The topics listed below correspond more to themes in which master theses can be realized, than to a detailed description of topics. Depending on the interest of the students, more theoretical or instead industry-related topics will be developed. Some of the proposed themes are more convenient for an internship, to be made before the master thesis. The themes proposed are preferably accessible mainly to students in engineering physics and in electromechanical engineering.


P. Henneaux (pierre.henneaux@ulb.ac.be), P.E. Labeau (pelabeau@ulb.ac.be), J.M. Dricot (jdricot@ulb.ac.be)

The energy transition leads towards smarter electric power systems taking the form of cyber-physical systems in which the electrical power grids are strongly interlinked with a growing number of information and communication systems. In that context, the CYPRESS project aims at developing novel knowledge, methods and tools needed to help ensuring the security of supply through the transmission grid, while accounting for the specific nature of cyber-threats and integrating them into a coherent probabilistic risk management approach. More specifically, the CYPRESS project aims at developing: i) novel models and benchmarks for computer simulation and laboratory testing of the cyber-physical electric power system security of supply, ii) techniques for assessing the cyber-physical security of electric energy supply, and iii) techniques for enhancing the cyber-physical security of electric energy supply. This MSc thesis will contribute to a specific research topic of the CYPRESS project.
The topics listed below correspond more to themes in which master theses can be realized, than to a detailed description of topics. Depending on the interest of the students, more theoretical or instead industry-related topics will be developed. Some of the proposed themes are more convenient for an internship, to be made before the master thesis. The themes proposed are preferably accessible mainly to students in engineering physics and in electromechanical engineering.

2. Probabilistic security assessment as a tool for transmission operation
P. Henneaux (pierre.henneaux@ulb.ac.be), P.E. Labeau (pelabeau@ulb.ac.be)

The security of a power system is its ability to withstand disturbances arising from faults and unscheduled removal of bulk power supply equipment without further loss of facilities or cascading outages. The security analysis of the transmission grid requires both deterministic and probabilistic approaches. The "N-1 security rule" is the deterministic approach classically used by Transmission System Operators for network planning and real-time operation. This rule relies on the assumption that an electrical grid will be secure if it stays electrically stable after any single failure among the N initially active network elements. Probabilistic studies can then complement (or replace?) this deterministic approach to assess the residual risk of cascading outages leading to an important amount of loss of load and to identify corresponding accidental scenarios. This MSc thesis will study how a probabilistic approach can be used in complement of or instead of a deterministic approach to optimally ensure a high security of supply in operation (e.g. through redispatch actions).
The topics listed below correspond more to themes in which master theses can be realized, than to a detailed description of topics. Depending on the interest of the students, more theoretical or instead industry-related topics will be developed. Some of the proposed themes are more convenient for an internship, to be made before the master thesis. The themes proposed are preferably accessible mainly to students in engineering physics and in electromechanical engineering.

3. Probabilistic adequacy assessment of decarbonized power systems

P. Henneaux (pierre.henneaux@ulb.ac.be), P.E. Labeau (pelabeau@ulb.ac.be)

The adequacy of a power system is its ability to satisfy the consumer demand at any time, considering the possible outages of components and the variability of renewable energy sources. In order to consider the stochastic nature of generation availability, the adequacy of a power system is characterized by probabilistic metrics such as the Loss Of Load Expectation (LOLE), which is the average number of hours per year with a lack of power supply for one or several customers (loads), or the Expected Energy Not Served (EENS) which is the average energy per year that the system is unable to supply (but should supply). In Belgium, by law, the LOLE must be below 3 hours/year. It is the case also in neighboring countries. The most common way to evaluate the adequacy of a power system is to use a sequential Monte Carlo simulation. However, a main drawback of this technique is the long computation times needed to reach a satisfying statistical accuracy. Furthermore, this technique relies often on an implicit assumption of perfect foresight over a specific timeframe: it considers implicitly that future weather conditions are perfectly known. These two drawbacks are expected to become limiting factors for the probabilistic adequacy assessment of decarbonized power systems. Indeed, they will integrate massively storage and it would be overoptimistic to dispatch that storage assuming a perfect forecast of future weather conditions. Moreover, the possible occurrence of extreme weather events (e.g. cold spell, dunkelflaute, dry year) might lead to higher computation times in decarbonized power systems. In that context, the purpose of this MSc thesis will be twofold: (i) the development of variance reduction techniques to improve computation times while considering extreme weather events, and (ii) the study of the impact of the perfect foresight assumption on the adequacy assessment. For that purpose, a dedicated tool will be developed and applied to a decarbonized power system.
4. Application of SDDP to assess the need of seasonal storage in decarbonized systems

P. Henneaux (pierre.henneaux@ulb.ac.be), P.E. Labeau (pelabeau@ulb.ac.be)

A fundamental ingredient to achieve a decarbonized European energy system at the horizon 2050 will be seasonal storage. However, because it is not possible to perfectly forecast future weather conditions, impacting renewable energy sources and the electricity demand, an optimal management of seasonal storage to ensure the security of supply must rely on stochastic optimization. A specific method, called Stochastic Dynamic Dual Programming (SDDP), was developed in the nineties to solve stochastic optimization problems in order to optimally manage hydro dams in Brazil. The objective of this MSc thesis will be the adaptation of that method to assess the need of seasonal storage in decarbonized systems, such as the European one in 2050.
5. Relaxation and decomposition techniques for stochastic optimization

P. Henneaux (pierre.henneaux@ulb.ac.be), P.E. Labeau (pelabeau@ulb.ac.be)

Power systems must be operated in the most economical way while ensuring the desired level of reliability. A fundamental tool allowing transmission system operators to meet that objective is the so-called Optimal Power Flow (OPF). It aims at minimizing a given objective function (e.g. operating cost) while respecting operational requirements of the power system. However, standard OPF algorithms make use only of a “best estimate” for the forecast for future power system conditions. They are then not adapted to future power systems dominated by renewable energy sources, because they are not able to consider forecast errors. The consideration of forecast errors in OPF algorithms leads to stochastic optimization problems. These problems are challenging to solve numerically, due to non-linearities, non-convexities and their large dimensions. This MSc thesis will explore relaxation and decomposition techniques to solve stochastic OPF problems.
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The themes proposed are preferably accessible mainly to students in engineering physics and in electromechanical engineering.

6. Risk assessment of the transmission system (in collaboration with Elia)

P. Henneaux (pierre.henneaux@ulb.ac.be), P.E. Labeau (pelabeau@ulb.ac.be), G. Schoore (Gaetan.Schoore@elia.be)

The increasing share of fluctuant renewable energy sources leads to an increasing complexity and uncertainty within transmission systems that must be considered both in long term planning and operational planning, in order to ensure the desired level of security of supply. Although the security criteria of being able to cope with the unplanned outage (incident) of a grid element (N-1 security criteria) stays an important element of security of supply, probabilistic approaches are needed to complement them, such that the risks due to multiple outages can be assessed. As it is not possible to assess every single combination of outages, smart search algorithms of the combination of outages relevant to be studied are needed. These smart search algorithms must consider the possibility to have remedial actions (e.g. topological actions, actions on phase-shifting transformers) between a first and a second outage, in order to precisely limit the risk. This MSc thesis will consist in integrating remedial actions in such a smart search algorithm.
The topics listed below correspond more to themes in which master theses can be realized, than to a detailed description of topics. Depending on the interest of the students, more theoretical or instead industry-related topics will be developed. Some of the proposed themes are more convenient for an internship, to be made before the master thesis. The themes proposed are preferably accessible mainly to students in engineering physics and in electromechanical engineering.

7. Lifetime and maintenance modeling in multi-component systems. Application to multi-asset structures in power systems

P.E. Labeau (pelabeau@ulb.ac.be), G. Schoore (Gaetan.Schoore@elia.be)

(To be confirmed)
8. Research and implementation metrics to approximate system stability & transient behavior based on steady-state calculations (in collaboration with N-SIDE)

P. Henneaux (pierre.henneaux@ulb.ac.be), P.-E. Labeau (pelabeau@ulb.ac.be), Wolf Berwouts (wbe@nside.com)

For this topic, an internship might be relevant before the MSc thesis.

N-SIDE is involved in building advanced analytics solutions that support system operators and planning engineers at transmission system operators in their daily operations. This consists of recommendations for grid reconfigurations or setpoints to keep congestion, frequency and voltage under control while safeguarding power quality and system stability. These supporting tools make use of optimization and machine learning techniques but have in common that they rely heavily on grid simulations (load flows). To make the solution computationally efficient and fast while optimizing, or validating for a large number of aspects, simplifications or approximations are key to be implemented. This opens up interesting questions on what metrics indicate power quality and system stability — even in the transient regime — while being easy and light to calculate. These metrics are linked to system stability or the risk of unwanted transients based on steady-state calculations. The list of metrics can be further extended. This MSc thesis will aim at (i) researching the existing metrics by performing and delivering a thorough literature review, (ii) testing and benchmarking implementations of these metrics in Python (using a Python-based power flow solver) to test the computational cost, (iii) making suggestions of metrics to use based on their predicting power and computational cost, and (iv) optimizing the implementations in collaboration with the N-SIDE experts and testing them on a real transmission grid.
9. Selection of a representative time series (in collaboration with Engie Laborelec)

B. Haut (bertrand.haut@engie.com), P. Henneaux (pierre.henneaux@ulb.ac.be), P.-E. Labeau (pelabeau@ulb.ac.be)

Context: In the important context of the energy and environmental transition, we have at our disposal some tools used for techno-economics simulations. For example, a simulation tool can be used to estimate the financial gain of a photovoltaic installation in presence of a battery and its control. These tools often require time series as input parameters (e.g. expected hourly consumption of a dwelling). This is information being usually not available, it is needed to use a representative time series. This time series will be selected among a set of available historical measurements.

Objective: among a large set of time series, how can we select the most representative one for a particular type of study?

Approach: A natural approach would be to consider the $n$ time series as a cluster and select the associated centroid. This leads to the following question: “which distance should be used between the time series”? The selection and/or construction of this distance should be done in function of the tool characteristic which will use these curves. Let us consider for example two types of computation:

- **Estimation and reduction of the peak consumption using a flexible asset.** In this first analysis, a temporal shift of 12h has no impact. So two time series shifted by 12 hours are equivalent.

- **Auto-consumption gain using solar production.** In this second analysis a temporal shift of 12 hours (meaning inverting day and night consumption) is obviously very important.
10. Identification of underperformances using a Bayesian approach (in collaboration with Engie Laborelec)

B. Haut (bertrand.haut@engie.com), P. Henneaux (pierre.henneaux@ulb.ac.be), P.-E. Labeau (pelabeau@ulb.ac.be)

Context: In the important context of the energy and environmental transition, we consider a photovoltaic production farms where multiple assets (PV panel strings) are naturally exposed to similar irradiance conditions. In general, the production of these assets should be similar. It is however possible that some of these assets are presenting underperformances.

Objective: We are doing the assumption that only the asset production measurements (kW) are available. In particular we don’t have any reliable irradiance measurement. We would like to identify the underperforming assets.

Approach: By doing the assumption that only a fraction of the assets are underperforming simultaneously, it seems natural to identify the underperformances by comparing each asset with a reference obtained using all assets. In practice the situation is a little more complex (missing data, assets having different nominal powers, partial shadowing of some PV panels…). We will focus on a Bayesian approach (MCM) for this problem in order to easily include expert knowledge via the “a priori” distributions, and to obtain a confidence interval on the “a posteriori” distribution of the underperformances.
11. Review and sensitivity analysis of a Monte-Carlo model for assessing risks of ice fall from wind turbines (in collaboration with Tractebel Engie)

P. Geerinck (pascal.geerinck@tractebel.engie.com), P.E. Labeau (pelabeau@ulb.ac.be), P. Henneaux (phenneau@ulb.ac.be)

For master thesis and internship
PROPOSAL FOR MASTER THESIS AND INTERNSHIP

- Review and sensitivity analysis of a Monte-Carlo model for assessing risks of ice fall from wind turbines

Context
In the context of energy transition, the development of wind energy projects situated in an industrial environment or close to cities is a preferred option in regions with high population densities, since it represents some major advantages related to landscape and noise pollution, NIMBY (Not In My Backyard) and the availability of an electrical connection to the grid. On the other hand, it also represents a drawback in terms of safety during winter conditions due to the presence of people in the vicinity of the wind turbine where ice accretion on the wind turbine blades represents a major risk as ice fall may cause incidents, even lethal accidents. To be able to access this risk Tractebel developed a risk-based decision icefall-model using empowered by Monte-Carlo engine. This model contains a big number of stochastic parameters related to physical phenomenon’s such as ice accretion, wind climate, ice shedding, trajectory model parameters, human exposure model parameters, etc.

Objectives of the master thesis
The objective of the master is to perform an in-depth sensitivity analyses of the available model (the model is fully described and runs under a Matlab environment). The aim is to have insight in those parameters which are critical in relation to the used risk measures and so need special attention in the modelling. It is proposed to use a 2-step approach: the first step would be a critical review of the developed model to have a clear insight of the different constituting components and eventually propose improvements, the next and main step is the detailed sensitivity analyses of the model. If needed an iteration can be performed towards step 1. Based on the result of these analyses it may also be an opportunity to optimize the Monte-Carlo sampling method that is the core of the modelling.

To have the possibility to be in close contact with the developers, have easy access to the code it is highly recommended to combine the subject of the master thesis with an internship in our offices in Brussels.

Contact: pascal.geerinck@tractebel.engie.com
We are a global community of imaginative experts engineering a carbon-neutral future.

Tractebel is a global engineering company delivering game-changing solutions for a carbon-neutral future. Insights gathered during our more than 150 years of experience in energy, urban, nuclear and water projects combined with local expertise allow us to tackle complex future-oriented projects.

By connecting strategy, design, engineering and project management, our community of imaginative experts helps companies and public authorities create positive impact towards a sustainable world where people, planet and profit collectively thrive.

With offices in Europe, Africa, Asia, the Middle East and Latin America, the company registered a turnover of 581 million Euros in 2020. Tractebel is part of the ENGIE Group, a global reference in low-carbon energy and services.

KEY FIGURES
Presence in more than 70 countries
Projects developed in over 150 countries
5,000 employees
€ 581 million turnover
More than 70 technical publications/year
High Safety Standard: Frequency Rate 0.7

PROJECT LIFE CYCLE
Tractebel adds value throughout the complete cycle of a project:
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The themes proposed are preferably **accessible mainly to students in engineering physics and in electromechanical engineering**.

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12. Safety risks associated with storage and transport through pipelines of CO₂ (in collaboration with Tractebel Engie)

D. Seys ([damien.seys@tractebel.engie.com](mailto:damien.seys@tractebel.engie.com)), P.E. Labeau ([pelabeau@ulb.ac.be](mailto:pelabeau@ulb.ac.be))

*For master thesis and internship*
PROPOSAL FOR MASTER THESIS/INTERNSHIP

- Safety risks associated with storage and transport through pipelines of CO$_2$ -

Context

In the context of energy transition, CO$_2$ will be more and more captured and stored or re-purposed. For instance, CO$_2$ can be combined with hydrogen to produce e-methane. This would decarbonize the activities of industrial sectors which are, for the moment, releasing significant amounts of CO$_2$. It would also decarbonize sectors which are not (yet) ready for electrification, e.g. airplanes.

In relation to safety there are no consolidated approach and models regarding the management of risks during the different phases of such projects.

Objective

The objectives of this master thesis are:

- To review the hazards and risks associated with CO$_2$ (transport, storage);
- To investigate the existing technology for transporting, using and storing CO$_2$;
- To study accidents or incidents which have occurred with CO$_2$, their causes and their consequences;
- To search for international standards / guidance / national guidelines regarding the transport, use and storage of CO$_2$;
- To update the existing technical code for risk assessment of pipelines, to make it applicable to CO$_2$ pipelines (currently it is applicable for flammable gases)
- To define a methodology for modelling CO$_2$ pipelines incidents (leaks, etc.): comparison of models, assumptions, sensitivity study to identify the most important parameters, etc. This comprises the comparison related to dispersion of existing empiric computer models (PHAST DNV used by TRACTEBEL) with 3D – CFD models.

It is preferred to associate this master thesis with an internship in the Risk & Safety Management team of TRACTEBEL, the engineering company of the ENGIE Group, active in many sectors – energy, urban, water & nuclear. It will be an opportunity to work with experienced colleagues in the field of risk management, have contact with clients developing infrastructure for the future, to get familiarized with industrial software for modelling of accidents, and to discover a rich and stimulating work environment in TRACTEBEL.

Contact: damien.seys@tractebel.engie.com
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13. Thorium-based opportunities for nuclear energy applications (in collaboration with Solvay)

M. Huart (michele.huart@solvay.com), P.E. Labeau (pelabeau@ulb.ac.be)

12-week internship !!!

Founded in 1863, Solvay today ranks among the world's top three companies for the vast majority of its activities and achieved net sales of 8.9 billion euros in 2020. With more than 23,000 employees in 64 countries, Solvay brings together people, ideas and elements to reinvent progress. The Group seeks to create sustainable shared value for all, in particular through its Solvay One Planet plan articulated around three pillars: protecting the climate, preserving resources and promoting a better life.

With a large quantity of thorium resulting from its historical rare earth extraction activities, Solvay wishes to investigate the opportunities of valorisation, particularly in nuclear energy.

The internship will cover a bibliography study of molten salt reactor (MSR) and small reactor (SMR) technologies, the main technical developments ongoing in the world, the search for opportunities for thorium (MSR, SMR, others) as well as for the main companies active in these developments, a comparative analysis of the use of thorium in nuclear fuels, ...

The intern will write a summary of his work (in English) as well as an executive summary in French.

A technical expert from the company will supervise the intern. In addition, a bimonthly meeting will allow to follow the progress of the work and to consider any possible reorientation, if needed. A final meeting will focus on sharing the conclusions of the work.
The topics listed below correspond more to **themes** in which master theses can be realized, than to a detailed description of topics. Depending on the interest of the students, more theoretical or instead industry-related topics will be developed. Some of the proposed themes are more convenient for an internship, to be made before the master thesis. The themes proposed are preferably **accessible mainly to students in engineering physics and in electromechanical engineering**.

14. Calculation of the decay heat for Boiling Water Reactor Spent Fuel (in collaboration with Tractebel Engie)

M. Vanderhaegen (matthias.vanderhaegen@tractebel.Engie.com), P.E. Labeau (pelabeau@ulb.ac.be)

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**12-week internship !!!**

Tractebel is looking for an intern for our business line Nuclear in the department of Nuclear Processes, more precisely the Nuclear Core & Fuel Studies, to work on the calculation of the decay heat for Boiling Water Reactor Spent Fuel.

**Internship at Tractebel**

**Brussel.**

The ENGIE Tractebel offices in Brussel are located next to the North station, making it easy accessible by public transport.

**Who is Tractebel?**

Tractebel, part of Engie group, had more than 150 years of experience and is one of the world's largest engineering consultancy companies. Tractebel offers his clients multidisciplinary solutions in the fields of energy, nuclear, water and urban. Our teams our responsible for the all the phases of a project, from the feasibility studies to implementation.

You will work as intern for the business line Nuclear in the Nuclear Core & Fuel Studies group which is responsible for the fuel management calculations of the Belgian Nuclear Fleet. These calculations span the entire spectrum of nuclear fuel applications, i.e. from the core reload design and the in-core thermal-hydraulics to studies for the spent fuel pools and spent fuel containers. Or as a figure says more than a 1000 words:

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In the framework of Tractebel's spent fuel services and operational support, it is important to characterize the decay heat of a spent fuel assembly with a high degree of certainty. This decay heat is an important parameter to determine the safety margins of the spent fuel pool and the compliance with spent fuel cask's thermal limits. Such decay heat calculations require a large set of codes and tools, together with a validation database. To remain competitive, Tractebel continuously follows the evolutions of different other codes used in the domain, whilst upgrading the existing
How will your day look like?
We are looking for a motivated intern to evaluate the decay heat of spent fuel coming from Boiling Water Reactors to extend the validation database, and determine the uncertainty on the prediction of the decay heat. This means that you will use state of the art industrial fuel evolution codes applied to Boiling Water Reactors. Thus:

- You will develop knowledge on boiling water reactor operation and the associated fuel modelling.
- You will develop competences in the use of the SCALE software package, more specifically with the SAS2H, TRITON and/or ORIGEN-S modules.
- You will analyse the predicted decay heat and compare to experimental data from the different facilities such as CLAB.
- You will perform statistical analysis on the ratio between the measured data and the calculated value to determine the code uncertainty.

Who are we looking for?
- You are a studying physics or engineering with a sound basis of nuclear physics and nuclear reactor theory and you wish to get hand-on experience with an internship in an engineering company for at least 6 weeks. **This subject can also be transformed in a Master Thesis.**
- Knowledge of Linux, Bash, Python, … is required.
- You are fluent in English and know either Dutch or French
- You are curious and have an initiative mindset
- You appreciate teamwork
- You are well organized and possess a strong team spirit
- You are eligible for a nuclear security permit delivered by FANC as you’ll be working with nuclear data.

What do we offer?
- An interesting and varied internship in an international environment, within a young and dynamic team.
- Being able to work in an environment that allows you to strengthen your professional and technical skills
- The opportunity to work in a team of experienced and motivated professionals and to receive appropriate professional guidance

How to apply?
Do you think Tractebel is the perfect fit for your internship? Send us an e-mail to [recruitment@tractebel.engie.com](mailto:recruitment@tractebel.engie.com) with your CV, motivation and for which project you apply. We hope to see you soon!
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15. Calculation routine to predict the radioactive inventory of the spent fuel hardware such as control rods, thimble plugs, and poison and source rods (in collaboration with Tractebel Engie)

M. Vanderhaegen (matthias.vanderhaegen@tractebel.engie.com), P.E. Labeau (pelabeau@ulb.ac.be)

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### 12-week internship !!!

Tractebel is looking for an intern for our business line Nuclear in the department of Nuclear Processes, more precisely the Nuclear Core & Fuel Studies, to develop a calculation routine to predict the radioactive inventory of the spent fuel hardware such as control rods, thimble plugs, and poison and source rods.

**Internship at Tractebel**

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Tractebel continuously follows the evolutions of different other codes used in the domain, whilst upgrading the existing validation database.

How will your day look like?
We are looking for a motivated intern to evaluate the decay heat of spent fuel coming from Boiling Water Reactors to extend the validation database, and determine the uncertainty on the prediction of the decay heat. This means that you will use state of the art industrial fuel evolution codes applied to Boiling Water Reactors. Thus:
- You will develop knowledge on boiling water reactor operation and the associated fuel modelling.
- You will develop competences in the use of the SCALE software package, more specifically with the SAS2H, TRITON and/or ORIGEN-S modules.
- You will analyse the predicted decay heat and compare to experimental data from the different facilities such as CLAB.
- You will perform statistical analysis on the ratio between the measured data and the calculated value to determine the code uncertainty.

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- You are a studying physics or engineering with a sound basis of nuclear physics and nuclear reactor theory and you wish to get hand-on experience with an internship in an engineering company for at least 6 weeks. This subject can also be transformed in a Master Thesis.
- Knowledge of Linux, Bash, Python, ... is required.
- You are fluent in English and know either Dutch or French
- You are curious and have an initiative mindset
- You appreciate teamwork
- You are well organized and possess a strong team spirit
- You are eligible for a nuclear security permit delivered by FANC as you’ll be working with nuclear data.

What do we offer?
- An interesting and varied internship in an international environment, within a young and dynamic team.
- Being able to work in an environment that allows you to strengthen your professional and technical skills
- The opportunity to work in a team of experienced and motivated professionals and to receive appropriate professional guidance

How to applicate?
Do you think Tractebel is the perfect fit for your internship?
Send us an e-mail to recruitment@tractebel.engie.com with your CV, motivation and for which project you apply. We hope to see you soon!
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16. Performance of in-house neutronic codes when applied to Molten Salt Reactors (in collaboration with Tractebel Engie)

M. Vanderhaegen (matthias.vanderhaegen@tractebel.engie.com), P.E. Labeau (pelabeau@ulb.ac.be)

12-week internship !!!

Tractebel is looking for an intern for our business line Nuclear in the department of Nuclear Processes, more precisely the Nuclear Core & Fuel Studies, to analyse the performance of in-house neutronic codes when applied to Molten Salt Reactors.

**Internship at Tractebel**

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Tractebel continuously follows the evolutions of different other codes used in the domain, whilst upgrading the existing validation database.

How will your day look like?
We are looking for a motivated intern to evaluate the decay heat of spent fuel coming from Boiling Water Reactors to extend the validation database, and determine the uncertainty on the prediction of the decay heat. This means that you will use state of the art industrial fuel evolution codes applied to Boiling Water Reactors. Thus:
- You will develop knowledge on boiling water reactor operation and the associated fuel modelling.
- You will develop competences in the use of the SCALE software package, more specifically with the SAS2H, TRITON and/or ORIGEN-S modules.
- You will analyse the predicted decay heat and compare to experimental data from the different facilities such as CLAB.
- You will perform statistical analysis on the ratio between the measured data and the calculated value to determine the code uncertainty.

Who are we looking for?
- You are a studying physics or engineering with a sound basis of nuclear physics and nuclear reactor theory and you wish to get hand-on experience with an internship in an engineering company for at least 6 weeks. *This subject can also be transformed in a Master Thesis.*
- Knowledge of Linux, Bash, Python, … is required.
- You are fluent in English and know either Dutch or French
- You are curious and have an initiative mindset
- You appreciate teamwork
- You are well organized and possess a strong team spirit
- You are eligible for a nuclear security permit delivered by FANC as you’ll be working with nuclear data.

What do we offer?
- An interesting and varied internship in an international environment, within a young and dynamic team.
- Being able to work in an environment that allows you to strengthen your professional and technical skills
- The opportunity to work in a team of experienced and motivated professionals and to receive appropriate professional guidance

How to applicate?
Do you think Tractebel is the perfect fit for your internship?
Send us an e-mail to recruitment@tractebel.engie.com with your CV, motivation and for which project you apply. We hope to see you soon!
The topics listed below correspond more to themes in which master theses can be realized, than to a detailed description of topics. Depending on the interest of the students, more theoretical or instead industry-related topics will be developed. Some of the proposed themes are more convenient for an internship, to be made before the master thesis. The themes proposed are preferably accessible mainly to students in engineering physics and in electromechanical engineering.

17. Performance of the SERPENT Monte-Carlo code when applied to a full core geometry of a Small Modular Reactor (in collaboration with Tractebel Engie)

M. Vanderhaegen (matthias.vanderhaegen@tractebel.Engie.com), P.E. Labeau (pelabeau@ulb.ac.be)

12-week internship !!!

Tractebel is looking for an intern for our business line Nuclear in the department of Nuclear Processes, more precisely the Nuclear Core & Fuel Studies, to analyse the performance of the SERPENT Monte-Carlo code when applied to a full core geometry of a Small Modular Reactor.

**Internship at Tractebel**

Brussel.

The ENGIE Tractebel offices in Brussel are located next to the North station, making it easy accessible by public transport.

**Who is Tractebel?**

Tractebel, part of Engie group, had more than 150 years of experience and is one of the world's largest engineering consultancy companies. Tractebel offers his clients multidisciplinary solutions in the fields of energy, nuclear, water and urban. Our teams our responsible for the all the phases of a project, from the feasibility studies to implementation.

You will work as intern for the business line Nuclear in the Nuclear Core & Fuel Studies group which is responsible for the fuel management calculations of the Belgian Nuclear Fleet. These calculations span the entire spectrum of nuclear fuel applications, i.e. from the core reload design and the in-core thermal-hydraulics to studies for the spent fuel pools and spent fuel containers. Or as a figure says more than a 1000 words:

In the framework of Tractebel's spent fuel services and operational support, it is important to characterize the decay heat of a spent fuel assembly with a high degree of certainty. This decay heat is an important parameter to determine the safety margins of the spent fuel pool and the compliance with spent fuel cask’s thermal limits. Such decay heat calculations require a large set of codes and tools, together with a validation database. To remain competitive, Tractebel continuously follows the evolutions of different other codes used in the domain, whilst upgrading the existing
How will your day look like?
We are looking for a motivated intern to evaluate the decay heat of spent fuel coming from Boiling Water Reactors to extend the validation database, and determine the uncertainty on the prediction of the decay heat. This means that you will use state of the art industrial fuel evolution codes applied to Boiling Water Reactors. Thus:

- You will develop knowledge on boiling water reactor operation and the associated fuel modelling.
- You will develop competences in the use of the SCALE software package, more specifically with the SAS2H, TRITON and/or ORIGEN-S modules.
- You will analyse the predicted decay heat and compare to experimental data from the different facilities such as CLAB.
- You will perform statistical analysis on the ratio between the measured data and the calculated value to determine the code uncertainty.

Who are we looking for?
- You are a studying physics or engineering with a sound basis of nuclear physics and nuclear reactor theory and you wish to get hand-on experience with an internship in an engineering company for at least 6 weeks. **This subject can also be transformed in a Master Thesis.**
- Knowledge of Linux, Bash, Python, … is required.
- You are fluent in English and know either Dutch or French
- You are curious and have an initiative mindset
- You appreciate teamwork
- You are well organized and possess a strong team spirit
- You are eligible for a nuclear security permit delivered by FANC as you’ll be working with nuclear data.

What do we offer?
- An interesting and varied internship in an international environment, within a young and dynamic team.
- Being able to work in an environment that allows you to strengthen your professional and technical skills
- The opportunity to work in a team of experienced and motivated professionals and to receive appropriate professional guidance

How to apply?
Do you think Tractebel is the perfect fit for your internship?
Send us an e-mail to recruitment@tractebel.engie.com with your CV, motivation and for which project you apply.
We hope to see you soon!
The topics listed below correspond more to themes in which master theses can be realized, than to a detailed description of topics. Depending on the interest of the students, more theoretical or instead industry-related topics will be developed. Some of the proposed themes are more convenient for an internship, to be made before the master thesis.

The themes proposed are preferably accessible mainly to students in engineering physics and in electromechanical engineering.

18. Exploring the options of probabilistic sampling schemes for efficient demonstration of the absence of radioactivity during decommissioning (in collaboration with Tractebel Engie)

S. Peetermans (steven.peetermans@tractebel.enganie.com), P.E. Labeau (pelabeau@ulb.ac.be)

12-week internship !!!

Business Line: Nuclear – Radiation Protection and characterization Team
Type: 3-months internship, with the option for prolongation or follow-up as a master thesis
Site: Brussels ENGIE Tower, home office possible as well in light of Covid-19

Who is Tractebel?
Tractebel, part of the ENGIE group, has more than 150 years of experience and is one of the world’s largest engineering consultancy companies. Tractebel offers its clients multidisciplinary solutions in the fields of energy, nuclear, water and urban. Our teams are present in all the possible phases of a project, from the feasibility studies to the implementation.

What will you be working on?
Decommissioning of a licensed facility includes demonstrating the absence of residual radioactivity on building structures and terrain. In many cases, a 100% verification is not necessary or possible (e.g. concrete core drilling for activation assessment, soil sampling) and one has to resort to sampling. The challenge lies in reaching sufficient confidence in the activity distribution and subsequent clearance decision, with as little samples as possible.

During the internship, the student will explore different sampling schemes, with a focus on geostatistics that can integrate spatial structure of recorded contamination values. He will apply them to existing available data in order to assess potential efficiency gains.
Who are we looking for?

- You speak fluently Dutch, French or English
- You are an Engineering student, preferably of nuclear physics
- You wish to do an internship in an engineering company for at least 3 months
- Knowledge of programming is a must, preferably Python or Matlab
- You are driven by the search of innovative solutions
- You are curious and have an initiative mindset

What do we offer?

- An interesting and varied internship in a large nuclear engineering company
- An environment that allows you to strengthen your professional and technical skills
- The opportunity to receive professional guidance by experts in different fields of engineering

How to apply?

Do you think that Tractebel is the perfect fit for your internship?
Send an e-mail to steven.peetermans@tractebel.engie.com with your CV, a few lines about your motivation and indicate which project you want to apply for.

We hope to see you soon!
19. Modélisation et optimisation du couplage d’une centrale nucléaire de type Small Modular Reactor (SMR) avec une boucle de stockage d’énergie thermique dans des réservoirs de sels fondus (en collaboration avec Tractebel Engie)

M.iker (mathieu.iker@tractebel.engie.com), P.E. Labeau (pelabeau@ulb.ac.be)

Tractebel

Tractebel est une société d’ingénierie employant 5000 personnes dans le monde et active dans les secteurs de l’énergie, de l’eau, du développement urbain et du nucléaire. Tractebel accompagne ses clients tout au long de leurs projets, de la définition stratégique à la mise à l’arrêt et démantèlement, en passant par la faisabilité, la mise en œuvre et le support à l’exploitation. La raison d’être de Tractebel est de concevoir un avenir zéro carbone.

Contexte

La décarbonisation de la production d’électricité passe par une augmentation de la part des énergies renouvelables intermittentes (en particulier éolienne et solaire) dans la production d’électricité. Cette intermittence de la production d’électricité rend(ra) plus difficile la mise en adéquation de l’offre et de la demande sur les réseaux de distribution électrique.

Les centrales nucléaires constituent une autre source d’électricité décarbonée. Néanmoins, elles sont peu adaptées à un suivi de charge rapide et de grande ampleur tel qu’il pourrait être requis dans des réseaux électriques où la part des énergies renouvelables est importante.

Pour gérer ce déséquilibre sans mettre à l’arrêt les capacités de production et sans avoir recours à des centrales de production d’électricité permettant d’assurer ce suivi de charge (généralement au gaz, ou hydroliques là où c’est possible), on peut essentiellement jouer sur 2 tableaux :

- Moduler la demande en fonction de la production (contrats avec les industries, pricing, smart grids);
- Stocker l’excédent d’énergie lors des pics de production et, éventuellement, le réutiliser pour produire de l’électricité lors des creux de production.

Le stockage d’énergie peut prendre plusieurs formes. Les plus utilisées actuellement sont le pompage/turbinage hydraulique (Pumped Hydro Storage – PHS, cfr. la centrale de Coo en Belgique) et les batteries (Li-ion, NaS, …). D’autres formes sont toutefois possibles, citons en particulier le stockage d’énergie thermique et la production d’hydrogène par électrolyse. Ces deux dernières permettent de réutiliser l’énergie stockée soit pour la production d’électricité, soit pour d’autres applications (e.g. chauffage urbain ou process industriel pour le stockage thermique, mobilité ou industrie chimique pour
l’hydrogène), permettant par là-même la décarbonisation d’autres secteurs.
En ce qui concerne les centrales nucléaires, la tendance est actuellement aux « Small Modular Reactors » (SMR), soit des centrales à la construction modulaire et offrant une puissance électrique réduite par rapport à la majeure partie des centrales nucléaires actuellement en service. Elles présentent un coût et une sécurité optimisés. Plusieurs constructeurs proposent déjà ce type de centrale (Terrestrial Energy, Moltex, GE Hitachi, NuScale, …). Afin de les rendre plus attractives dans le contexte décrit ci-dessus, le couplage de ce type de centrale avec des solutions de stockage d’énergie est à l’étude. En particulier, à l’instar de ce qui existe pour les centrales de type CSP (Concentrated Solar Power), il devrait être possible d’utiliser (une partie de) l’énergie thermique fournie par la centrale pour chauffer des sels fondus et les stocker dans des réservoirs. Cette réserve d’énergie thermique peut être utilisée pour produire de l’électricité (via un cycle vapeur) ou pour d’autres applications (chauffage urbain par exemple).

**Objectif du mémoire**

Le mémoire consistera à modéliser le couplage entre un réacteur de type SMR (source de chaleur intermittente, fonction de la demande électrique instantanée) et une boucle de stockage d’énergie thermique sous forme de sels fondus. Le mémoire étudiera le fonctionnement dynamique de ce système pour différents profils de demande électrique et/ou d’applications utilisant l’énergie thermique (e.g. chauffage urbain). Le mémoire s’intéressera à l’optimisation du système et au dimensionnement du stockage, et étudiera le rendement des différentes options possibles. Une analyse technico-économique peut également être proposée (e.g. pour déterminer si l’énergie stockée devrait être utilisée pour la production d’électricité, une autre application ou les deux).

**Outils de modélisation**

- Aspen HYSYS et/ou ;
- Aspen Plus et/ou ;
- (Open) Modelica et/ou ;
- Autres outils à proposer.

**Résultat attendu**

- Un modèle thermo-hydraulique de la boucle de stockage d’énergie thermique et de son couplage avec la source de chaleur et avec les utilisateurs.
- Une méthodologie pour dimensionner le stockage en fonction des profils « in et out ».
- Une analyse du rendement de l’installation, optimisation du process, …
- Optionnel : un benchmark des outils de modélisation (si différents outils sont utilisés).
- Optionnel : une analyse technico-économique.
- Optionnel : modélisation et comparaison avec d’autres méthodes de stockage d’énergie (électrolyse d’hydrogène, compression d’air, stockage cryogénique (air liquide), …).
- Autres à définir en cours d’étude.
Students interested in an internship and/or a master thesis in the nuclear industry (Engie, Westinghouse, SCK-CEN Mol, Bel-V…) can contact Pierre-Etienne LABEAU (pelabeau@ulb.ac.be) to know the industrial collaborators of the department.

Many master thesis topics are proposed by the **Belgian Nuclear Research Center in Mol (SCK-CEN):**


Topics of particular interest to engineering physics students are related to the development of the research reactor MYRRHA, to nuclear safeguards, nuclear fuel and materials…
1. Interface effect in surface analysis

N. Pauly (nicolas.pauly@ulb.be)

When an electron crosses an interface between two different media, it undergoes an energy loss depending on its initial energy, on the angle of its trajectory with respect to the interface and on the considered media. Moreover its mean free path is modified. The goal of this work consists in the calculation of the probability of interface excitation between the 2 media and in the calculation of the variation of the mean free path close to the interface. Finally, these results will be applied to a complex structure made in several thin layers of various media. Indeed this morphology is particularly used in the development of power and memory nanodevices.

The student will first acquire basic concepts of surface analysis. Indeed, the theory behind the Master Thesis has already been established in the department of Métrologie Nucléaire. Then she/he will develop her/his own software to perform the calculations of surface excitations and of inelastic mean free paths.

1. Study of the characteristics of neutrinos with the JUNO detector 1

B. Clerbaux (bclerbau@ulb.ac.be), N. Pauly (nicolas.pauly@ulb.be), JM. Sparenberg (jmspar@ulb.ac.be)

JUNO is a liquid scintillator detector designed to detect electronic anti-neutrinos emitted from nuclear reactors situated at a distance of 53 km. The detector is located 700 m below the rock and consists of 20 kilotons of liquid scintillator contained in a 35 m diameter acrylic sphere, instrumented by more than 18000 large photomultipliers (PMTs) of 20 inches in diameter. The international JUNO collaboration was established in 2014; construction of the site started in 2015 and the R&D and production phase for the detector is underway. The start of data taking is expected at the end of 2022. The main objective of the experiment is to determine the mass hierarchy of neutrinos, but it has also other physical goals. In fact, it will be useful for the detection of other natural sources of neutrinos, including the measurement of oscillations of atmospheric neutrinos produced during interactions of cosmic rays, or of neutrinos from supernova explosions.

The student will work with simulations of these interacting neutrinos in the JUNO detector in order to characterize their detection according to their origin and their energy, taking into account the performance of JUNO and the different background noises involved.

2. Study of the characteristics of neutrinos with the JUNO detector 2

B. Clerbaux (bclerbau@ulb.ac.be), N. Pauly (nicolas.pauly@ulb.be), JM. Sparenberg (jmspar@ulb.ac.be)

JUNO is a large liquid scintillator detector whose purpose is the detection of anti-neutrinos emitted by nuclear reactors situated at a distance of 53 km. The detector is located 700 m below the rock and consists of 20 kilotons of liquid scintillator contained in a 35 m diameter acrylic sphere, instrumented by more than 18000 20-inch photomultipliers tubes (PMTs). The main objective of the experiment is to determine the mass hierarchy of neutrinos, but it has also other physical goals. In fact, it will also be useful for the detection of
other natural sources of neutrinos, including the measurement of oscillations of atmospheric neutrinos produced during interactions of cosmic rays, or of neutrinos from supernova explosions. The international JUNO collaboration was established in 2014, construction of the site started in 2015 and the R&D and production phase for the detector is underway. The start of data collection is expected at the end of 2022.

Two thesis work subjects are proposed:

• Study of the energy spectrum of atmospheric neutrinos measured by the JUNO detector. The work will consist more particularly in defining the selection criteria of the physical events of interest for the analysis, which will have as final goal the determination of the parameters of the oscillations of these neutrinos and the combination with the measurements of the neutrinos of the reactors.

• Prospective study of the possibility of using JUNO data in the case of an analysis with multi-messengers (in particular JUNO - IceCube) with an alert system to trigger on signals coming from very violent astrophysical events. The work will focus on the feasibility of developing such an analysis (trigger system and threshold energy).
1. From 2D planar to 3D SPECT $^{131}$Iodine dosimetry

N. Pauly (nipauly@ulb.ac.be), O. Debeir (odebeir@ulb.ac.be), C. Marin (clementine.marin@bordet.be), B. Vanderlinden (bruno.vanderlinden@bordet.be)

Background:
In radiopharmaceutical therapy (RPT), a radionuclide is systemically or locally delivered with the goal of targeting and delivering radiation to cancer cells while minimizing radiation exposure to untargeted cells. Radiopharmaceuticals are a group of pharmaceutical drugs containing radioactive isotopes. The pharmacokinetic of radiopharmaceutical in the lesions and organs allows estimating the dose absorbed and so predict the effect of radiations. The pharmacokinetic is obtained by image quantification of the administered radiopharmaceutical.

An example of current RPTs includes thyroid ablation with the administration of $^{131}$Iodine. $^{131}$Iodine is a radioactive isotope that has a link to thyroid and emits some beta- particle, but also additional gamma rays emissions.

These gamma rays are conventionally detected through scintillation Gamma-Cameras to acquire multiple 2-D images (also called projections), from different time points or angulation. Software is further used to quantify the activity through these time points to obtain pharmacokinetics.

2-D images are simple to acquire but difficult to correct for quantification. It is why quantification is preferred on 3-D images, where multiple corrections are applied. Single-photon emission computed tomography (SPECT) is the tomographic imaging technique using these 2-D projections to reconstruct 3-D corrected images. The Jules Bordet Institute had just acquired the last generation of Gamma-Cameras allowing $^{131}$Iodine SPECT, leading a unique opportunity to make the step towards 3-D dosimetry.

Goal:
The goal of this master thesis is to define the procedure to quantify 3-D images to determine the pharmacokinetic of $^{131}$Iodine administered. First, the Master student will review the available literature on the subject. Secondly, based on literature findings and discussion with the medical physics team and the physician, the student will determine a list of experiment to investigate. Thirdly she/he will prepare and acquire phantoms (plastic objects that mimics human abdomen) containing activity of $^{131}$Iodine, with activities and geometries corresponding to the previous decisions. Then the student will reconstruct all acquired phantoms with each predefined reconstruction parameters and will perform image quality assurance on quantification. Finally, based on these results, the student will propose the new 3-D procedure for $^{131}$Iodine dosimetry.

2. Comparing quantitative $^{177}$Lu SPECT with scintillation or semiconductor Gamma-Cameras

N. Pauly (nipauly@ulb.ac.be), O. Debeir (odebeir@ulb.ac.be), G. Marin (gwennaelle.marin@bordet.be), B. Vanderlinden (bruno.vanderlinden@bordet.be)

Background:
Nuclear medicine examination requires delivery of a gamma-emitting radiopharmaceutical product into the patient, normally through injection into the bloodstream. The pharmacokinetics of the radiopharmaceutical in an organ allows studying the biology or the functionality of the considered organ. The pharmacokinetic is obtained by image quantification of the administered radiopharmaceutical.
177Lu is a radioisotope used to produce radiopharmaceutical products for therapeutic purpose because it emits beta particles, but as it also emits gamma rays the treatment could be imaged through gamma-cameras. Single-photon emission computed tomography (SPECT) is a tomographic imaging technique based on the detection of the gamma rays emitted by the radiopharmaceutical product. These gamma rays are conventionally detected through scintillation Gamma-Cameras to acquire multiple 2-D images (also called projections) from multiple angles. Software is then used to apply a tomographic reconstruction algorithm to the multiple projections, yielding the 3-D data set (SPECT).

A new generation of Gamma-Camera combining a new type of detectors made of semiconductor and a new type of geometry (ring shape) is now available. This new type of Gamma-Camera is very promising but still needs to be evaluated. (https://www.youtube.com/watch?v=TJzmTjdAMH8). The Jules Bordet Institute has just acquired the two last generations of these two types of Gamma-Cameras allowing 177Lu imaging, leading to a unique opportunity to directly compare their capabilities.

**Goal:**
The goal of this master thesis is to compare the efficiency in term of resolution and sensitivity of both systems. First, the Master student will study the available literature on the subject. Secondly, based on literature findings and discussion with the medical physics team, the student will determine a list of experiments to conduct. Thirdly she/he will prepare and acquire phantoms (plastic objects that mimic the human abdomen) containing activity of 177Lu, with activities and geometries corresponding to the previous decisions. Then the student will reconstruct all the acquired phantoms with each predefined reconstruction parameters and will perform image quality analysis. Finally, based on these analyses, the student will compare the two systems.
In a proton therapy center, the protons are transported from the cyclotron to the patient that will be treated by a beam line composed of dipoles and quadrupoles magnets as well as collimators and other devices. The goal here is to study the impact of the different parameters of the different devices on the stability of the optics of the beam line. For example, if one of the quadrupoles is misplaced, what would be the impact on the beam size in the patient? This project will first request to understand how the beam transport is done on an IBA proton therapy center as well as how the simulator works, what physics is behind it. It will then be necessary to work on a few easy examples with the simulator before really studying the impact of the different parameters. Another exercise could be to find a new optical solution for the beam transport line so that at low energy the beam size is smaller (with probably a loss of efficiency).

Supervisor: M. Dechamps

Cyclotrons with axial external injection have a vertical incoming beam inserted by an electrostatic inflector into the horizontal median plane. The 6-dimensional phase space of the beam (with positions and momentum of the particles) is altered with couplings between the transversal and longitudinal dimensions. An important property of an inflector is the transmission: the total amount of beam correctly injected in the median plane. An idea to improve the transmission of the beam is to apply angles to the entrance and/or exit of the electrode faces, to create a more uniform effective length seen by all the particles. The goal of the study would be to first calculate the theoretical dependence of the beam propagation on the angles. Second, simulation studies in 3D would be performed to validate the theoretical calculations and find the optimum angles for certain IBA cyclotrons.

Supervisor: Erik van der Kraaij
Le Service de Métrologie Nucléaire poursuit des activités dans les domaines de la proton thérapie et de la physique des accélérateurs avec plusieurs partenaires incluant l’Organisation Européenne pour la recherche nucléaire (CERN), Ion Beam Applications (IBA), le SCK-CEN et Royal Holloway (University of London). Les mémoires suivants sont proposés dans le cadre de ces collaborations aux étudiants de MA2 pour l’année académique 2021-2022.

Pour toute information complémentaire : Cédric Hernalsteens (cedric.hernalsteens@ulb.be - +33 7 85 69 47 07)

1. Machine protection studies for the High-Luminosity LHC (HL-LHC)

Mémoire et possibilité de couplage avec un stage MA2

Contacts: Cédric Hernalsteens (cedric.hernalsteens@ulb.be)

With a nominal stored energy of 362 MJ in each of the two proton beams of the LHC, which will be further increased to about 700 MJ in the future High Luminosity LHC (HL-LHC), uncontrolled beam losses represent a significant challenge for the integrity and safe operation of the machine. This work will focus on fast failures, critical for the protection and integrity of the machine and will study these failure modes with beam tracking simulations. A complete model of the HL-LHC will be provided, along with a toolbox to perform simulations, as done at CERN.

Cases related to the installation of new components in the machine (in particular, the hollow electron lens and the so-called “crab” cavities) will be studied in detail and discussed with experts at CERN.
2. Simulation of antiproton production for the CERN antimatter factory using a Monte-Carlo code based on Geant4

Contacts: Hernalsteens (cedric.hernalsteens@ulb.be)

The CERN antiproton complex has been producing antiprotons since the 1970s using intense 26 GeV proton beams from the CERN Proton Synchrotron impacted on a metallic target. The production capability and reliability of the accelerator complex to produce extra low-energy antiprotons have been increased recently, with the commissioning of a new low-energy ring (ELENA) and with the design of a new target, among other activities. The so-called “antimatter factory” will thus be the host of exciting new activities and experiments for years to come.

This project aims at modelling the antiproton target region (starting from the extraction line coming from the CERN Proton Synchrotron, including the target and the magnetic horn and the antiproton decelerator injection line), to assess the antiproton production and capture performance, using a numerical code based on Geant4: BDSIM. Using BDSIM, a model of the magnetic transport line, of the target and surrounding shielding will be constructed and numerical simulation will be carried out and discussed in detail.

The student interested in this project is encouraged to follow the course PHY-H504 “Introduction to particle accelerators” to have the opportunity to visit the antiproton complex and to share its results with CERN experts.

Figure 2 The antiproton decelerator target region and its associated shielding blocks.
3. Transverse coupling resonance crossing and emittance exchange study in Vertical Fixed-Field Accelerators (VFFAs)

**Contacts**: Cédric Hernalsteens ([cedric.hernalsteens@ulb.be](mailto:cedric.hernalsteens@ulb.be)) & Marion Vanwelde ([Marion.Vanwelde@ulb.be](mailto:Marion.Vanwelde@ulb.be))

The transverse emittances are physical beam parameters that characterize the density function of the transverse distribution of particles. They are of significant importance in the study of beam dynamics in particle accelerators. In the linear and uncoupled theory of motion, these transverse emittances are invariant. However, in realistic machines, a coupling of the transverse motion (residual coupling or coupling by design) drives coupling resonances. The transverse emittances are then pseudo-invariants, and a transverse emittance sharing occurs. Moreover, transverse emittance exchange is observed when dynamically crossing a coupling resonance. These phenomena have already been described theoretically and observed in several machines (notably in the CERN Proton Synchrotron).

The project aims to study the emittance exchange mechanism induced by resonance crossing and assess relevant parameters' influence (notably the time-dependent dynamics of the resonance crossing and the coupling strength). In addition to conventional machines, the study of resonances and resonances crossing will be extended to machines strongly coupled by design, such as the novel Vertical Fixed-Field Accelerators. This study will be carried out via simulations using the ray-tracing code Zgoubi and its python interface Zgoubidoo.

*Figure 3: Example of emittance exchange in the horizontal and vertical phase spaces (Kallestrup, J. and Aiba, M. (2020) ‘Emittance exchange in electron booster synchrotron by coupling resonance crossing’)*
4. Evaluation of the beam losses and activation in realistic geometries of proton therapy installations using BDSIM/Geant4

Contacts: Cédric Hernalsteens (cedric.hernalsteens@ulb.be) & Prof. Nicolas Pauly (nicolas.pauly@ulb.ac.be)

The realistic modeling of particular accelerators and beam transport lines including complex geometries, detailed magnetic fields models and beam dynamics using Monte-Carlo simulation codes is a challenging task. BDSim is a software built on top of the Geant4 Monte-Carlo library developed at Royal Holloway – University of London (RHUL).

A recent collaboration between IBA and RHUL lead to the modeling of the IBA compact proton therapy solution “Proteus One”. This work will pursue that effort by developing simulation tools and methods using BDSim for high-energy machines such as the CERN Proton Synchrotron (PS).

For the PS, the detailed study of the beam losses is necessary to reduce the activation of the machine elements and allow long-term operation, safe maintenance, and ultimately a high machine availability. A BDSIM model of the CERN Proton Synchrotron has already been made. The student will have to use it and improve it in order to correctly model the residual activation induced by the beam losses. Simulations will also be carried out to study the beam extraction processes.

Figure 4: Picture representing a part of the CERN Proton Synchrotron