European Commission Nuclear Safety Research for the Nuclear Renaissance

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Joint Research Centre, European Commission

http://ie.jrc.ec.europa.eu

International Conference on Opportunities and Challenges for Water Cooled Reactors in the 21st Century
27-30 October 2009, IAEA, Vienna, Austria
Baseline

Global emissions, excluding “Land Use, Land Use Change and Forestry” (LU LUCF), increase by 57% over the period 1990-2020. They increased in the modelled baseline by 23% over the period 1990-2005 and are projected to increase by a further 28% over the period 2005-2020.
Total EU energy consumption is projected to increase by 15% respect to 2000

The energy consumption increase is expected to be met by natural gas and renewables

Natural gas is projected to rise from 23% in 2000 to 27% in 2030

Renewables are projected to rise from 6% in 2000 to 20% in 2020

Oil and solid fuels consumption in 2030 would not exceed the current level

Following the nuclear-phase out in certain old Member States (Belgium, Germany and Sweden) and the closure of plants with safety concerns in some new Member States, nuclear is smaller in 2030 respect to 2000 (minus 11%)

Energy related CO2 emissions would increase by 5% compared to 1990 (failure of the Kyoto Protocol)
The Three Challenges

Competitiveness “LISBON”
- Renewable energy
- Energy efficiency
- Nuclear
- Research and innovation
- Emission trading
- International Dialogue
- European stock management (oil/gas)
- Refining capacity and energy storage
- Diversification

Sustainable Development “KYOTO”
- Renewable energy
- Energy efficiency
- Nuclear
- Research and innovation
- Emission trading

Security of supply „MOSCOW“
- International Dialogue
- European stock management (oil/gas)
- Refining capacity and energy storage
- Diversification

- Internal Market
- Interconnections (Trans-European Networks)
- European electricity and gas networks
- Research and innovation
  SET-Plan
  - Joint Strategic Planning
  - Effective implementation
  - Resources
  - International Cooperation

FULLY BALANCED INTEGRATED AND MUTUALLY REINFORCED

- **Joint strategic planning – European Community Steering Group and Information System**

- **Effective implementation:**
  - European Industrial Initiatives: strategic technology alliances
  - European Energy Research Alliance (EERA)
  - Trans-European Energy Networks and Systems of the Future – transition planning

- Increase in resources, both financial and human

- Reinforce international cooperation
SET-Plan

EU Energy Technology Policy

SEER (EEP)

International tech. cooperation

Capacity building (R&D infrastructures, training)

EU energy system Transition Planning (incl. energy security)

PNR & technology reference, validation, support to innovation
Technology Map 2007

CO₂ reduction in Power Generation

Annual Avoided CO₂ Emissions [Mt CO₂]

Estimated emission reductions needed to meet the 20% target in 2020

Baseline

EC Trends to 2030 - update 2007

Renewables

CCS Power

Nuclear Fission Power
Some facts about nuclear energy

Nuclear power provides over 50% of Europe’s base load electricity

KEY FACTS

- EU 27: 145 reactors (2007) in operation (133 GWe) in 15 countries
- 8 new reactors are under construction
- 31% of total electricity production in Europe is via nuclear
- Reactor life-extension requests have been made in France, Sweden, Finland & Hungary
- Phasing out of reactors is planned in Belgium, Germany & Spain

EU27, 30/06/2007 (Ref. European Commission (TREN))
A European vision of nuclear energy development

- **First Reactors**
  - Dismantling & clean-up
  - Generation I
  - Produces 31% of Europe’s electricity

- **Current Reactors**
  - Generation II

- **Advanced Reactors**
  - Generation III
  - New build in Finland and France (EPR), other countries...

- **Future Systems**
  - Generation IV
  - Start of industrial deployment in 2040-2050

Timeline:
- 1950
- 1970
- 1990
- 2010
- 2030
- 2050
- 2070
- 2090
Vision on Sustainable Nuclear Energy

1975

2000

2025

2050

2075

Reactors

Current fleet

Life-time extension

Gen. IV

Gen. III

Nuclear fission energy for the 21st century

Large development, "renaissance"

Generation-III reactors with best available technologies for recycling

Long-term sustainability

Generation-IV fast reactors with advanced technologies for recycling

What EC R&D to support this vision?
What are the major issues?

### The policy issues:
- To establish a nuclear energy roadmap to improve the nuclear legal framework;
- To support a greater harmonisation of safety requirements at EU level for nuclear installations in the EU.

### The research challenges:
- Present generation of reactors: ensure a safe and efficient operation, considering their life extension
- Safe and efficient deployment of the new generation of LWRs
- Consolidate the management of technological solutions for the back-end of the fuel cycle and its societal acceptance
- Long-term sustainable solution: implement the GEN IV fast reactor systems
- Explore the non-electricity use of nuclear energy: high temperature processes for heat production
- Ensure nuclear controls and security within Europe and outside
- Accelerate European research integration, and setting up of priorities
- Enhance and coordinate efforts in Education & training

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- A solution to the problem of managing wastes
- The economic viability of the new generation of power stations
- The safety of reactors in Eastern Europe, in particular NMS and applicant countries
- The public acceptance
- Ensure adequate training, qualitatively and quantitatively, for nuclear engineers and technicians, regulatory authorities staff, etc.
- Strengthening nuclear security, supporting the reinforcement of non proliferation
• Promote a true “European Research Area” in nuclear science and technology
  – Major stakeholders agree “Strategic Research Agenda” and coordinated “deployment strategy” in key fields

• Support key EU policy initiatives
  – Lisbon Agenda
  – Energy Policy for Europe

• International cooperation
  – Bilateral (e.g. with Russia, China, …) / multilateral (e.g. GIF)
• Establish a sound scientific & technical basis for the safe long-term management of hazardous radioactive waste

• Promote safer, more resource-efficient and competitive exploitation of nuclear energy

• Ensure a robust and socially acceptable system of protection of man & the environment against the effects of ionising radiation.
Management of radioactive waste:
- Geological disposal
- Partitioning & Transmutation

Reactor systems:
- Nuclear installation safety
- Advanced nuclear systems

Radiation protection:
- Risk from low doses
- Medical uses of radiation
- Emergency management

Key cross-cutting activities:
- Research infrastructures
- Human resources, mobility & training

Launching Event Nov. 12
First Workshop 2009
### An example of FP research – Indirect Actions:
**FP6 projects on Gen-IV systems**

<table>
<thead>
<tr>
<th>Project acronym and title</th>
<th>Key areas of R&amp;D</th>
<th>Coordinating organisation &amp; no of partners*</th>
<th>Start date &amp; duration</th>
<th>Total budget / EU contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RAPHAEL</strong> Reactor for Process Heat, Hydrogen &amp; Electricity Generation</td>
<td>Performance of fuel, materials and components of VHTR</td>
<td>AREVA (FR) 33 partners from 10 countries</td>
<td>15/4/05 48 months</td>
<td>€19.8M / €9.0M</td>
</tr>
<tr>
<td><strong>GCFR</strong> Gas-Cooled Fast Reactor</td>
<td>Conceptual design, direct coolant cycles, trans-mutation, safety, etc.</td>
<td>NNC Ltd. (UK) 9 from 7</td>
<td>01/3/05 48 months</td>
<td>€3.6M / €2.0M</td>
</tr>
<tr>
<td><strong>HPLWR</strong> High Performance LWR – Phase 2</td>
<td>Critical issues and technical feasibility of SCWR</td>
<td>FZK (DE) 10 from 8</td>
<td>01/9/06 42 months</td>
<td>€4.65M / €2.5M</td>
</tr>
<tr>
<td><strong>ELSY</strong> European Lead-Cooled System</td>
<td>Core design, PA, main components &amp; systems, system integration, safety, etc.</td>
<td>ANSALDO ENERGIA S.p.A. Nuclear (IT) 20 from 12</td>
<td>01/9/06 36 months</td>
<td>€6.5M / €2.95M</td>
</tr>
<tr>
<td><strong>ALISIA</strong> Assessment of Liquid Salts for Innovative Applications</td>
<td>Support action – preparation of future activities/proposals</td>
<td>CEA (FR) 15 from 9</td>
<td>Jan. 07 1 year</td>
<td>€574k / €250k</td>
</tr>
<tr>
<td><strong>EISOFAR</strong> Roadmap for a European Innovative Sodium-cooled Fast Reactor</td>
<td>Support action – preparation of future activities/proposals</td>
<td>CEA (FR) 14 from 9</td>
<td>Jan. 07 1 year</td>
<td>€607k / €250k</td>
</tr>
</tbody>
</table>
An example of FP research – Indirect Actions:
FP7 projects on Gen-IV systems

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<th>Coordinating organisation &amp; no of partners*</th>
<th>Start date &amp; duration</th>
<th>Total budget / EU contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>GETMAT – Gen-IV and Transmutation MATerials</td>
<td>Structural materials for core and primary components of Gen-IV and ADS</td>
<td>FZK (DE) 24 partners from 11 countries</td>
<td>1/2/08 60 months</td>
<td>€13.96M / €7.5M</td>
</tr>
<tr>
<td>ACSEPT – Actinide reCycling by SEPoration and Transmutation</td>
<td>Advanced partitioning - chemical processes; aqueous &amp; pyro</td>
<td>CEA (FR) 34 from 14</td>
<td>1/3/08 48 months</td>
<td>€23.79M / €9.0M</td>
</tr>
<tr>
<td>F-BRIDGE – Basic Research for Innovative Fuel Design for GEN IV systems</td>
<td>Basic research on Gen-IV fuel-cladding systems</td>
<td>CEA (FR) 20 from 8</td>
<td>2nd quarter 08 48 months</td>
<td>€10.2M / €5.5M</td>
</tr>
<tr>
<td>FAIRFUELS – FAblication, Irradiation and Reprocessing of FUELS and targets for transmutation**</td>
<td>Fuels an targets for partitioning, with close links to Gen-IV</td>
<td>NRG (NL) 11 from 6</td>
<td>1/2/09 48 months</td>
<td>€7.7M / €3.0M</td>
</tr>
<tr>
<td>CP-ESFR – Collaborative Project on European Sodium Fast Reactor **</td>
<td>Key viability and performance issues supporting development of a Gen-IV European SFR</td>
<td>CEA (FR) 24 from 9</td>
<td>1st quarter 09 48 months</td>
<td>€11M / €5.8M</td>
</tr>
</tbody>
</table>
SNE-TP is a key initiative ensuring maximum integration and sharing of resources around a common vision for fission R&D.
67 organisations from 19 European Countries
Strategic Research Agenda (SRA) SNETP

Reactor Technology Road-Maps

• Current and future Light Water Reactors
  – Plant life management, material ageing issues
  – Advanced modelling tools & intelligent plant monitoring systems

Maintain competitiveness in fission technologies

• Generation IV Fast Neutron Reactors
  – Innovative fuels (incl. MA-bearing for transmutation) and core performance
  – Improved materials
  – Advanced instrumentation, in-service inspection systems

Demonstration of a new generation (Gen-IV) of fission reactors for increased sustainability

• Other applications of nuclear energy:
  Optimization of reactor design (LWR, HTR, FNR) and heat process applications for production of:
  – \( \text{H}_2 \)
  – Synthetic fuel (2nd gen. biofuels, CtoL)

Nuclear as a low carbon energy supply to other industries

Base load electricity

New applications
**OBJECTIVE**

- To demonstrate the sustainability of Generation IV Fast Reactors (exploit full energy potential of uranium and minimization of waste) and its industrial and economic viability to ensure that nuclear energy remains a long-term contributor to the low-carbon economy.

**SECTOR TARGET**

- Commercial deployment of Generation IV from 2040 while retaining at least 30% share of EU electricity with an expansion towards cogeneration of process heat for industrial applications

**SUGGESTED REQUIRED INVESTMENT BY THE SECTOR**

- 6 - 10 billion €
**EII on Nuclear Fission: Actions**

- **Design, construction and operation of a 1) prototype sodium Fast Reactor (SFR) coupled to the grid and 2) a demonstrator of alternative technology Gas or Lead Cooled Reactor (GFR/LFR)**
  - Design, license and start operation of 250-600 MWe (SFR) and 50-100 MWth GFR/LWR from 2020
  - Demonstrate safety, economic competitiveness and waste reduction

- **Supporting infrastructure**
  - Fuel fabrication workshop
  - Experimental facilities (hot cells, irradiation facilities, loops) for component design and system analysis

- **Cross-cutting R&D Programme**

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**SFR Prototype Astrid**

250-600 MWe

**ETPP European Technology Pilot Plant**

LFR Demo

Allegro GFR Demo

- Test bed of GFR technologies
- Innovative fuel
- MA transmutation
- Coupling to heat applications

MA fuel micropilot

MOX fuel fab unit

2040: Target for deployment of Gen-IV Fast Neutron Reactors or earlier if new energy needs (electric vehicles, process heat applications)

Cost: €6-10billion
Creation of the International Forum

- Started in Jan 2000 by nine countries and established Jul 2001. Agreed that nuclear energy is needed to meet future needs. Defined four goal areas to advance nuclear energy into its next, ‘fourth’ generation:
  - Sustainability
  - Safety & reliability
  - Economics
  - Proliferation resistance and physical protection

- Will collaborate to make ‘Generation IV’ systems deployable in large numbers by 2030, or earlier
An example of international cooperation - GIF

<table>
<thead>
<tr>
<th>Country</th>
<th>GIF Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>Active</td>
</tr>
<tr>
<td>France</td>
<td>Active</td>
</tr>
<tr>
<td>Germany</td>
<td>Active</td>
</tr>
<tr>
<td>Japan</td>
<td>Active</td>
</tr>
<tr>
<td>Korea</td>
<td>Active</td>
</tr>
<tr>
<td>South Africa</td>
<td>Active</td>
</tr>
<tr>
<td>USA</td>
<td>Active</td>
</tr>
<tr>
<td>Brazil</td>
<td>Joining</td>
</tr>
<tr>
<td>Russia</td>
<td>Non-active</td>
</tr>
</tbody>
</table>

* Technical Director is Chair of the Experts Group

Experts Group
- Chair*
- Co-Chairs

Methodology Working Groups
- PR&PP, Economics, Risk & Safety

System Steering Committees
- Co-Chairs

Policy Group
- Chair
- Co-Chairs

Policy Secretariat
- NEA, Paris

Technical Secretariat
- Provides Secretariat for
- Communicates closely with
- Coordinates with
Examples of JRC research areas

**Nuclear Reactor Safety**

- Safety of Ageing Components in Nuclear Power Plants
- Safe Operation of Nuclear Installations
- Analysis and Management of Nuclear Accidents
- Nuclear Safety Clearinghouse for European operational experience feedback
- Safety of Innovative Reactor Design

**ACCIDENT PREVENTION:**

- Integrity of the Reactor Coolant System
  - with investigation on:
    - material’s degradation (irradiation, corrosion, thermal fatigue)
    - in-service inspection
    - structural integrity
    - preventive maintenance

**ACCIDENT MITIGATION:**

- Integrity of the Confinement System
  - with investigation on:
    - accident analysis (test interpretation, code validation) - “severe accidents”
    - accident management
    - system interaction

**Horizontal activities:**

- probabilistic & risk assessment methodologies
- data management & dissemination
- training
Potential hydrogen explosion within a NPP containment as consequence of a SA

- REACFLOW: 3D reactive gas flow code for turbulent combustion, deflagration and detonation of highly reactive gas mixtures in large, complex enclosures
- Full scale simulation of the containment of a PWR:

Without two external walls

Non-nuclear application
Examples of JRC research areas

Life management of existing reactors

A new, unified model for Plant Life Management, integrating safety, economics and knowledge management

Safety and Licensing
- Continuous safety upgrading
- Life management of critical SSCs
- Strategic key issues; prerequisites for success

Production and Economy
- 50 years operation
- Long-term personnel plan
- Long-term investment plan
- Human resources

Economics — A ready-to-use spreadsheet was developed to integrate economics with maintenance and outage management

Safety — A proposal for safety classification of SSCs was developed in relation to PLIM

All program features have been identified and detailed to support PLIM:

- Maintenance program should be reliability-based > how to implement it
- ISI should be risk informed > to what extent
- Ageing management should feed ISI and Maintenance > how
- Asset management should cover outage, maintenance, ISI and ageing management > economics and managerial aspects

Expected result from application

Operating cost reduction with the application of the proposed EU model (estimated)
Integrated approach for assessment of operational experience of EU NPPs and development of tools and mechanisms for improvement applications.

Establishment of European best-practice for assessment of NPP operational events.
Conventional and Advanced Nuclear Fuels

- Development and fabrication of advanced sustainable fuels
- Fuel properties and in-pile behaviour of nuclear fuel at extended burn-up
- Post-Irradiation Examination (PIE)
- Code and Modelling: Transuranus

HTR Fuel
- Coated particle (CP) retention of fission products (FP)
- Quality control of CP fuel (licensing)
- FP transport in CP and fuel elements (FE):
- CP failure mechanisms
- Modeling (CP, FE, and whole system)
- Optimization of CP design: extension of fuel limits (higher burn-up, temperature)
Irradiation to explore the potential for high performance and high burn-up of existing and newly fabricated fuel pebbles for application to the conceptual Generation IV Very High Temperature Reactor (VHTR).

Examples of JRC research areas

Nuclear Safety – Fuel cycle – VHTR Fuel

KÜFA Facility

Irradiation test HFR-EU1 in the HFR Petten
Examples of JRC research areas

Fabrication, Characterisation, Irradiation

- Gen II, III LWR (MOX, Th-MOX, CERMET)
- Gen IV FR / ADS (Oxide, Carbide, Nitride, Composites)
- Gen IV VHTR

Fabrication, Characterisation, Irradiation

Examples of JRC research areas

Fabrication of advanced sustainable fuels

Fabrication, Characterisation, Irradiation

- Gen II, III LWR (MOX, Th-MOX, CERMET)
- Gen IV FR / ADS (Oxide, Carbide, Nitride, Composites)
- Gen IV VHTR

EUROTRANS - HELIOS irradiation programme in HFR.

Fabrication of 4 fuels (two homogenous, two cermets)

1. $\text{Zr}_{0.800}\text{Y}_{0.134}\text{Am}_{0.066}\text{O}_{2-x}$
2. $\text{Zr}_{0.767}\text{Y}_{0.127}\text{Pu}_{0.038}\text{Am}_{0.066}\text{O}_{2-x}$
3. $\text{Zr}_{0.666}\text{Y}_{0.111}\text{Am}_{0.223}\text{O}_{2-x} + 71.3\%\text{vol Mo}$
4. $\text{Pu}_{0.801}\text{Am}_{0.199}\text{O}_{2-x} + 84.2\%\text{vol Mo}$

- Innovation in the MA-Lab fabrication process – **Carbon addition**
  - improve microstructure
  - improve infiltration behaviour

- First Am fuel with annular pellets
- 5 pins (4 ITU + 1CEA) fabricated – 2 with thermocouples

- Transport to Petten 11 October 2007
EXTENDING THE APPLICATION RANGE OF A FUEL PERFORMANCE CODE FROM NORMAL OPERATING TO DESIGN BASIS ACCIDENT CONDITIONS

Development of computer codes for

- Safe and economic operation in compliance with safety criteria under both normal operation and postulated accidents.

- Validation of the JRC TRANSURANUS code for the predictions for both PWR and VVER fuel rod performance in an OECD benchmark programme confirming the applicability of the code in DBA analyses.

Validation of the TRANSURANUS Code
Integral test in OECD Halden Reactor

P. Van Uffelen et al., J. Nuclear Materials
Nuclear Waste Disposal

Geological disposal in crystalline rock (Sweden and Finland)

Geological disposal in clay (France)

Waste Radiotoxicity

Relative radiotoxicity vs. time
- a) spent fuel
- b) processed waste with minor actinides and fission products
- c) fission products only
EU Nuclear knowledge had been built up continuously since 1900.

Interest of younger generations for nuclear studies dramatically decreased. Nuclear education abandoned by many engineering faculties.

First generation senior nuclear experts are retiring. Gradually shortage of qualified professionals and increased risk of losing valuable knowledge.

Nuclear Human Resources Observatory: central point for collection and trend analyses on development and preservation of nuclear human resources and nuclear safety expertise in Europe.
Basic Principles

- Legal certainty by EU binding nuclear safety rules
- To reinforce role and autonomy of national regulatory bodies
- Proposal anchored on obligations of the IAEA Convention on Nuclear Safety and Safety Fundamentals
- Full subsidiarity
- ENSREG principles on nuclear safety regulation
- Flexibility to address future safety concerns

ENSREG (European Nuclear Safety Regulator Group) has key role in future development, e.g. development of improved safety requirements for new NPPs

Nuclear Safety Directive decoupled from nuclear waste and financial issues
A unique platform for a **broad discussion among all stakeholders**, free of any taboos, on transparency issues as well as the opportunities and risks of nuclear energy.

3 Working Groups:

- **Opportunities:**
  - Competitiveness
  - Financing models
  - Legal roadmap

- **Risks**
  - Safety harmonisation
  - Waste disposal
  - Training and education
  - Non-proliferation

- **Transparency**
  - Better information & communication
  - Developing an appropriate consultative process
Conclusions & Perspectives

- Security of energy supply, competitiveness and sustainability are key concerns in the EU of today.
- Low-carbon energy at the top of EU’s policy agenda
- Through its various programmes the JRC addresses the major concerns of European nuclear energy technical and scientific issues

Continuous contribution of EC-JRC to the safety improvement of:

- Fuel fabrication & characterisation
- Operating NPPs
- Fuel properties and in pile behaviour
- Waste management
- Alternative and advanced fuel cycle
- Modelling and code development