The Swiss Master in Nuclear Engineering: A Collaboration between Universities, Research Centre and Industry

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\textsuperscript{d} ETHZ, Zurich, Switzerland

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Contents

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- Program Goals, Qualification Profile
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Introduction

- 40% of electricity in Switzerland, nuclear
  - Important option for future
  - University-level education in field, crucial national need

- Swiss Federal Institutes of Technology: Lausanne (EPFL), Zurich (ETHZ)
  - Long tradition of nuclear-related education
  - Optional courses (physics, mech. eng.)
  - PhD research, often with PSI collaboration
  - Support of industry (swissnuclear)

- Pooling of resources recently for set-up of new Master of Science in Nucl. Eng. (NE)
  - Present paper: main features, experience with running of this first-ever joint degree
Program Goals

- Provide in-depth knowledge on nuclear energy fundamentals, technology
  - Represents primary goal
  - Strongly inter-disciplinary field implies wide range of subjects to be taught
- Provide complementary knowledge on nuclear fusion
  - Strong background of fusion research at EPFL
- Provide knowledge on nuclear techniques in medicine, research and industry
  - Optional courses in radioisotope applications, accelerator physics
- Provide view of entire fuel cycle, from uranium mining to the back-end
  - Sustainability largely defined by fuel cycle, corresponding compulsory course
- Underline role of nuclear energy as part of a sustainable, global energy mix
  - Several electives related to non-nuclear energy production
Qualification, Employment Prospects

- Qualification profile corresponding to wide range of potential employers
  - From utilities, via nuclear service companies, to NPP vendors and developers
- Thus, in Switzerland
  - Nuclear utilities: Alpiq, Axpo, BKW-FMB
  - Nuclear waste disposal organisations: Nagra, ZWILAG
- Other types of industrial employers mainly abroad
  - Reactor vendors, fuel manufacturers, enrichment plants, reprocessing facilities
- R&D organisations, both inland (PSI) and abroad (GRS, IRSN,…)
- National nuclear safety authorities and other related government institutions
  - Swiss Federal Nuclear Safety Inspectorate (ENSI), …
- Non-nuclear fields, e.g. general energy sector, R&D (fluids, materials,…)
Curriculum Structure

- Student’s achievements measured in ECTS credit points
  - Full academic year: 60 ECTS, i.e. 1 ECTS ~ 1h class + 1h homework per week
- Swiss NE Master currently 90 ECTS, i.e. 3-semester, program
  - 2 semesters, course work; 3rd: 8-week industrial internship + 17-week project
- EPFL-ETHZ-PSI-swissnuclear collaboration reflected by:
  - 1st semester fully at EPFL, 2nd at ETHZ, 3rd at PSI
- Overall structure:
  - 28 ECTS compulsory courses, 20 core electives
  - 4 ECTS free elective, 2 entrepreneurship course, 6 Semester project
  - 30 ECTS Master thesis
- Teaching language: English
Compulsory Courses

- Seven compulsories
  - Each to be cleared separately
- First four at Lausanne
  - EPFL: Physics, Materials
- Other three at Zurich
  - ETHZ: Th’hydls, Engineering
- Several courses, “standard”
- Reactor Experiments, uses CROCUS reactor at EPFL
- Special Topics in Reactor Physics, advanced aspects
- Nuclear Systems, fuel cycle and impact on NPP operations

<table>
<thead>
<tr>
<th>No.</th>
<th>Course</th>
<th>Responsible University</th>
<th>Semester</th>
<th>Held at</th>
<th>ECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Neutronics</td>
<td>EPFL</td>
<td>Autumn</td>
<td>Lausanne</td>
<td>4</td>
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<tr>
<td>2</td>
<td>Reactor Experiments</td>
<td>EPFL</td>
<td>Autumn</td>
<td>Lausanne</td>
<td>4</td>
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<td>3</td>
<td>Reactor Technology</td>
<td>ETHZ</td>
<td>Autumn</td>
<td>Lausanne</td>
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<td>4</td>
<td>Nuclear Fuels and Materials</td>
<td>EPFL</td>
<td>Autumn</td>
<td>Lausanne</td>
<td>4</td>
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<tr>
<td>5</td>
<td>Nuclear Safety</td>
<td>ETHZ</td>
<td>Spring</td>
<td>Zurich</td>
<td>4</td>
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<tr>
<td>6</td>
<td>Special Topics in Reactor Physics</td>
<td>EPFL</td>
<td>Spring</td>
<td>Zurich</td>
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<tr>
<td>7</td>
<td>Nuclear Energy Systems</td>
<td>ETHZ</td>
<td>Spring</td>
<td>Zurich</td>
<td>4</td>
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</tbody>
</table>

Total: 28
Core Electives - 1

- 20 ECTS of core courses (5 electives), chosen from three different tracks
  - A. Energy Systems
  - B. Physics & Materials
  - C. Thermal-hydraulics
- Tracks, not specializations, solely to guide students in their choice
- Advice also provided by “tutor”

<table>
<thead>
<tr>
<th>No.</th>
<th>Course</th>
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<th>Semester</th>
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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Advanced Fossil and Renewable Energy Systems</td>
<td>EPFL</td>
<td>Autumn</td>
<td>Lausanne</td>
</tr>
<tr>
<td>2</td>
<td>Hydraulic Turbomachines</td>
<td>EPFL</td>
<td>Autumn</td>
<td>Lausanne</td>
</tr>
<tr>
<td>3</td>
<td>Probabilistic Safety Analysis and Risk Management for Critical Energy Infrastructure</td>
<td>ETHZ</td>
<td>Spring</td>
<td>Zurich</td>
</tr>
<tr>
<td>4</td>
<td>Renewable Energy Technologies II, Energy Storage and Conversion</td>
<td>ETHZ</td>
<td>Spring</td>
<td>Zurich</td>
</tr>
</tbody>
</table>
## Core Electives - 2

### Track B: Physics and Materials

<table>
<thead>
<tr>
<th>No.</th>
<th>Course</th>
<th>Responsible University</th>
<th>Semester</th>
<th>Held at</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Nuclear Fusion and Plasma Physics</td>
<td>EPFL</td>
<td>Autumn</td>
<td>Lausanne</td>
</tr>
<tr>
<td>2</td>
<td>Introduction to Particle Accelerators</td>
<td>EPFL</td>
<td>Autumn</td>
<td>Lausanne</td>
</tr>
<tr>
<td>3</td>
<td>Radioisotope and Radiation Applications</td>
<td>EPFL</td>
<td>Spring</td>
<td>Zurich</td>
</tr>
<tr>
<td>4</td>
<td>Advanced Topics in Nuclear Reactor Materials</td>
<td>EPFL</td>
<td>Spring</td>
<td>Zurich</td>
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</tbody>
</table>

### Track C: Thermal-hydraulics

<table>
<thead>
<tr>
<th>No.</th>
<th>Course</th>
<th>Responsible University</th>
<th>Semester</th>
<th>Held at</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Instability and Turbulence</td>
<td>EPFL</td>
<td>Autumn</td>
<td>Lausanne</td>
</tr>
<tr>
<td>2</td>
<td>Two-Phase Flows and Heat Transfer</td>
<td>EPFL</td>
<td>Autumn</td>
<td>Lausanne</td>
</tr>
<tr>
<td>3</td>
<td>Multi-Phase Thermal Fluid Dynamics</td>
<td>ETHZ</td>
<td>Spring</td>
<td>Zurich</td>
</tr>
<tr>
<td>4</td>
<td>Advanced CFD Methods</td>
<td>ETHZ</td>
<td>Spring</td>
<td>Zurich</td>
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</tbody>
</table>
Semester Project

- Introduction to nuclear R&D
- 1 day per week during 2\textsuperscript{nd} sem.
  - Preparation for Master thesis
- Basis for choice of topic:
  - Course work during 1\textsuperscript{st} sem.
  - Advice of tutor
  - Visit to PSI at end of 1\textsuperscript{st} sem. (national centre for nuclear R&D), site for Master research
  - Presentation of main R&D activities underway in NES Dept., e.g. in Dec.'09

<table>
<thead>
<tr>
<th>No.</th>
<th>R&amp;D Activity</th>
<th>Responsible Laboratory</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Experimental Reactor Physics</td>
<td>Reactor Physics and Systems Behaviour</td>
</tr>
<tr>
<td>2.</td>
<td>LWR Core &amp; Transient Analysis</td>
<td>Reactor Physics and Systems Behaviour</td>
</tr>
<tr>
<td>3.</td>
<td>Gen. IV Fast Reactor Studies</td>
<td>Thermal-hydraulics</td>
</tr>
<tr>
<td>4.</td>
<td>Thermal-hydraulic Phenomena</td>
<td>Thermal-hydraulics</td>
</tr>
<tr>
<td>5.</td>
<td>Severe Accident Phenomena</td>
<td>Nuclear Materials</td>
</tr>
<tr>
<td>6.</td>
<td>Nuclear Fuels R&amp;D</td>
<td>Nuclear Materials</td>
</tr>
<tr>
<td>7.</td>
<td>Reactor Component Safety</td>
<td>Hot Lab</td>
</tr>
<tr>
<td>8.</td>
<td>High Temperature Materials</td>
<td>Waste Management</td>
</tr>
<tr>
<td>9.</td>
<td>Analytical Techniques (Fuels)</td>
<td>Energy Systems</td>
</tr>
<tr>
<td>10.</td>
<td>Waste Management</td>
<td>Centre for Research in Plasma Physics (EPFL)</td>
</tr>
<tr>
<td>11.</td>
<td>Technology Assessment</td>
<td></td>
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<tr>
<td>12.</td>
<td>Risk &amp; Human Reliability</td>
<td></td>
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<tr>
<td>13.</td>
<td>Materials for Nuclear Fusion</td>
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<tr>
<td>14.</td>
<td>Magnets for Nuclear Fusion</td>
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</tbody>
</table>
Master Project

- Master project (30 ECTS): two parts
  - 8-week industrial internship (NPPs, ENSI, Nagra, etc.)
  - 17-week Master thesis, usually built upon semester project

- Master thesis
  - Enhance capability for independent theoretical and/or experimental NE research
  - Condition for starting: clearance of at least 50 ECTS of course work (from total of 60 needed)
  - Supervision: senior PSI/NES scientist + responsible professor

Examples of chosen research topics, 2008 batch

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<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>1.</td>
<td>HELIOS analysis of a SCWR-like test lattice in PROTEUS</td>
</tr>
<tr>
<td>2.</td>
<td>Improved Monte Carlo calculations of RPV fluence</td>
</tr>
<tr>
<td>3.</td>
<td>Analysis of PHENIX pre-shutdown tests</td>
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<tr>
<td>4.</td>
<td>Feasibility study for neutron tomography of 2-phase flows</td>
</tr>
<tr>
<td>5.</td>
<td>Validation of CFD modelling results</td>
</tr>
<tr>
<td>6.</td>
<td>Modelling of reactor containment flows</td>
</tr>
<tr>
<td>7.</td>
<td>An isotopic dilution technique for fission gas analysis</td>
</tr>
<tr>
<td>8.</td>
<td>LCA analysis of waste disposal and CO₂ sequestration</td>
</tr>
</tbody>
</table>
Organisational Aspects: Core Group, Tutors

- Program conducted under supervision of NE “Core Group” (NECG)
  - Professors from each university, PSI-NES department head, swiss nuclear representative, …
  - Decisions on academic matters by professors (formal ratification by both universities)

- Each student chooses a tutor at start of program
  - Academic mentor, advisor (e.g. on choice of optional courses)

- Many of the courses taught by professors, but not all
  - Additional lecturers needed for meeting demands of wide-based curriculum
  - Necessary academic personnel, largely from among senior PSI-NES scientists
  - Approval from university department through NECG professor
Admission Requirements, Procedure

- Program open to wide range of Bachelor degree holders
  - Mechanical/Electrical/Chemical Engineering, Materials Science, Physics, Chemistry, Maths.
  - Justified by multi-disciplinary character of NE Master
  - Common admission profile, corresponding to ~ first 2 years of Bachelor
    - 18 ECTS Mathematics, 12 ECTS Natural Sciences, 12 ECS Engineering Sciences

- Evaluation of candidates on basis of detailed dossiers
  - NE Core Group, role of Admission Committee (AC)
  - Principal criteria: degree, parent university, academic performance

- Several decisions taken on individual basis
  - Subsidiary course requirements, if necessary
  - Allocation of students from abroad to the 2 different universities (registration)
Administration, Mobility Support, Degree

- Admission / registration for courses, 2 independent procedures
  - All students registered at EPFL for 1st semester, at ETHZ for 2nd
  - Exchange student status for those admitted at “other” university
  - Creditation of courses, responsibility of host university

- Semester, Master projects
  - Responsibility with EPFL or ETHZ professor, depending on topic (may or may not be tutor)

- Mobility support granted by ETH-Domain’s energy competence centre (CCEM-CH)
  - Funding to cover extra expenditure related to “multi-campus” nature of program

- Degree issued jointly by the 2 universities
  - Master of Science EPF-ETH in Nuclear Engineering
Experience to Date

- First 2 batches of similar size
  - 12 students in 2008 (4 from Swiss universities, 8 from abroad)
  - 13 students in 2009 (7 from Swiss universities, 6 from abroad)
  - Large fraction of students from abroad, reflection of “Bologna spirit”

- Bachelor degrees of various types (among the 25 students to date)
  - Domination of Physics, Mech. Eng., in line with “host” departments at EPFL, ETHZ

- Feedback from students, generally very positive
  - Attending classes in 2 different universities with different “cultures”, enriching experience
  - Despite “mixed” background of students, courses found both interesting and challenging
  - Wide range of R&D topics offered at PSI, felt to be a noteworthy strength
Future Prospects

- Current 90 ECTS (3 semester) program would benefit from upgrade to 120 ECTS
  - Make course work less “dense”
  - Allow greater flexibility in structuring industrial internship, Master project
  - Render program fully compatible with “3 + 2”-year Bologna system

- Deliberations during 2009, decision to implement new curriculum starting this Sept.
  - Main change: additional, new 3rd semester at PSI for semester project and 4 “block” courses

### NE core (block) courses in 3rd semester of new 120 ECTS curriculum

<table>
<thead>
<tr>
<th>No.</th>
<th>Course</th>
<th>Responsible University</th>
<th>Course Type</th>
<th>Held at</th>
<th>ECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Radiobiology and Radiation Protection</td>
<td>ETHZ</td>
<td>Compulsory (new)</td>
<td>PSI</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>Adv. Topics in Nucl. Reactor Materials</td>
<td>EPFL</td>
<td>Core Elective</td>
<td>PSI</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>System Codes Lab</td>
<td>EPFL</td>
<td>Core Elective (new)</td>
<td>PSI</td>
<td>3</td>
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<tr>
<td>4</td>
<td>Beyond-Design-Basis Safety</td>
<td>ETHZ</td>
<td>Core Elective (new)</td>
<td>PSI</td>
<td>3</td>
</tr>
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<td></td>
<td>Total:</td>
<td></td>
<td></td>
<td></td>
<td>14</td>
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</table>
Conclusions

- As first-ever common EPFL- ETHZ degree, Swiss NE Master a unique collaboration between universities, research centre and industry

- Although mainly addressing national needs, to be viewed in international context
  - Reflected in high fraction (> 50%) of students from abroad

- Program upgrade to 4 semesters from Sept. 2010 onwards
  - Further strengthening of curriculum
  - Greater conformity with other NE programs, increased prospects for international collaborations
Thank you for your attention!