Nuclear Education and training in France:

New challenges

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Energy Needs

- Energy is essential for development:
  - Raising productivity, both industrial and agricultural
  - Reducing poverty
- Need of reliable and secure access to sources of energy:
  - 1.6 billion people have no access to electricity,
  - 2.4 billion people have no access to modern fuels and rely on traditional biomass for cooking and heating
- 2 factors: demography and economical development
  - 2050 : World population increased by 3 billions
  - it will be necessary to double the energy production
  - 70% of growth is likely to come from developing countries
- World challenge remains to satisfy basic needs: water, energy, food

Energy Needs and Sustainable Development

- Fossil energy will be depleted over the next decades for oil and gas, the next century for coal, while they presently provide 85% of the world energy

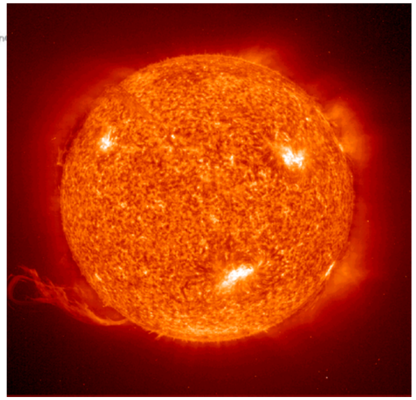
- Man-made GHG emission into the atmosphere has lead to global climate change and this may have dramatic consequences (see IPCC reports)

- Reconciling growth in energy consumption with fossil depletion and environment protection with a view towards sustainable development.

- The challenge: more energy and less CO_2.

- Save energy, diversify energy sources and intensify R&D on innovative technologies .

Renewable Energies



In principle wind and direct solar energy can produce enough electricity or heat

But intermittency and storage still prevent these energies to share a significant part of the mix

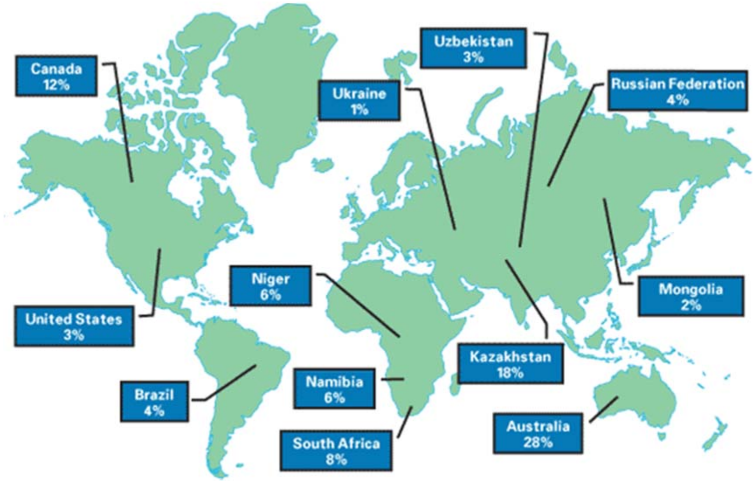
So far , the only easy massive storage for renewable energies is hydraulic storage

Today there is no solution for even a mid term massive storage (> a week).
No realistic solution is foreseen for the next future.

« There is no choice between nuclear or renewables, nuclear and renewables have to go together »

attractive features of nuclear energy

- An almost domestic energy
  - Uranium is distributed over the World.
  - Uranium supply is not an issue of energy security as oil or gas can be



- An economical cost which is predictable.
  - Main cost is construction. Important long term investment
  - Relatively low marginal and operation costs
  - When a plant is built : a predictability of cost for the next 60 years.
  - The cost of uranium is only about 5% of the KWh cost

- Nuclear produces no CO_2

Nuclear Renaissance

- Presently: 436 nuclear power reactors (in 31 countries) yield 372 GWe
  - 16% of total world electricity (31% in Europe)
  - Mostly LWR's
  - An increase of only 31 Gwe over the last 10 years

- All studies forecast an increase of nuclear power capacity
  - Replacement and new constructions
  - January 2010: 57 reactors (55GWe) on construction (IAEA source)
  - An increase of about 10 Gwe/year which may double or triple at mid-term
  - An additional capacity from 175 Gwe up to 520 Gwe by 2030

Future availability of Uranium fuel

- LWRs (1GWe) need 180 tons Unat per year => 67 000 tons/year needed presently

- known recoverable U reserves are 4.7 million tonnes (< 100 €/kg)

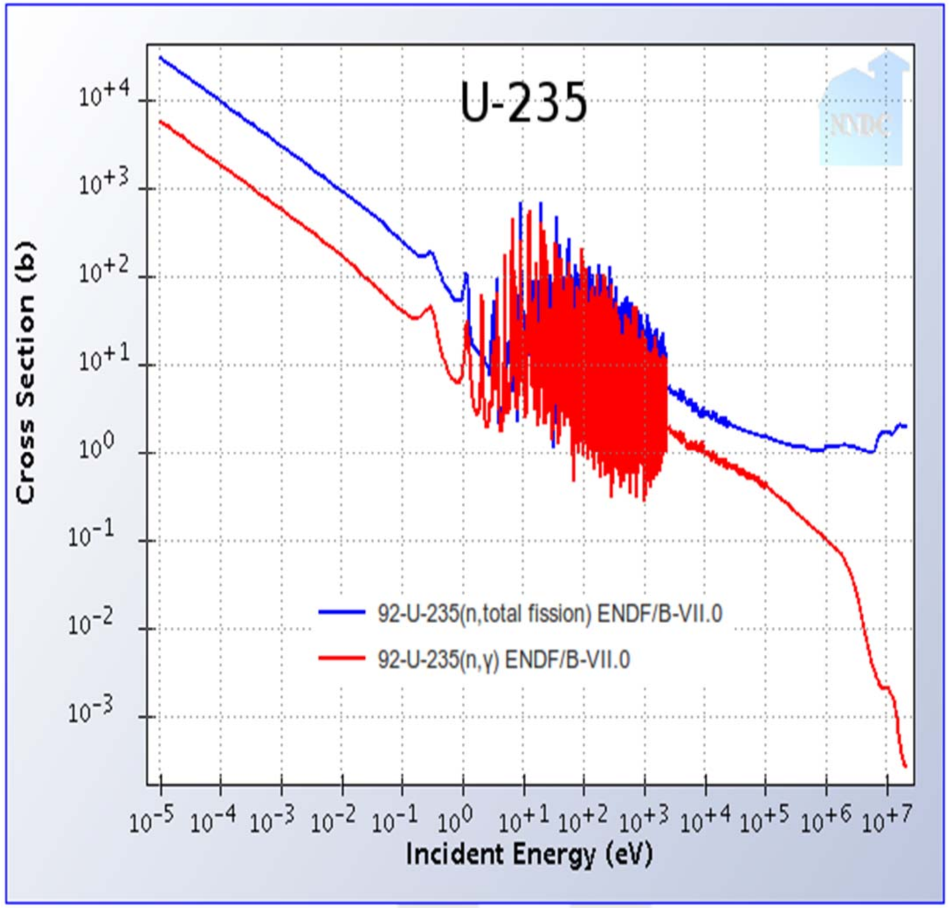
- For < 200 €/kg, go up to 15 million tons. At higher prices: phospates, sea water, coal
- At current consumption rate (67 000 t/y) reserves exhausted in about 200 years

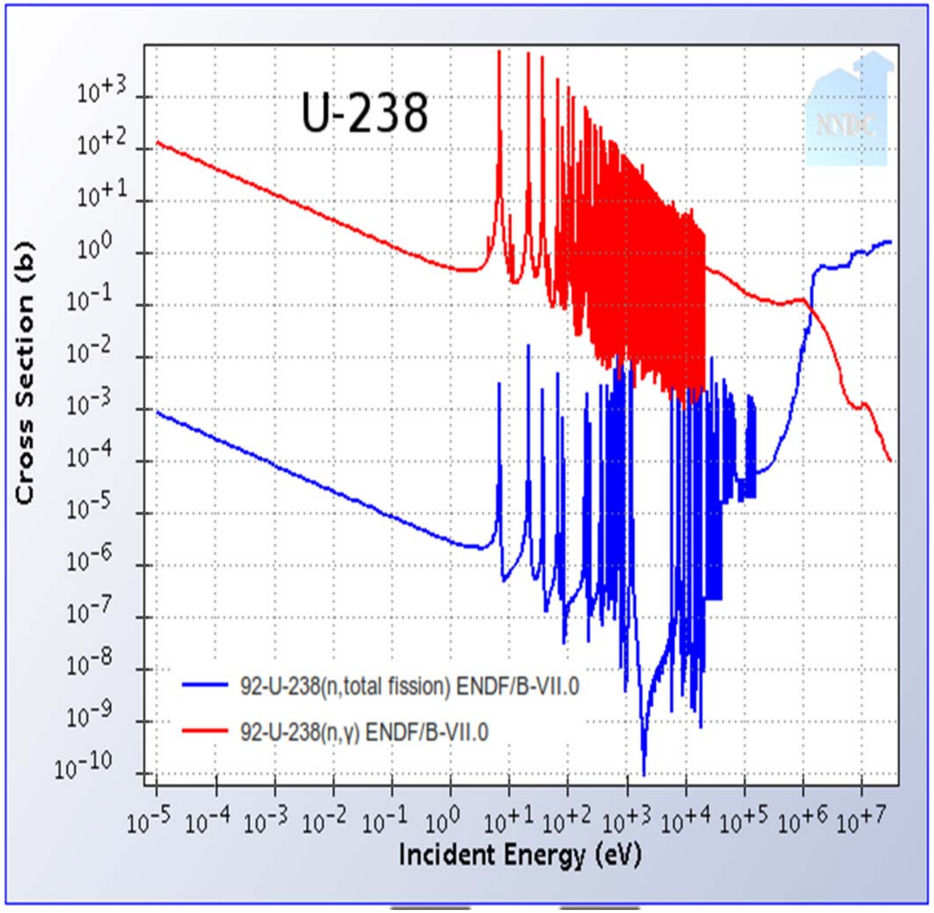
- Assume in 2050: 1000 GWe and 150 t/GWe/y => reserves exhausted in less than a century

- **Sustainability of nuclear only if fast breeders (FBR) are used**

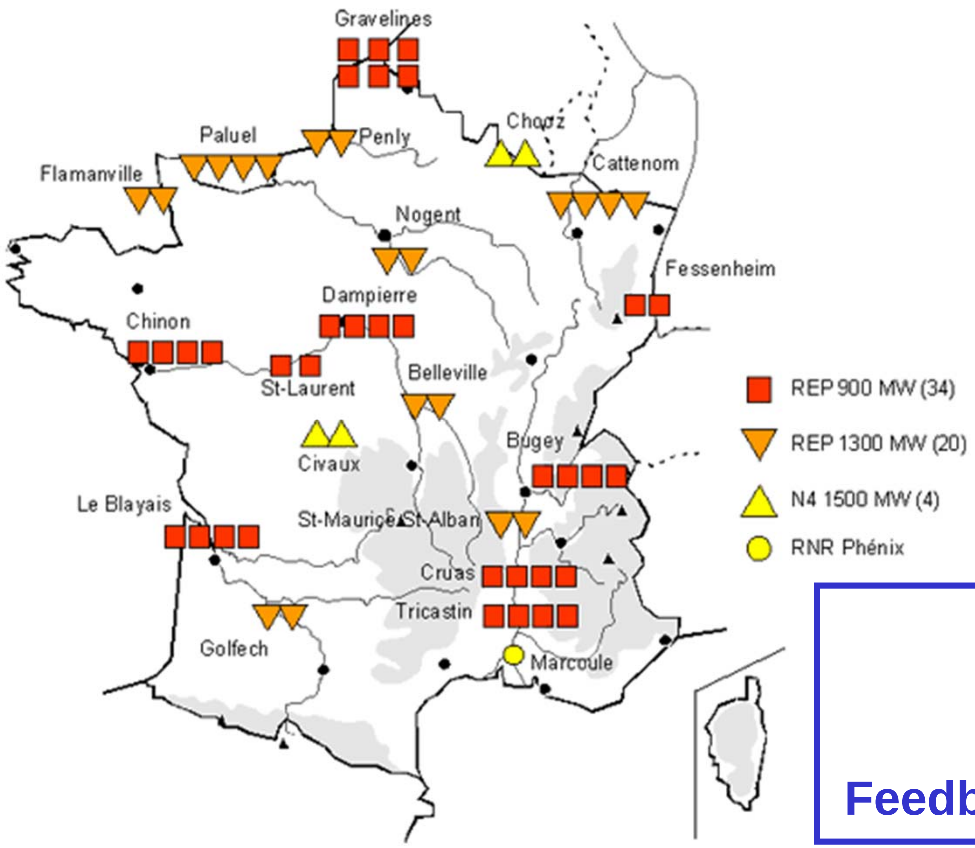
=> 4th generation

Odd-N nuclei fission with thermal neutrons
Even-N nuclei capture thermal neutrons





Nuclear Power Plants in France



58 PWR units on 19 sites
Net installed capacity : 63 GWe
highly standardized fleet
Feedback on safety and cost effectiveness

418 nuclear TWh in 2008, 76.2% of total
Hydro 12.4%
Fossil 10.4%
Wind + Photovoltaic 1%

130 Mtons CO2 avoided (= transport)

Generation III: European Pressurized Reactor (EPR)

Designed and developed by AREVA and Siemens

High safety standards and high efficiency

- The facility is robust enough to prevent evolution to severe accident.
- Core catcher, redundant safety system
- If an accident occurs: the facility is designed to limit its consequences
- Protection against external hazards (airplane crash, explosion, earthquake…)

Towards 4th generation and sustainability

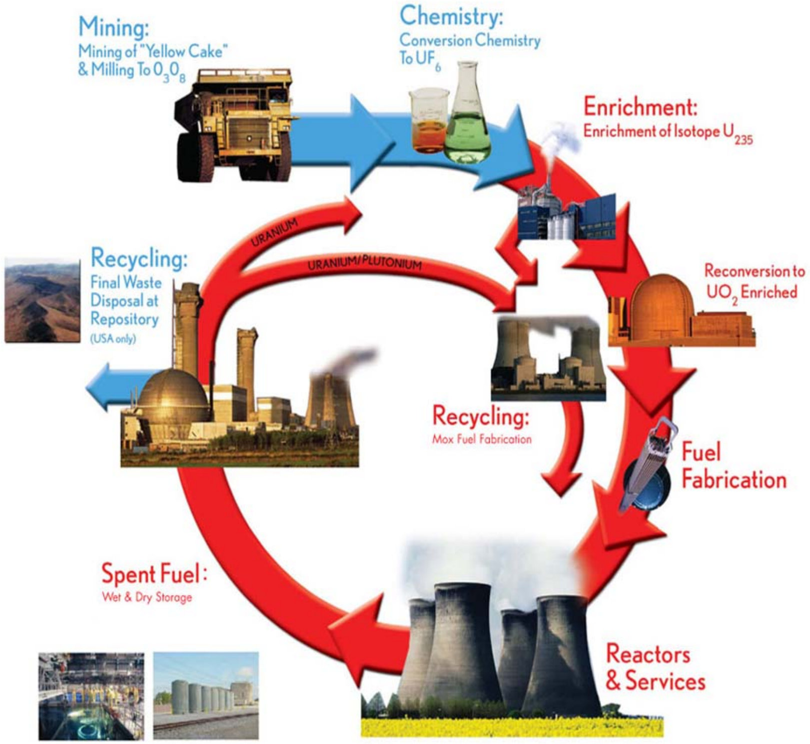
Act on sustainable management of radioactive materials and waste (June 28 -2006)

- **Main orientations:**
- Reduction of quantity and toxicity of wastes by processing spent fuels
- Deep geological depository of ultimate radioactive wastes

- **Associated research:**
- Deep geological storage (reversible > 100 y) and selection of a site
  - 2015 document for authorisation; 2025 starting the operation
- Separation and transmutation of High-Level-Long-Lived waste

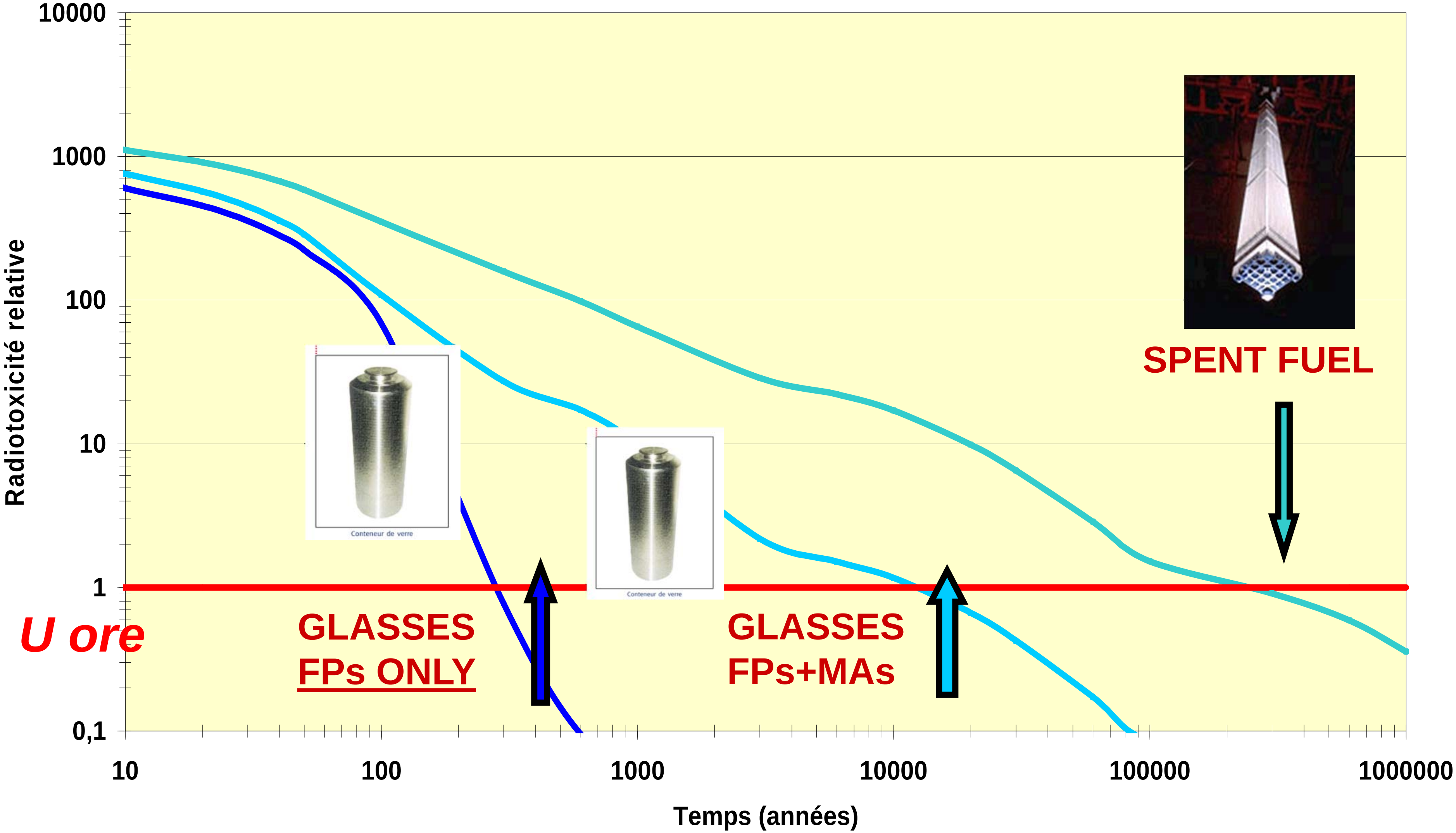
- ***studies and research in relation with those on the new generation of FNR so that an assessment can be made in 2012 and a prototype installation set in operation by 2020***

Closing the fuel cycle
a 25 years old industrial experience



- 20 000 t_{HM} spent fuel reprocessed
- 1200 t_{HM} MOX fuel recycled
- 1100 t_{HM} /yr of spent fuel discharged from PWRs
- Up to 1 600 t_{HM} /yr of spent fuel reprocessed (domestic + foreign)

Final waste toxicity



Nuclear Future: A need for substantial R&D

- Extending the lifetime of reactors
  - Better (new) materials to sustain higher irradiation, chemical corrosion, mechanical stress, higher temperature..
- Fast Breeder Reactors
  - core studies for a better void coefficient
  - for a better breeding factor without blankets
  - from oxides to carbides (higher density, higher thermal conductivity) or metals
- Recycling of Minor actinides
  - Homogeneous incorporation of MA in fuel
  - Heterogeneous recycling
- Waste management
  - Ageing of glasses
  - Transport of radioelements in clay

Strong demand for new materials

- **Materials for cladding and structural components**
- **Transuranic fuel materials**

- **materials able to sustain intense irradiation (fast neutrons)**
- **materials able to sustain high temperature, thermal creep**
- **materials able to sustain high mechanical stress and corrosion.**
- **Materials able to sustain high burn-up**

- **New grades of steel : Oxide dispersion strengthened steel (ODS) for cladding resisting swelling and High T**
- **Ceramics and composites (SiC-SiC…) resisting very high temperature**
- **Liquid metal technologies.**

Damage of materials under irradiation a massively multiscale problem

Defects created by irradiation

Interstitials vacancies

Migration
Clusters
Extended structures

Effects on mechanical properties
Performance degration
Failures

Neither experiment nor theory has yet captured the complexity in a single framework

Wigner effect: formation of metastable defect structures

Energy stored by defects can lead to a catastrophic release of energy
remember the Windscale fire (graphite moderator at 200-250 C)

Nuclear Fuel Chemistry

- **Innovative nuclear fuels for future reactors (Na FNR and Gas FNR)**
- **Partitioning and transmutation of MA (Np, Am, Cm) => reduce toxicity and heat generation of high level radioactive waste**
- **Co-processing of actinides => increased proliferation resistance**
- **Mixed actinide fuels**

Basic actinide research on solid-state physics, solution chemistry, solid-liquid interfaces

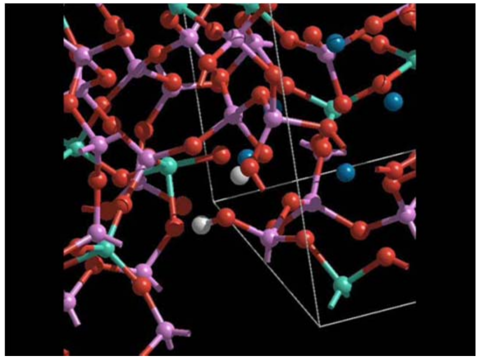
Long term behaviour of nuclear glasses

Theoretical and modelling issues

✓Glassy transition and slow dynamics

✓Stress corrosion : from subcritical fracture propagation to rupture

✓Ageing of glasses



✓Need for high performance algorithms

✓Need for better inter-atomic potentials

✓Need to couple MD with hydrolysis reactions

✓Diffusion of water in fractures (mesoscopic scale) coupling with MD

Multiscale modeling of melted nuclear glasses for process engineering

Building a nuclear industry raises big challenges

- It is a complex industrial and business system
- It requires highest safety and security standards
- It requires to comply with international rules
- It requires to have developed an in-depth and comprehensive understanding of the technologies at all levels and complexities
- It requires a critical mass of competent human resources

Share best practices in education and training

A nuclear accident somewhere is an accident everywhere

- Safety and security of nuclear reactors and fuel plants
  - in depth understanding of the physical science and technology
  - capacity to improve the technology
  - capacity to set new efficient safeguards

- Strong ethics at workplace
  - Ability to inform and communicate
  - Ability to anticipate and prevent departure from normal operating conditions
  - Ability to react rationally and efficiently to an unexpected event

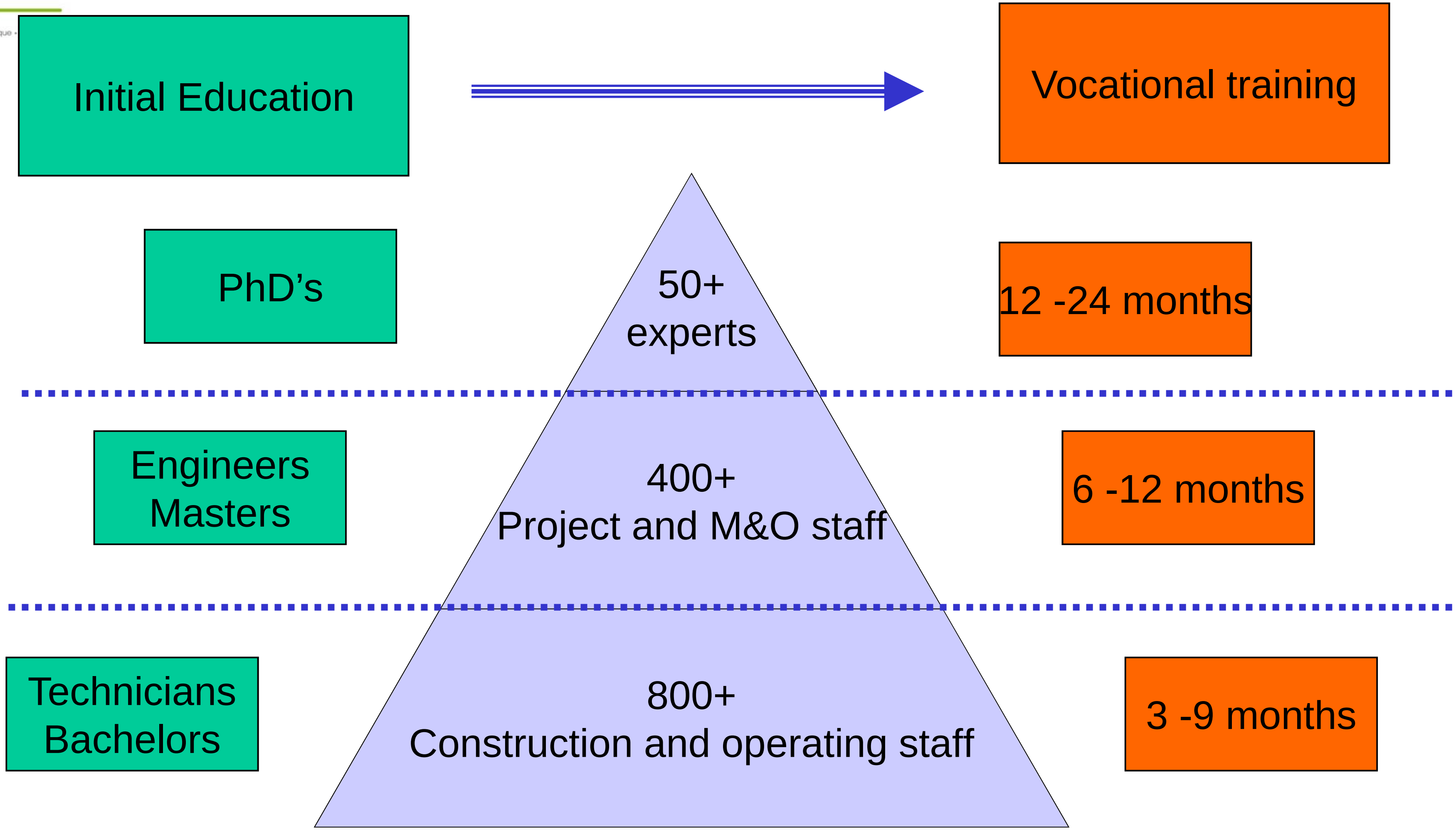
- A world shared responsibility:
  - Sharing experience and initiatives

Share best practices in education and training

Need of a comprehensive knowledge in in nuclear security

- In-depth knowledge in the main areas of nuclear security
  - Detection of and response to malicious acts
  - Detection of nuclear material for combating illicit traficking
  - Physical protection systems design and evaluation
  - Forensic techniques
- Threat assessment
  - External and internal threats
- International and national legal framework regulating nuclear security
  - History and role of international organizations
  - NPT and additional protocol

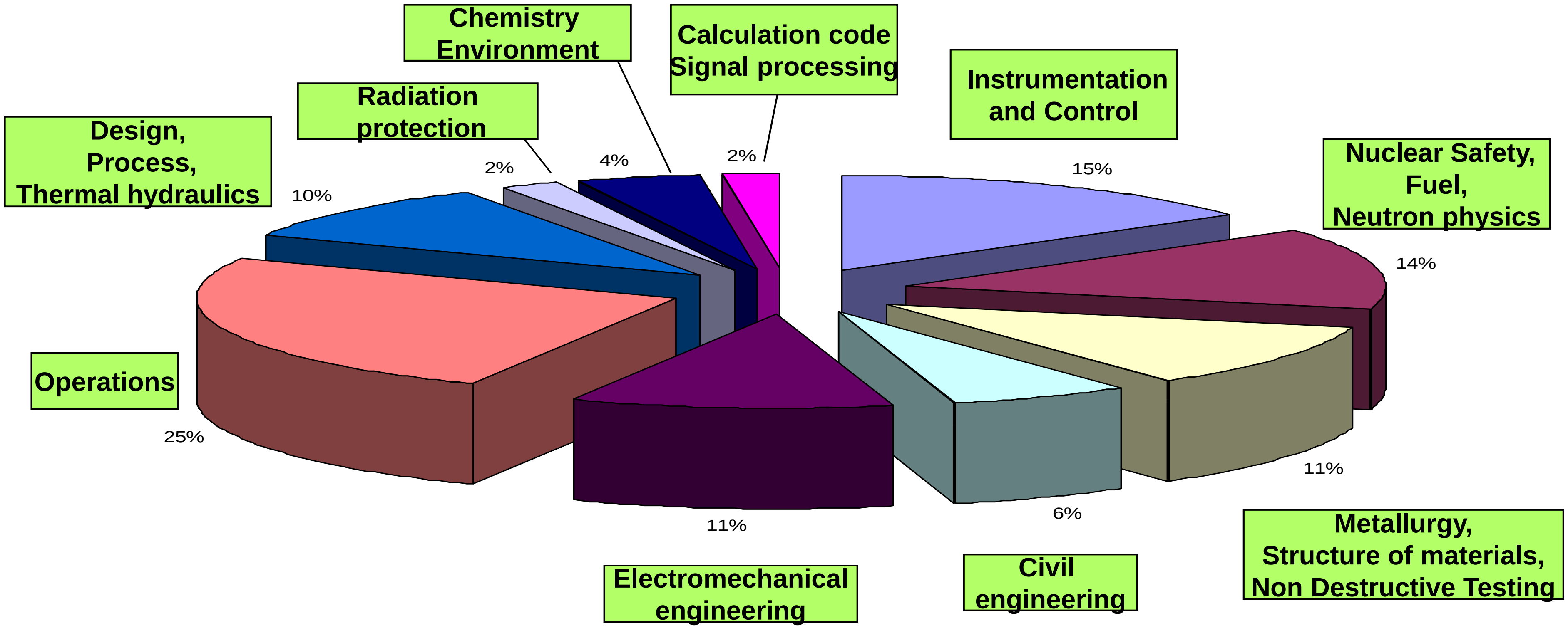
From initial to vocational training



From AREVA

Typical workforce needs for 2 NPP's

Recruitment of Engineers by EDF in the nuclear sector



Need for skills for Design, Construction, Operations, Dismantling,… of NPPs goes beyond pure nuclear education and training

Education needs in France at nuclear master level

– about 1200 engineers per year for at least the next ten years,

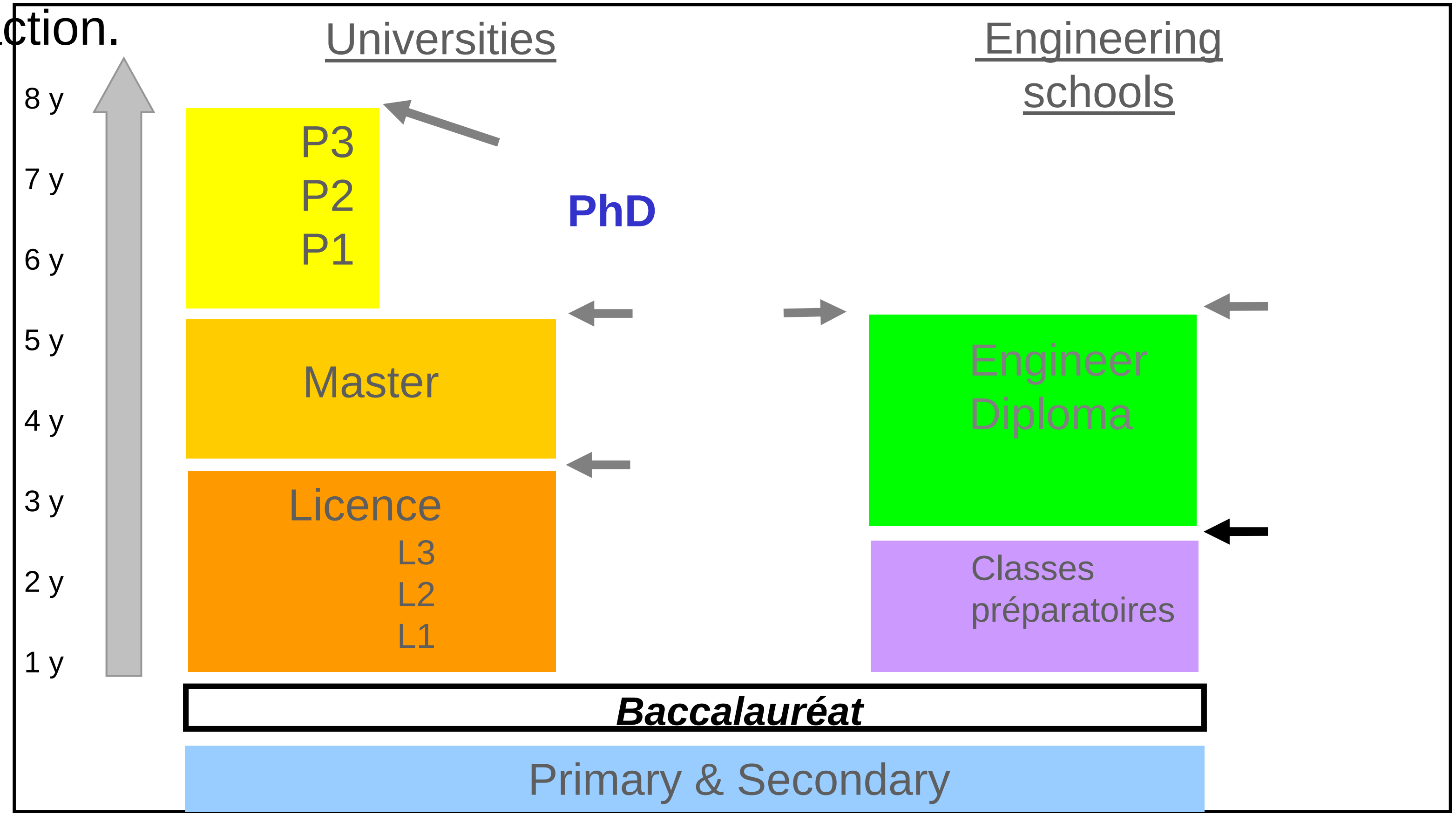
– about 100 PhD candidates per year during the coming years in main agencies for R&D in nuclear technologies, safety, waste management, such as CEA, IRSN (TSO) , or ANDRA

– around 200 foreign students

– Total of about 1500 Master level graduates every year.

French educational system

- Engineers are usually trained in special schools rather than at universities.
- Currently, around 25 000 students graduate at a Master Level per year in the French Engineering Schools. The engineering graduates from Universities need to be added to this figure, but they remain a small fraction.



Present capacities of nuclear education

- About 300 Master students graduated in 2006 (as in the years before)

- setting up new curricula and extending existing ones.
  - About 20 main schools and universities concerned

- At the end of 2008, various curricula contributed to:
  - about 600 graduated at Master level in nuclear engineering or related
  - about 100 graduated at PhD level

- December 2009 : 886 students enrolled in nuclear related masters and a potential of 1250 enrolments

- It is worth noting that most of the employees in the major companies are trained “on the job” through internal processes.

CFEN
French Council for Education and training in Nuclear energy

CFEN was created by the Minister of High Education and Research in 2008

- CFEN aims to assess the adequacy between the education offer, the students population in different curricula and the industrial/research needs.

- It advises the Office of High Education on opening new academic curricula in the nuclear domain. It gives a label.

- CFEN informs students of various educational curricula and possible professional careers and opportunities in nuclear power technology.

- CFEN coordinates the international recruitment of students.

- CFEN promotes international curricula such as the new International Master of Science in Nuclear Energy starting in Paris 2009.

CFEN

http://www.cfenf.fr/

Chaired by the High Commissioner for Atomic Energy (Catherine Cesarsky)

Members are:

- representatives of governmental authorities in Education, Research and Industry, Foreign Affairs
- representatives of academic institutions (universities and engineering schools),
- representatives of the main industrials actors (AREVA, EDF, GDF-SUEZ, sub-contractors),
- representatives of main nuclear R&D institutions (CEA, IRSN, ANDRA)
- Secretary (C. G.)

Master of Science

in Nuclear Energy

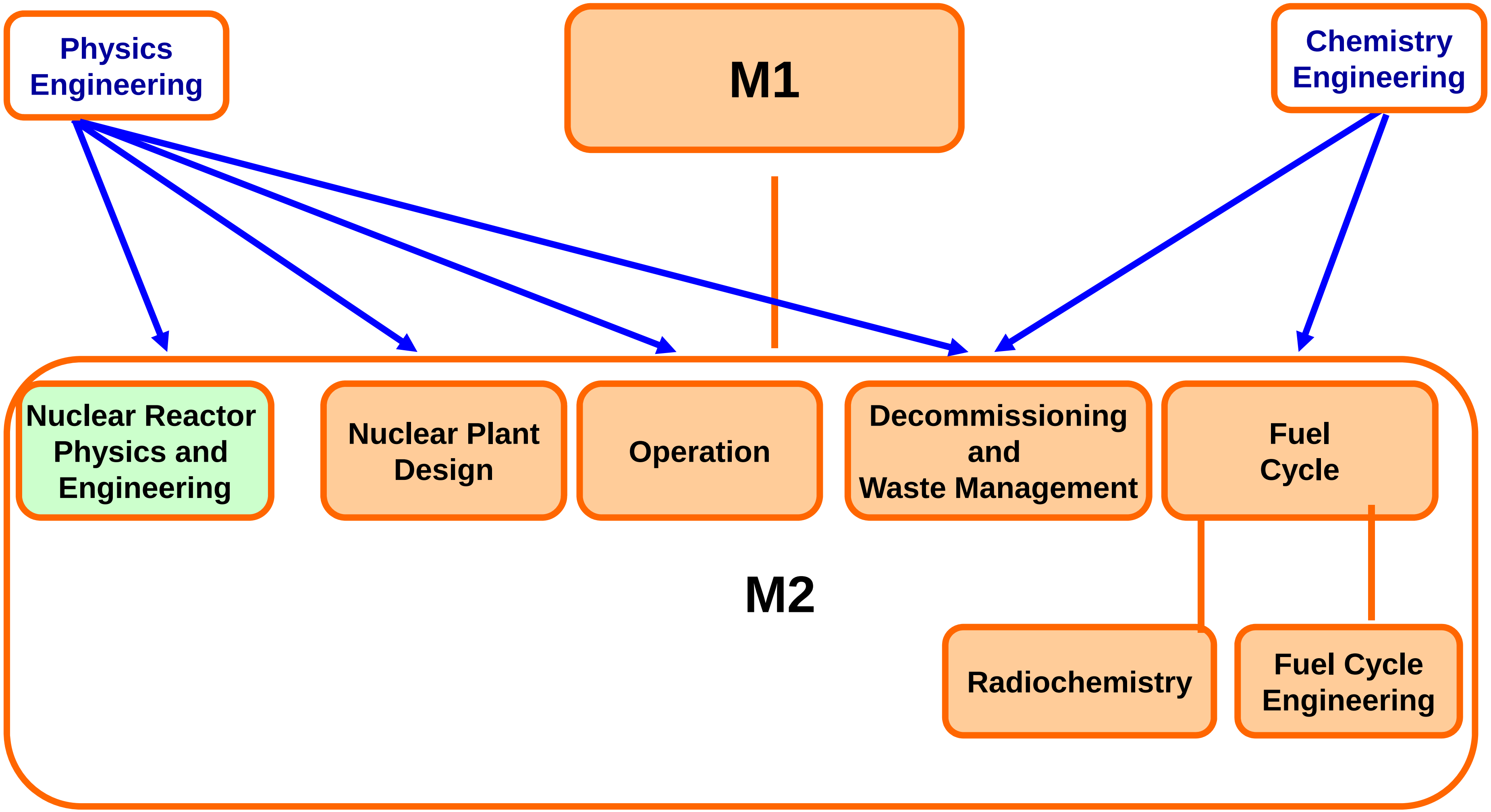
Master of Science in Nuclear Energy

- The most renowned academic institutions of the Paris area, involved in undergraduate and graduate nuclear education …
  - **Université Paris-Sud**
  - **ParisTech (Ecole Polytechnique, ENSTA, Chimie Paris, Mines Paris, Ponts et Chaussées, Arts et Métiers)**
  - **Ecole Centrale Paris – Supélec**
  - **CEA/INSTN**
- responding to an EDF initiative to create a high level degree in nuclear energy
- have designed and implement an ambitious joint Master Program
- benefiting from the unique expertise of world leaders in Nuclear Research and Nuclear Industry

EDF, CEA, AREVA, GDF SUEZ

MIEN: General information

- **Opening:** **September 2009**
- **Location:** **Paris**
- **Duration:** **2 years**
- **Targeted number of students to be trained each year:** **200**
- **Number of students enrolled in 2009-2010:** **85**
- **Admission of high-potential French and international students with at least a Bachelor's degree in one of the following fields: Physics, Mechanical Engineering, Electrical Engineering, Chemical Engineering, Chemistry**
- **All courses and exams are in English**


Physics
Engineering
M1
Chemistry
Engineering
Nuclear Reactor
Physics and
Engineering
Nuclear Plant
Design
Operation
Decommissioning
and
Waste Management
Fuel
Cycle
M2
Radiochemistry
Fuel Cycle
Engineering

MIEN: Program contents in 1st year

Courses – Semester 1

- ❖Elements of Nuclear Physics
- ❖Thermodynamics
- ❖Continuum Mechanics
- ❖Materials Science
- ❖Chemical Engineering I
- ❖Energy Production Technologies
- ❖Option 1: Quantum Mechanics
- ❖Option 1: Electrical Power Engineering

Courses – Semester 2

- ❖Fluid Mechanics
- ❖Mathematics
- ❖Solution Chemistry
- ❖Project Management
- ❖Economics of Energy
- ❖Option 2: Chemical Engineering II
- ❖Option 2: Automatic Control Systems
- ❖Option 2: Basic Neutronics

- **Language and Culture courses**
- **Student project or internship (10 weeks)**

MIEN: Program contents in 2nd year

- **Core courses**
  - **Nuclear safety and radiation-protection**
  - **Project and risk management**
  - **Functional description of a power station**
  - **Environment & Society**
- **Choice between 5 majors**
  - **Nuclear Reactor Physics and Engineering**
  - **Nuclear Plant Design**
  - **Operation**
  - **Fuel Cycle** (Radiochemistry or Engineering)
  - **Decommissioning and Waste Management**
- **Experimental sessions and training on EDF simulators**
- **Visits of nuclear sites**
- **Master's thesis or internship (20 weeks)**
  - **within an industry company (for students aiming at an industrial career)**
  - **within a research lab (for students aiming at a research career)**

Int. Master's in Material Science for Nuclear Engineering

http:/phelma.grenoble-inp.fr

energie atomique • energies alternatives

- At Institut National Polytechnique at Grenoble (Grenoble-INP) in close cooperation with EDF and CEA, in partnership with Mc Master University
- A degree suitable both for industry and R&D.
- M2 course is open to French and Foreign students after Physics or Chemistry M1 level, and for engineers in the context of professional training.
- 300 hours course deals with metallurgical and physico-chemical aspects of under irradiation ageing of nuclear fuels and material for reactors.
- Optional 'structural materials' course by EDF engineers-on site
- Optional 'nuclear fuel materials' course by CEA engineers on-site

Institut National des Sciences et Techniques Nucléaires INSTN ***http://www-instn.cea.fr***

- As a part of CEA, INSTN was created in 1956. It provides high level courses in nuclear energy disciplines including training of nuclear physicians, radio-pharmacists and medical physicists

- The over 50 years old "Génie Atomique" curriculum has trained a large fraction of the French leading nuclear practitioners.

  - open to students having an engineering degree. Today "Génie Atomique" curriculum welcomes 120 graduates.

  - Open to foreign French speaking students with similar pre requisites

  - It provides them with an extra diploma which certifies their qualification in nuclear engineering, operation of reactors, safety management, decommissioning, and waste management.

INSTN. Continuing education.

International training seminars are organized within the ENEN framework

or in collaboration with IAEA

- Advanced training for experienced professionals. Contact with French industry

- Specific seminars for non-nuclear professionnals willing to learn about a specific topic

- Courses for nuclear professionnals with neither Master nor engineer degree. Typically bachelors

Institute of Radioprotection and Nuclear Safety (IRSN)

- IRSN trains medical staffs and people professionally exposed
  - Practical training for the evaluation for radiological and nuclear risks
  - Radioprotection of staffs exposed in industry
  - Evaluation of worker's exposure to ionizing radiations, dosimetry
  - Sensitisation to radioprotection
- Criticality
- Principles and practices of nuclear safety: safety of PWR
- the trainers are national or/and international experts, contribute to the research, and to the standardization and the legislation of the subject taught.
- about 100 teachers

ENSTTI (European Nuclear Safety Training and Tutoring Institute)

- Recently created by 4 European TSO (IRSN, GRS, UJV, LEI)
- Intended for professional having a good background in nuclear engineering with a Master degree
- It provides training programs organized as
  - courses (6 weeks)
  - Internships and tutorship (few months)
- It aims at sharing best standards and practices => ability to analyse any nuclear event and assess nuclear and radiological risks
- It aims at working closely with IAEA and all partners willing to develop nuclear power programs

AREVA
http://www.areva.com/

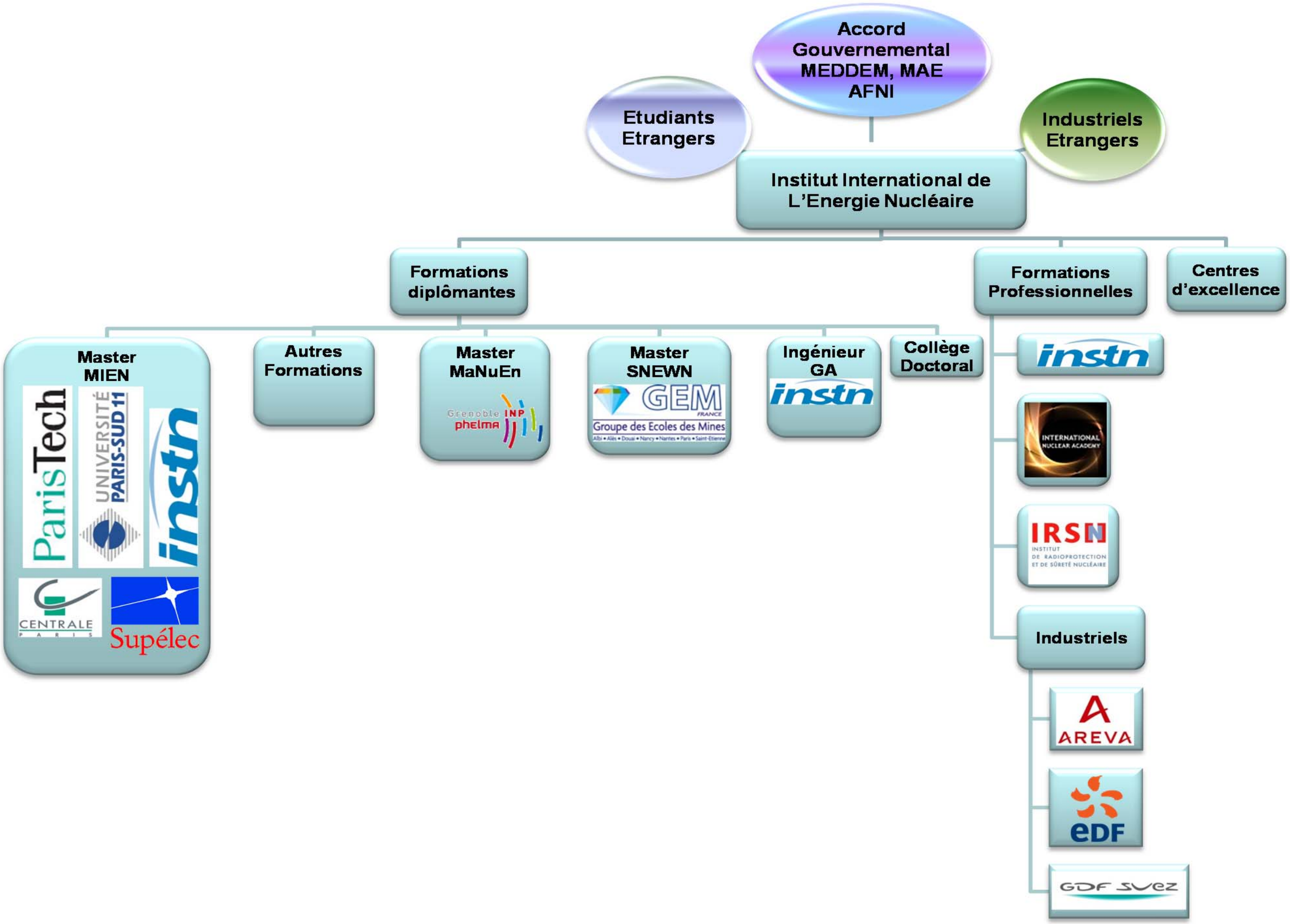
- *AREVA* (*global nuclear industry, fuel cycle, reactor design and construction, related service*) provides all related skills and training solutions to its partners
- A dozen of training centers in France, Germany and USA
- Scientific and technical training, Project management, Facility operations,.;
- 500 courses on offer
- 100 trainers, and thousands of students/year
- E-learning, simulators training, study trips,..
- Courses available to group's partners and stakeholders: gvt authorities, customers and suppliers, electric utilities, fuel cycle operators,.

Sharing knowledge and best practices

- Paris, March 8th 2010: Conference on Access to Nuclear Energy
  - On his opening address President Sarkozy announced the creation of an International Institute for Nuclear Energy.

- This institute located on the Saclay Campus, comprises:
  - A network of the best nuclear S&T curricula in France (CFEN label) in particular those taught in English.
  - A « centre of excellence for a sustainable nuclear energy future »
  - A in-house team in charge:
    - of promoting the French offer in nuclear education and training
    - of coordinating the recruitment and orientation of foreign students applying through international agreements and partnerships
    - of the operational support to CFEN
    - of coordinating bids of pedagogical engineering in response to requests from foreign partners

International Institute of Nuclear Energy



Center of excellence for a sustainable nuclear energy future

- **Objectives**

  - Build up a strong culture of safety and security with new comers
  - Build up the set of knowledge necessary to nurture this culture.

  - Be a think tank on nuclear challenges:
    - role of nuclear in the energy mix
    - waste management
    - proliferation risk
    - security of nuclear plants and nuclear materials
    - environmental issues
    - public debates and political decisions

  - Be part of a network of CoE worldwide

Center of excellence for a sustainable nuclear energy future

- **Method**

  – Organising high level workshops and seminars. Participants from universities, industry, governmental agencies, decision makers.

  – Tutorials for professionals: technical, economics, law and regulation, .

  – Production and publication of reports

  – Summer schools for fresh students

  – Public conferences

Franco-Chinese Institute of Nuclear Energy IFCEN

- French consortium in civil nuclear engineering : Grenoble Institute of Technology, INSTN, Ecole des Mines de Nantes, Ecole Nationale Superieure de Chimie de Montpellier and the Ecole Nationale Supérieure Chemiein Paris.
- University Sun Yat-sen in Canton
- opens in September 2010 on the Zhuhai campus of the University of Sun Yat-sen in Canton.
- Academic year 2010: the launch of the preparatory-cycle in China of French lessons, maths and physics in French. 100 students
- Academic year 2013: beginning of the Engineering cycle
- Summer 2016: first class engineering graduates

Teacher training

• A new programme to train the teachers and instructors has been implemented by the major French nuclear energy stakeholders.

• It is devoted to the training of university faculty and scholars

• It is implemented in a close working relationship with them, on the basis of an in-depth analysis of the local education system.

• It usually consists of a three-phase course that includes visits and conferences at the chief French nuclear energy sites and facilities

▶Cooperation between France and Poland.

▶ Partnership between all French nuclear energy stakeholders.

- **Phase 1. A six weeks nuclear Tour de France**
  - ✓To get well acquainted with a broad nuclear context
  - ✓To visit nuclear plants: NPP, fuel cycle, waste
  - ✓To meet and exchange with French education network
  - ✓To learn and exchange about communication and public acceptance

- **Phase 2. twelve weeks intense advanced training**
  - ✓ Fundamental nuclear science
  - ✓Applied courses (safety, radioprotection, NPP's, waste,…
  - ✓Access to experimental facities: ISIS, irradiation and characterization
  - ✓Access to simulators
  - ✓Focus on pedagogical issues

- **Possible phase 3. Assistance in education and training program design**

Conclusion

Nuclear energy will remain an important option in the World energy mix for the next centuries

It has many assets but there also risks associated with its development

Safety of plants, fuel and waste management, decommissioning, radiotrotection, are paramount

Security and non-proliferation are a major concern

Need of highly educated and trained human resources
Need of highly skilled engineers and technicians to operate plants
Need of developing a strong culture and awareness in nuclear safety and security.
Need to develop high level R&D in all fields related to nuclear energy