance modelling, risk perception

Teaching duties in BNEN: Advanced courses

Other duties: invited professor at the Helsinki University of Technology (Finland) and the Ecole Nationale de l'Industrie Minérale de Rabat (Maroc), member of the board of the technical committee of the conferences of the French Institut de Maîtrise des Risques, chairperson of the FNRS contact group "Sûreté de fonctionnement industrielle", member of various scientific committees in Belgium and France.

OBJECTIVES

The advanced courses are an essential part of the post-graduate programme for Master of Science in Nuclear Engineering, as they address specialized topics corresponding either to extensions of the contents of regular courses or to practical domains of nuclear engineering.

CONTENT

- At the beginning of the academic year the Teaching Committee offers a menu of advanced courses.
- The student communicates his/her choice of **two courses** to Prof. P.E. Labeau and the BNEN secretariat before October 15.
- Students may submit to the Teaching Committee motivated proposals to follow advanced courses, not appearing in the menu offered. A course should be accessible to all BNEN students and present an academic added value to be eligible. If such a proposal is accepted, students will provide the course material in electronic format to the academic responsible.

PRE-ASSUMED KNOWLEDGE OR PREREQUISITES

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TEACHING LOAD AND METHODS

Seminars/courses on specific topics related to nuclear engineering, preparing the student to a personal research and reporting exercise.

WAY OF EXAMINATION

- Within 3 weeks after the event, students prepare a one-page note presenting a scientific/technical topic related to the course, which they want to present/discuss, and the main lines of the treatment they plan to develop. This treatment should be mainly based on a personal research, beyond the contents of the course material.
- Comments on this note are sent by the academic responsible within a few days.
- By the next 3 weeks, a 15-20 page report developing the topic selected by the student must be sent to Prof. P.E. Labeau (pelabeau@ulb.ac.be) and the BNEN secretariat (bnen@sckcen.be). The respect of this deadline influences the mark received by the students.
- Reports should display a clear structure (clear introduction and conclusion, references cited in the body of the text). A mark of 00 out of 20 will be given to reports presenting evidences of cut-and-paste construction.