European Commission Nuclear Safety Research for the Nuclear Renaissance

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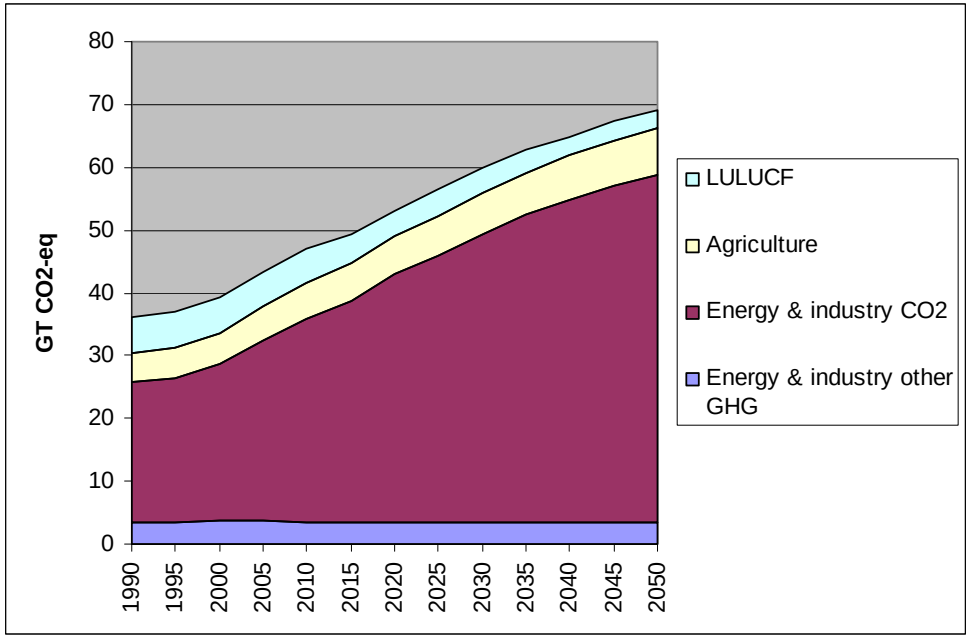
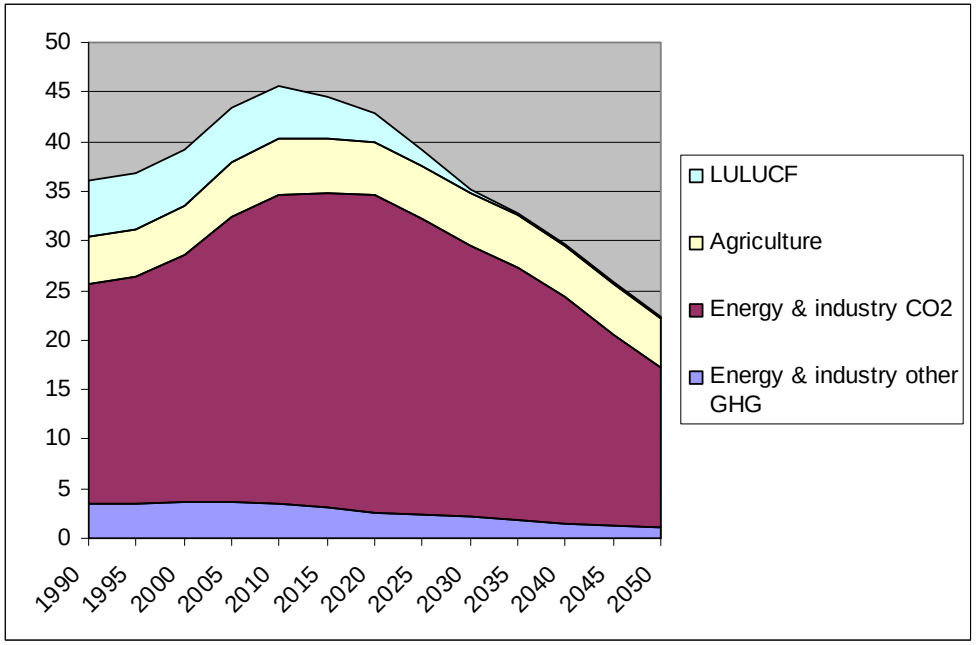
Joint Research Centre, European Commission

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



Limiting climate change to 2 C

Source: POLES (JRC-IPTS, Uni Grenoble), G4M (IIASA, Austria), Image (PBL)

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.

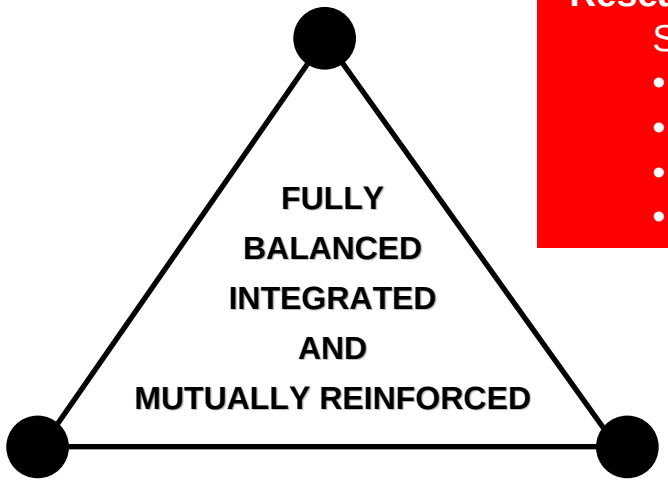
EU Trend to 2030

- 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"

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



Sustainable Development "KYOTO"

- Renewable energy
- Energy efficiency
- Nuclear
- Research and innovation
- Emission trading

Security of supply „MOSCOW"

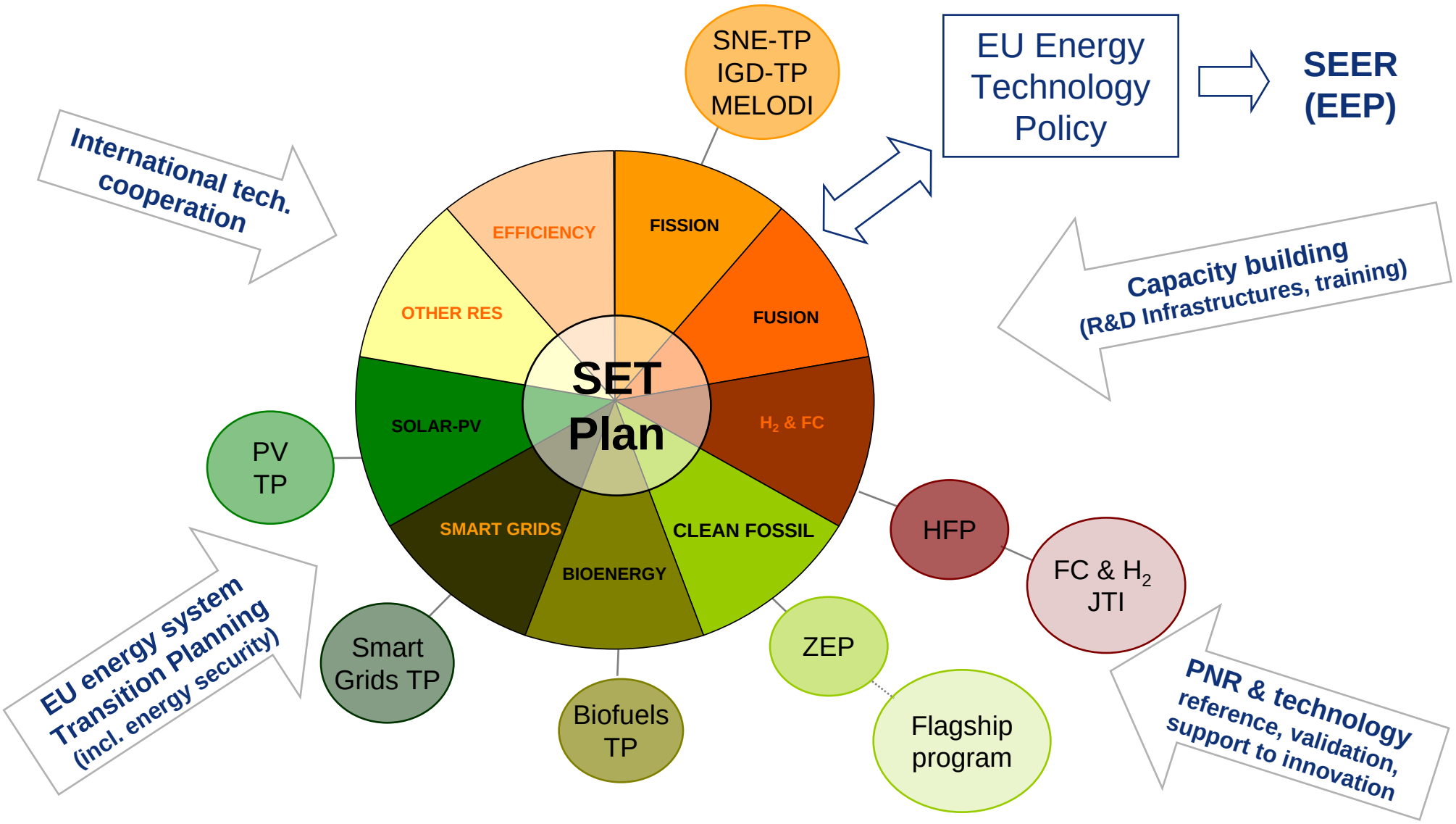
- International Dialogue
- European stock management (oil/gas)
- Refining capacity and energy storage
- Diversification

SET-Plan

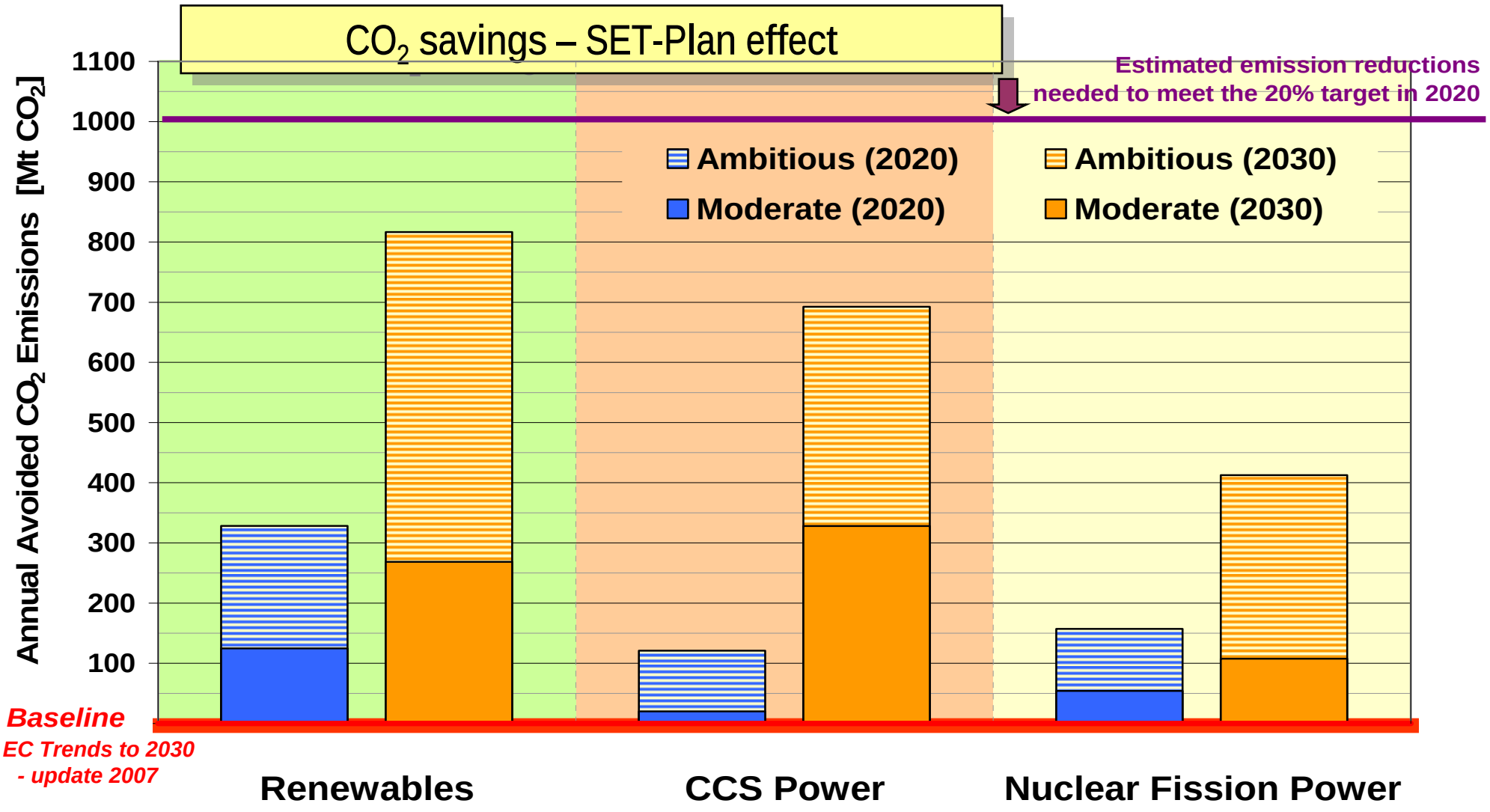
The SET-Plan Communication - COM(2007)723 - was adopted by the Commission in November 2007, and endorsed by the European Council on 13 March 2008.

- **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

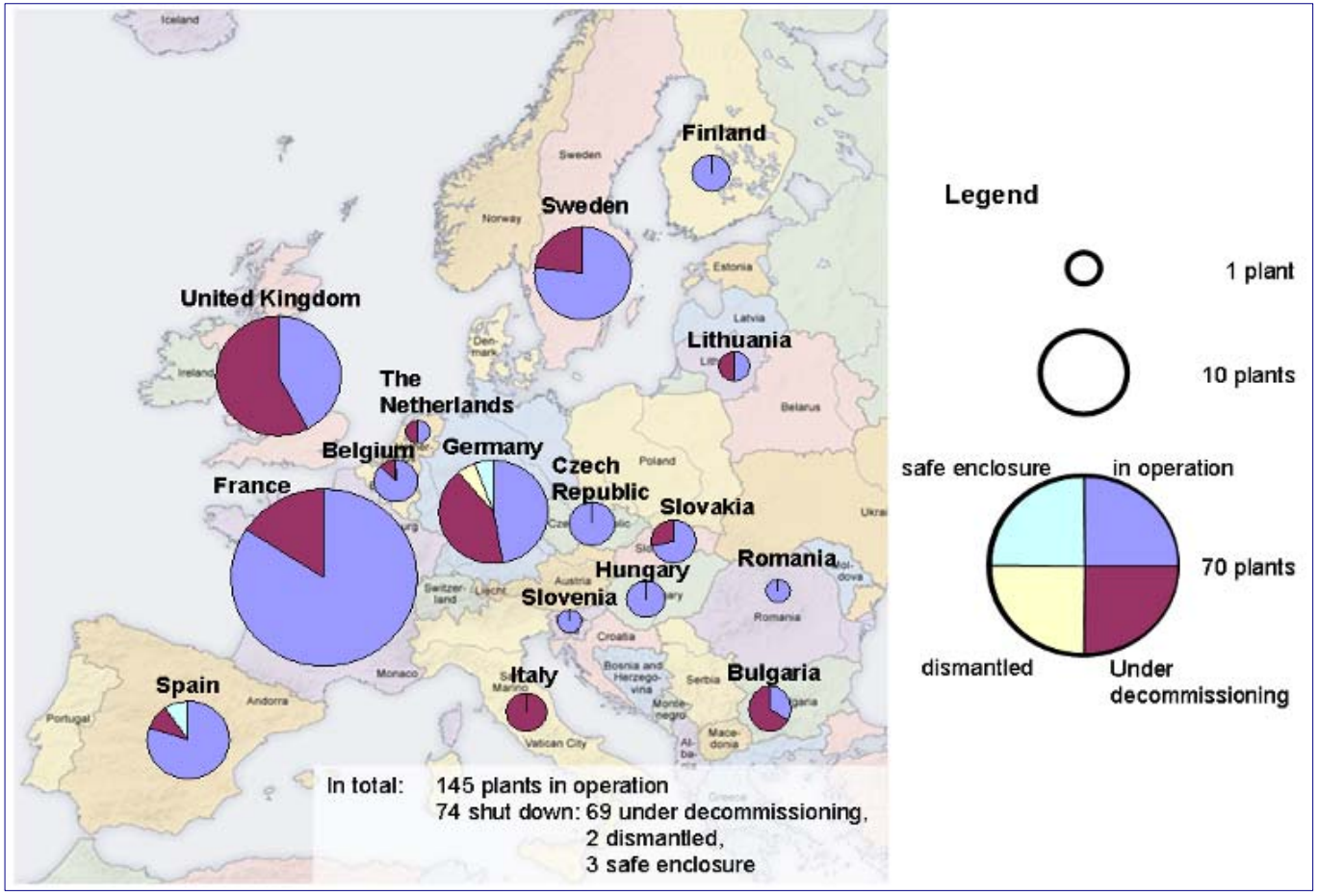

SNE-TP
IGD-TP
MELODI
EU Energy Technology Policy
SEER (EEP)
International tech. cooperation
Capacity building (R&D Infrastructures, training)
EFFICIENCY
FISSION
OTHER RES
FUSION
SET Plan
SOLAR-PV
H_2 & FC
SMART GRIDS
CLEAN FOSSIL
BIOENERGY
PV TP
HFP
FC & H_2 JTI
ZEP
Smart Grids TP
Biofuels TP
Flagship program
EU energy system Transition Planning (incl. energy security)
PNR & technology reference, validation, support to innovation

CO_2 reduction in Power Generation



Some facts about nuclear energy

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

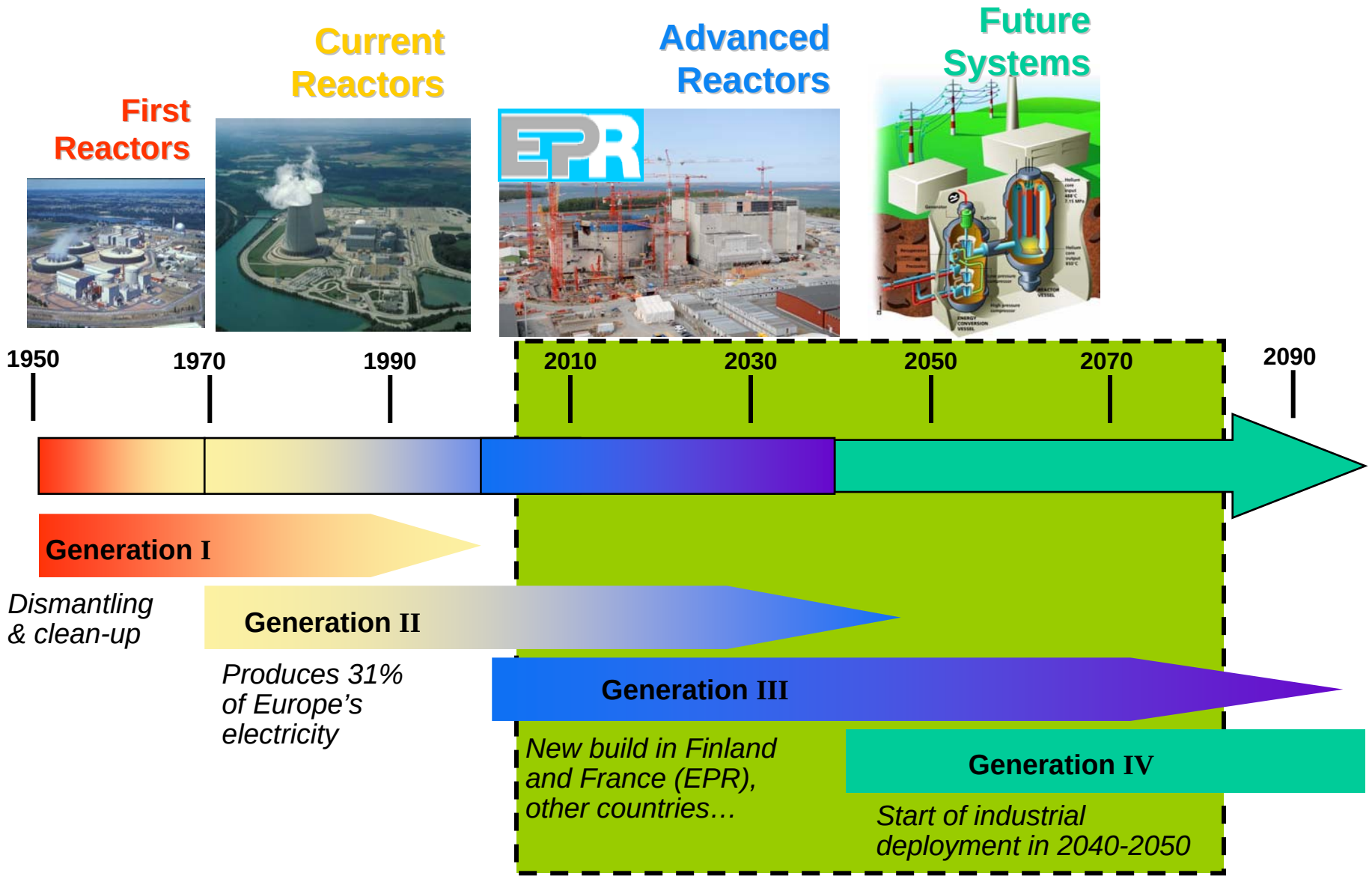


EU27, 30/06/2007 (Ref. European Commission (TREN))

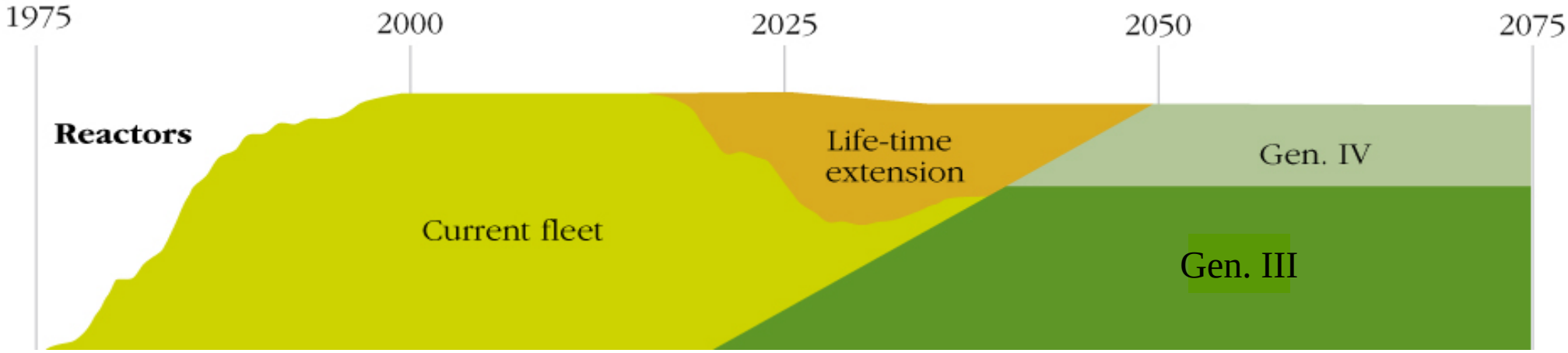
KEY FACTS

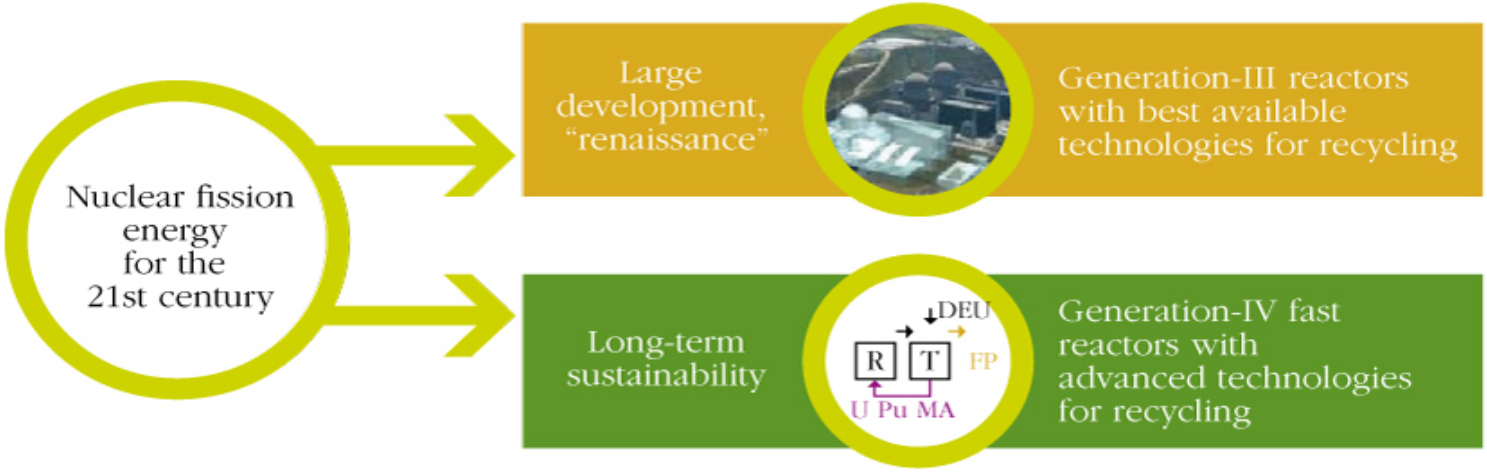
- EU 27: 145 reactors (2007) in operation (133 GWe) in 15 countries
- 8 new reactors are under construction
- 31% of total electricity production in Europe is via nuclear
- Reactor life-extension requests have been made in France, Sweden, Finland & Hungary
- Phasing out of reactors is planned in Belgium,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

A European vision of nuclear energy development



Vision on Sustainable Nuclear Energy





What EC R&D to support this vision?

What are the major issues ?

- 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

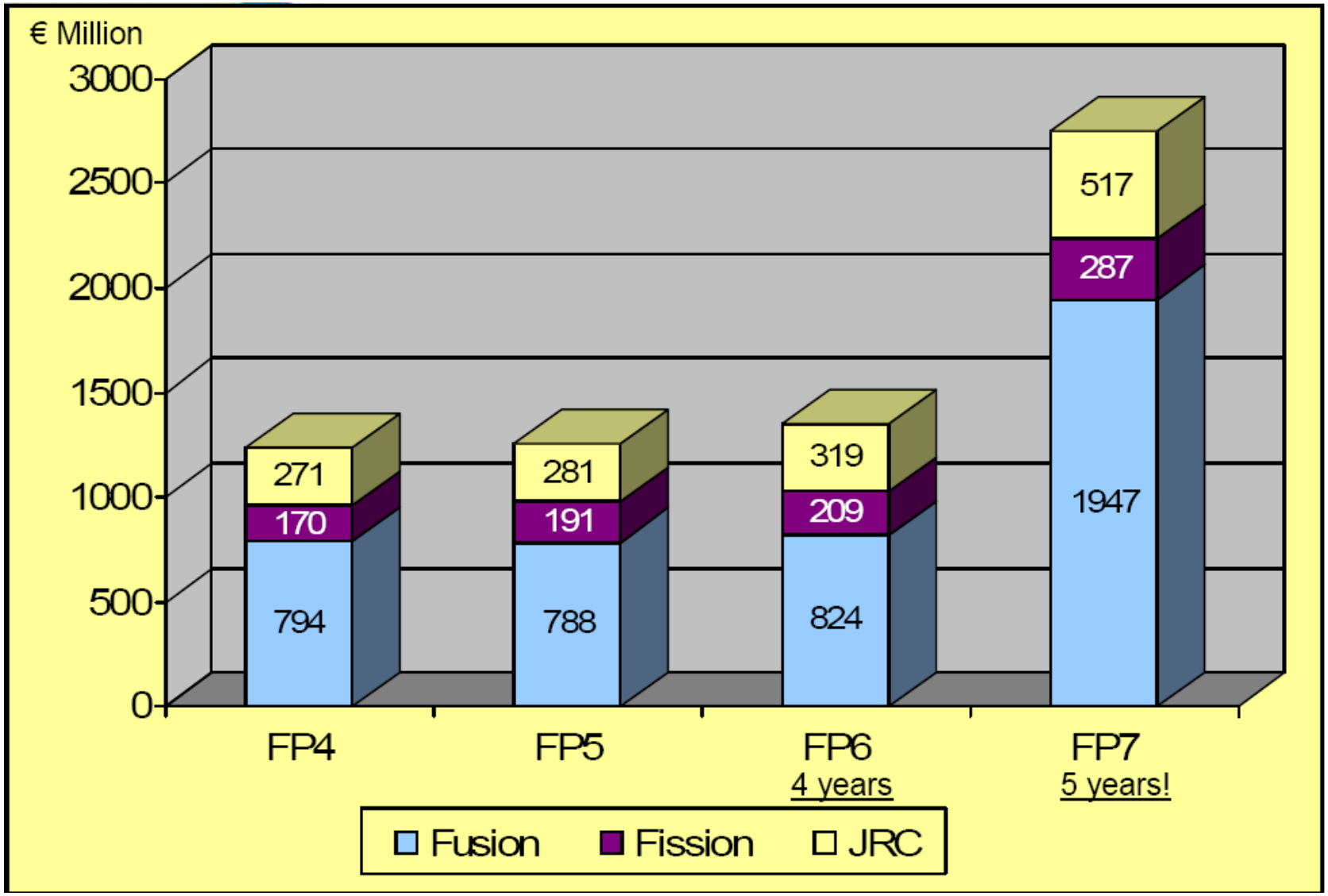
The policy issues:

- 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

EURATOM Research Budget



Euratom FP7 fission & RP – Strategic priorities

- 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)

Euratom FP7 fission & RP - Programme objectives

- 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.

Euratom FP7 fission & Radiation Protection

Launching Event Nov. 12

IGD-TP

Management of radioactive waste:
- **Geological disposal**
- **Partitioning & Transmutation**

S N E T P

Reactor systems:
- **Nuclear installation safety**
- **Advanced nuclear systems**

MELODI

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

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

First Workshop 2009

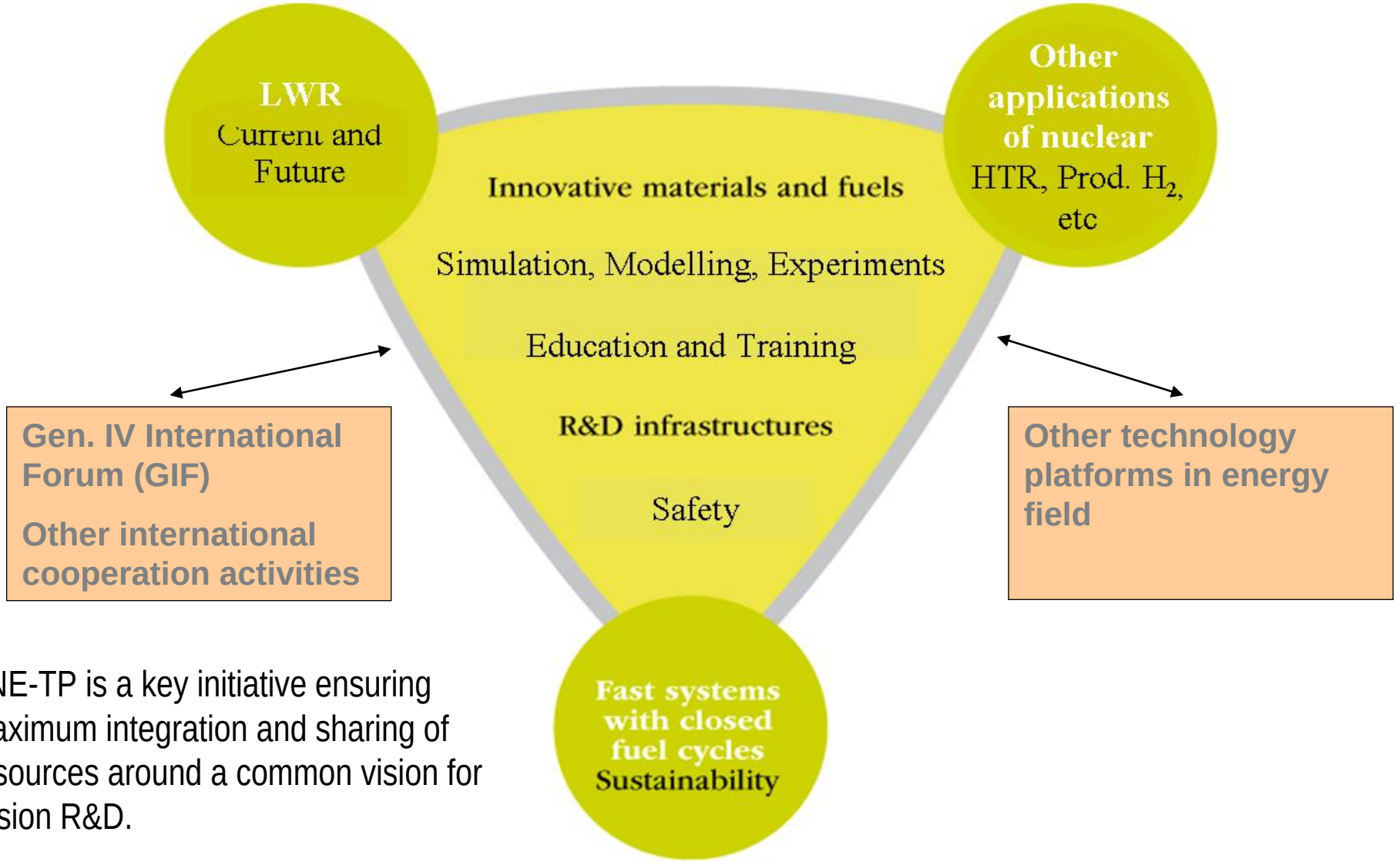
An example of FP research – Indirect Actions: FP6 projects on Gen-IV systems

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

An example of FP research – Indirect Actions: FP7 projects on Gen-IV systems

Project acronym and title	Key areas of R&D	Coordinating organisation & no of partners*	Start date & duration	Total budget / EU contribution
GETMAT – Gen-IV and Transmutation MATerials	Structural materials for core and primary components of Gen-IV and ADS	FZK (DE) **24 partners from 11 countries**	1/2/08 60 months	**€13.96M / €7.5M**
ACSEPT – Actinide reCycling by SEParation and Transmutation	Advanced partitioning - chemical processes; aqueous & pyro	CEA (FR) **34 from 14**	1/3/08 48 months	**€23.79M / €9.0M**
F-BRIDGE – Basic Research for Innovative Fuel Design for GEN IV systems	Basic research on Gen-IV fuel-cladding systems	CEA (FR) **20 from 8**	2nd quarter 08 48 months	**€10.2M / €5.5M**
FAIRFUELS – FAbrication, Irradiation and Reprocessing of FUELS and targets for transmutation**	Fuels an targets for partitioning, with close links to Gen-IV	NRG (NL) **11 from 6**	1/2/09 48 months	**€7.7M / €3.0M**
CP-ESFR – Collaborative Project on European Sodium Fast Reactor **	Key viability and performance issues supporting development of a Gen-IV European SFR	CEA (FR) **24 from 9**	1st quarter 09 48 months	**€11M / €5.8M**

SNE-TP



SNE-TP is a key initiative ensuring maximum integration and sharing of resources around a common vision for fission R&D.

SNE-TP


Utilities
EDF
EnBW
endesa
Enel
L'ENERGIA CHE TI ASCOLTA.
e·on
Fortum
IBERDROLA
RWE
suez
TVO
VATTENFALL
Technology Providers
AnsaldoNucleare
Una Società Finmeccanica
AREVA
EMPRESARIOS AGRUPADOS
Studsvik
Consultancy/Other
Deloitte.
tecnatom
TSO
European TSO Network
Research Organisations
AEKI
cea
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
CIRTEN
ENEA
FZJ
DIRECTORATE-GENERAL
Joint Research Centre
NRG
nexiasolutions
PAUL SCHERRER INSTITUT
PSI
SCK·CEN
STUDIECENTRUM VOOR KERNENERGIE
CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE
SCN
VTT
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ÚJV
VGB
67 organisations from
19 European Countries
Universities
The University of Manchester
Dalton Nuclear Institute
LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
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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**

Base load electricity

- Generation IV Fast Neutron Reactors
  - Innovative fuels (incl. MA-bearing for transmutation) and core performance
  - Improved materials
  - Advanced instrumen-tation, 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:
  - H_2
  - synthetic fuel (2^{nd} gen. biofuels, CtoL)

Nuclear as a **low carbon energy supply** to other industries

New applications

EII on Nuclear Fission (ESNII)

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

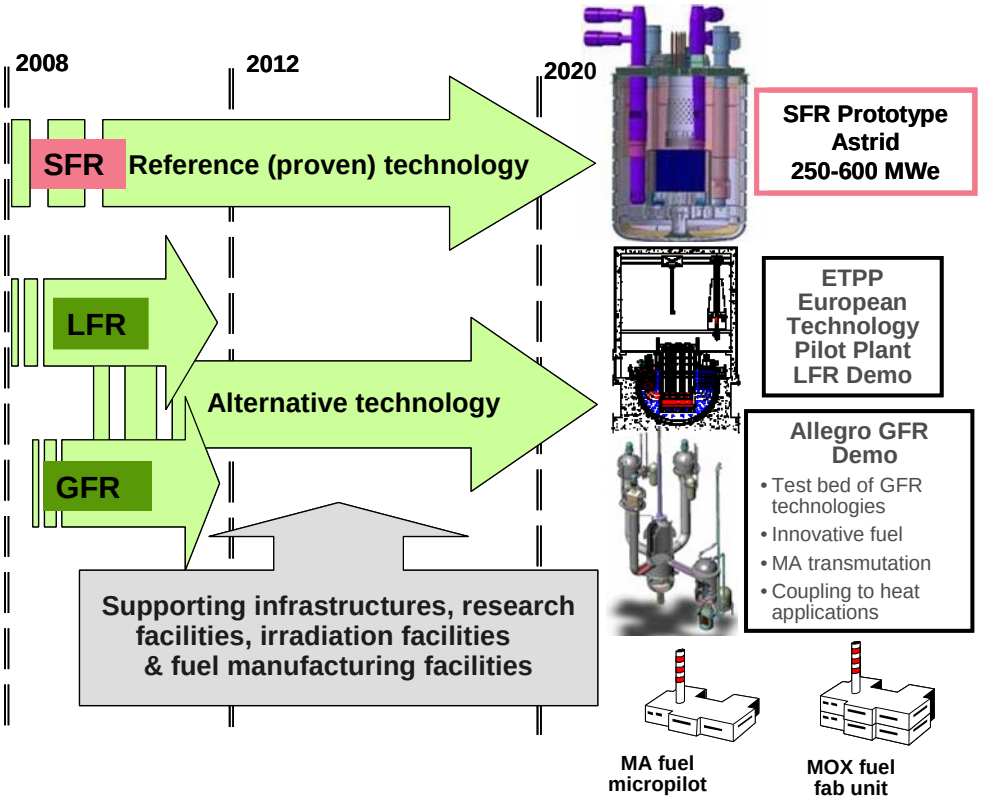
•6 -10 billion €

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 facilites, loops) for component design and system analysis

- Cross-cutting R&D Programme



2040: Target for deployment of Gen-IV Fast Neutron Reactors

or earlier if new energy needs (electric vehicles, process heat applications)

Cost: €6-10billion

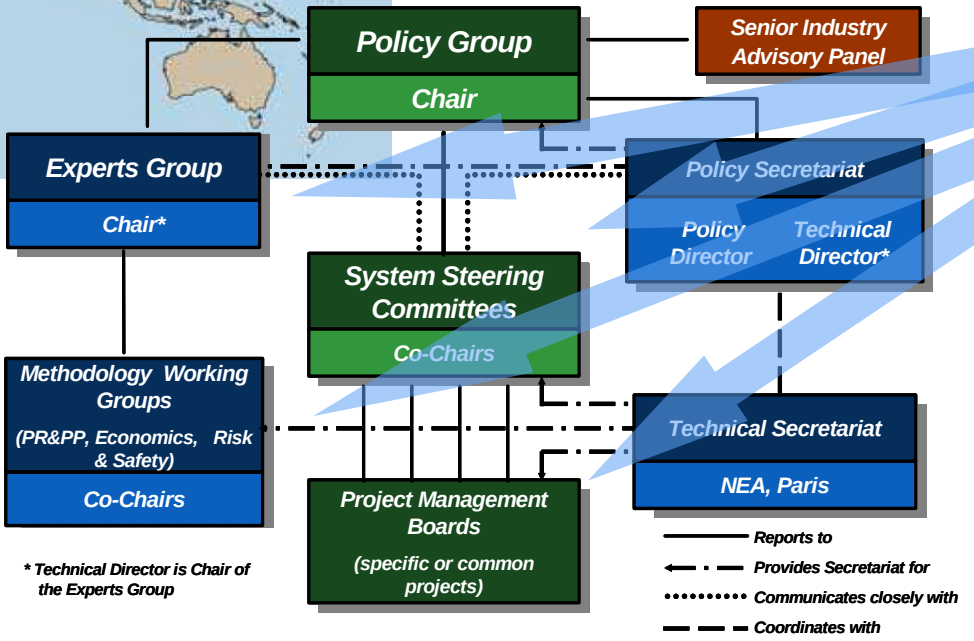
An example of international cooperation - GIF

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

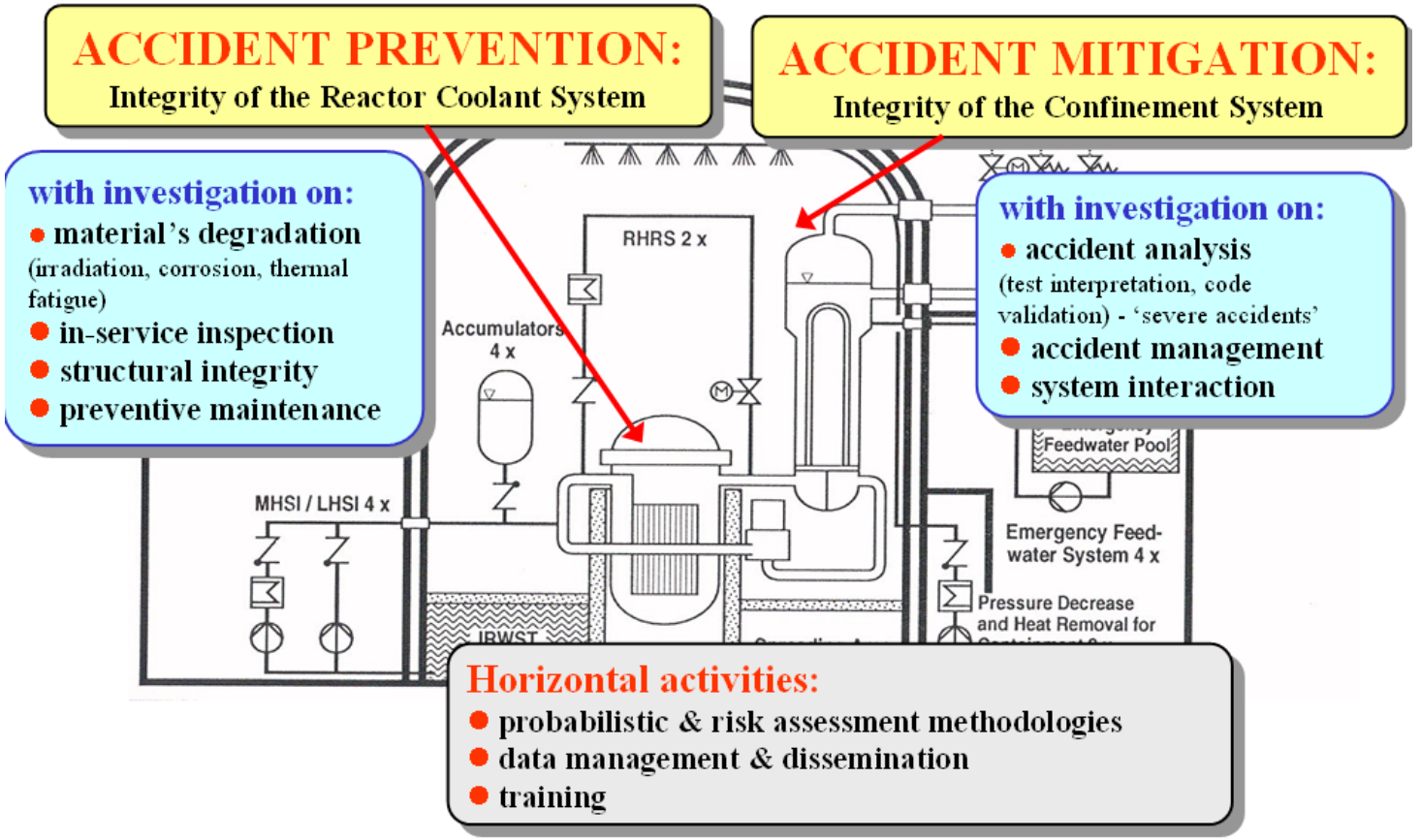
VHTR	●	●	●	●	●	●	●	●	●
GFR			●	●	●			●	
SFR		●	●	●	●	●			●
SCWR	●		●		●				
LFR			●		●				
MSR			●	●					



JRC

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

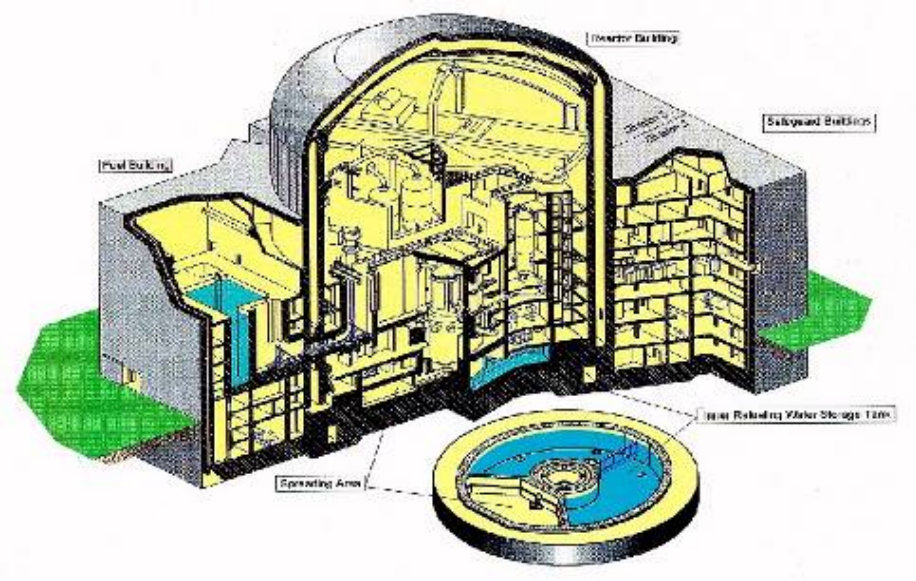


Examples of JRC research areas

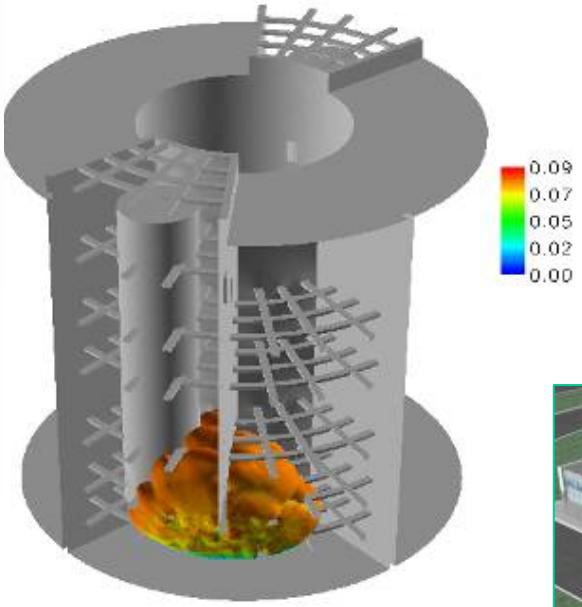
Accident analysis for existing & future reactors

Potential hydrogen explosion within a NPP containment as consequence of a SA

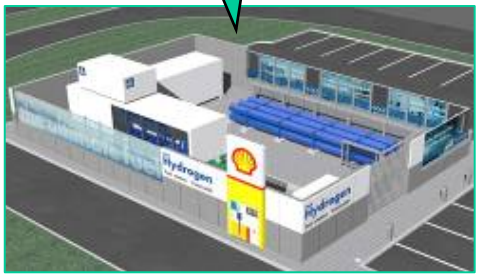
- REACFLOW: 3D reactive gas flow code for turbulent combustion, deflagration and detonation of highly reactive gas mixtures in large, complex enclosures
- Full scale simulation of the containment of a PWR:



Without two external walls

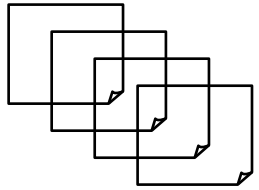


Non-nuclear application



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

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

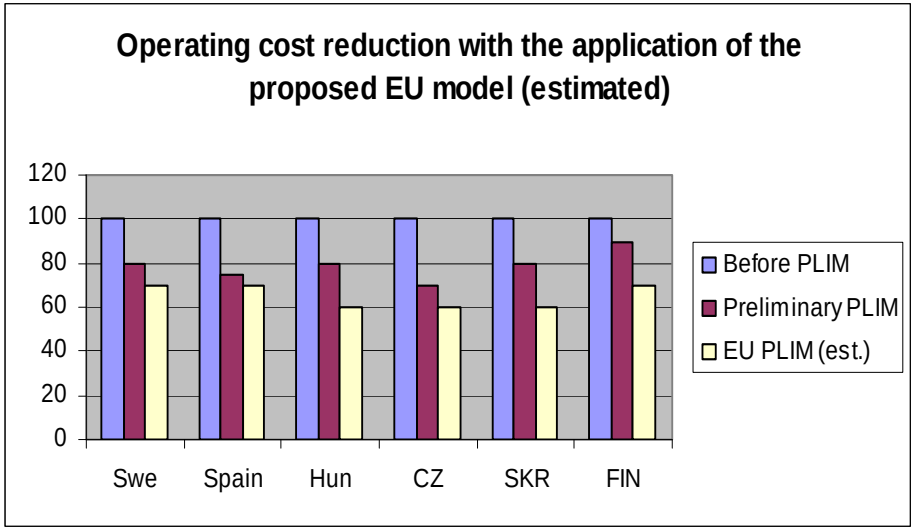


Safety – A proposal for safety classification of SSCs was developed in relation to PLIM

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

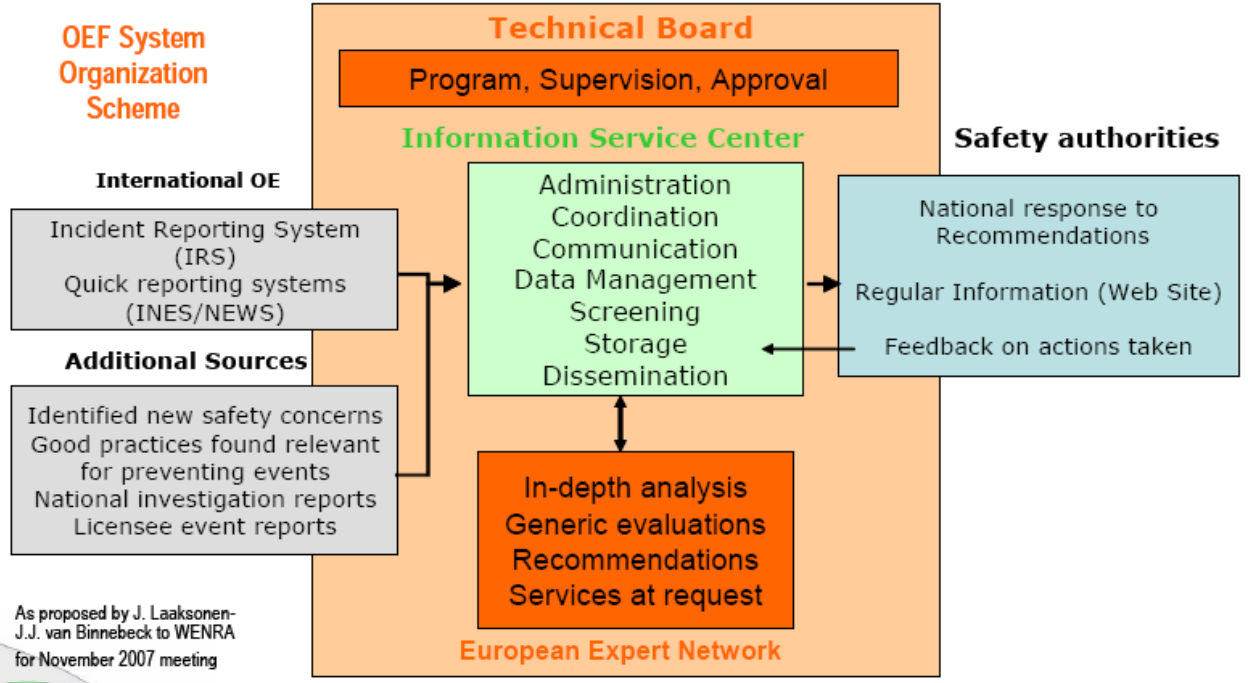


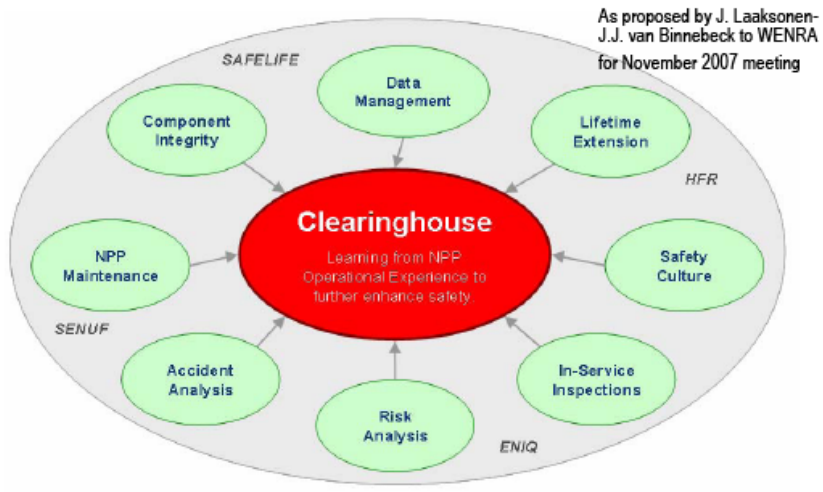
Examples of JRC research areas

European Clearing House for NPP Operational Safety Feedback

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.





Membership of CEOF

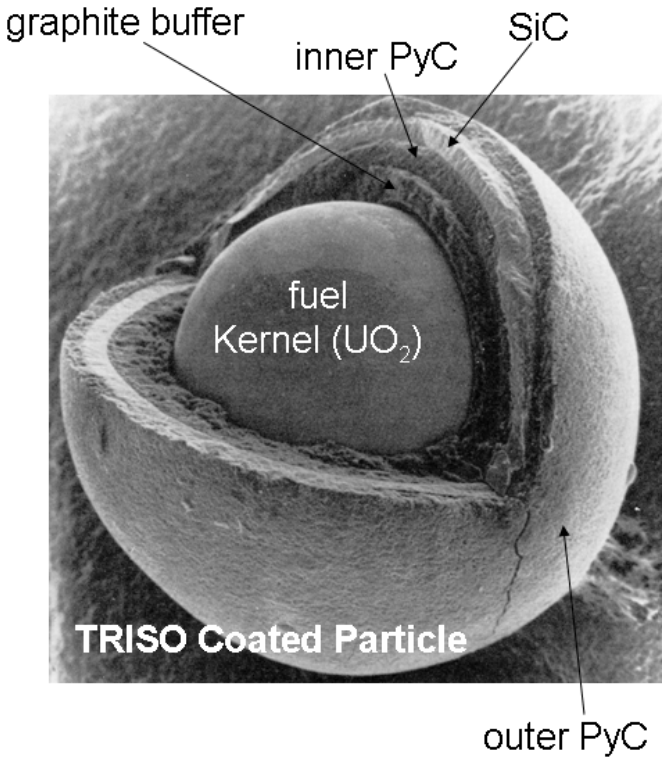
Nuclear Regulators from *Finland, Hungary, Lithuania, The Netherlands, Romania, Slovenia, Switzerland*

Observer : *Spain*

Ongoing : *France, Germany, Belgium), IAEA, NEA, …*

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



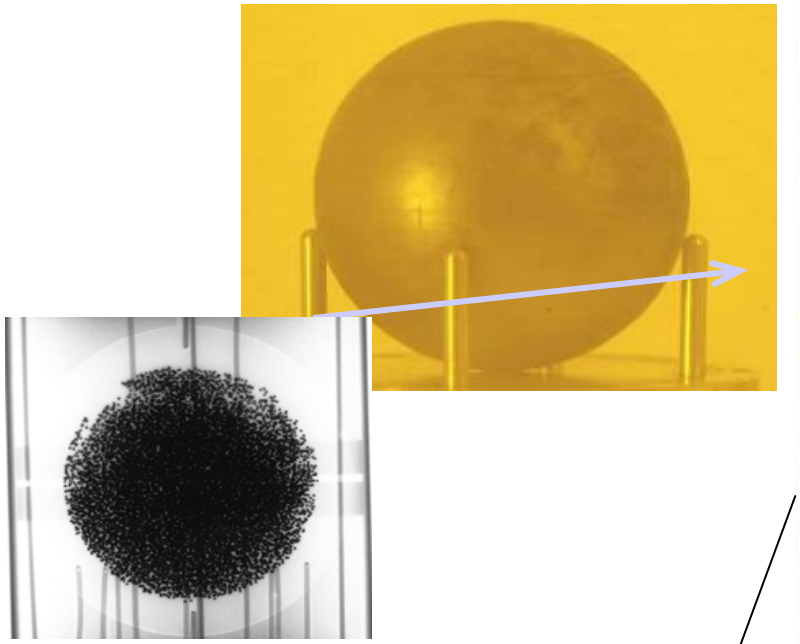
HTR Fuel

- 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)

Examples of JRC research areas

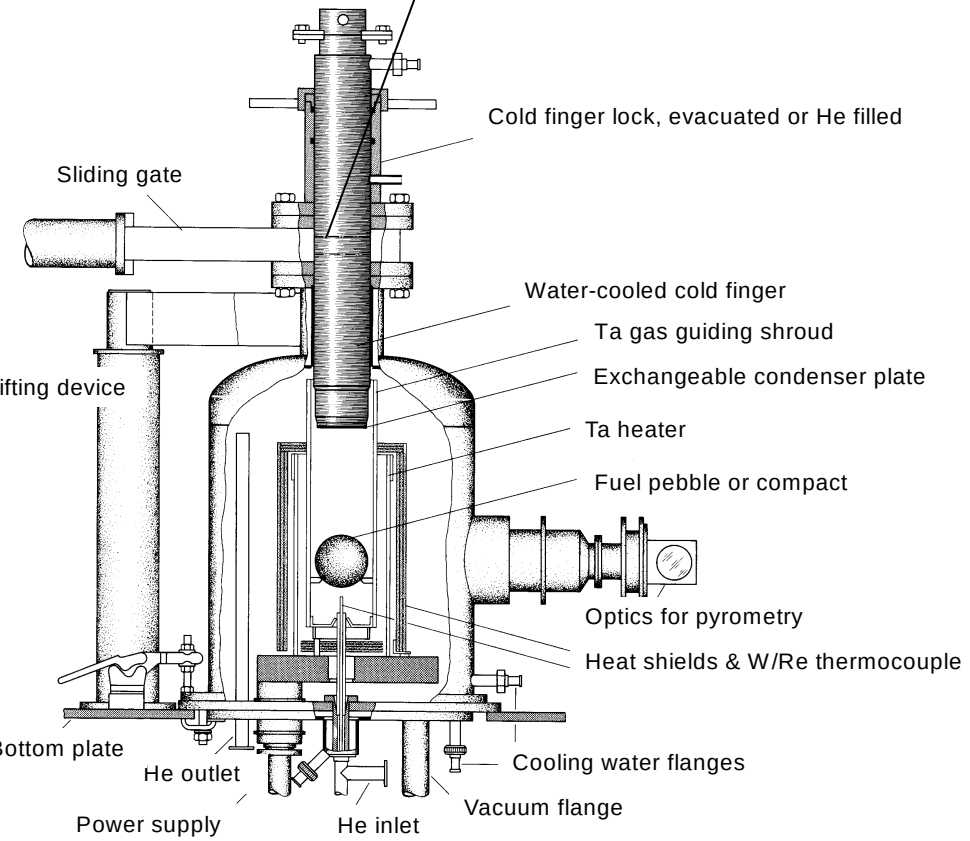
Nuclear Safety – Fuel cycle – V/HTR Fuel

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)



Irradiation test HFR-EU1 in the HFR Petten

KÜFA Facility



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) $Zr_{0.800}Y_{0.134}Am_{0.066}O_{2-x}$;
(2) $Zr_{0.767}Y_{0.127}Pu_{0.038}Am_{0.068}O_{2-x}$
(3) $Zr_{0.666}Y_{0.111}Am_{0.223}O_{2-x}$ + 71.3 %vol Mo
(4) $Pu_{0.801}Am_{0.199}O_{2-x}$ + 84.2 %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

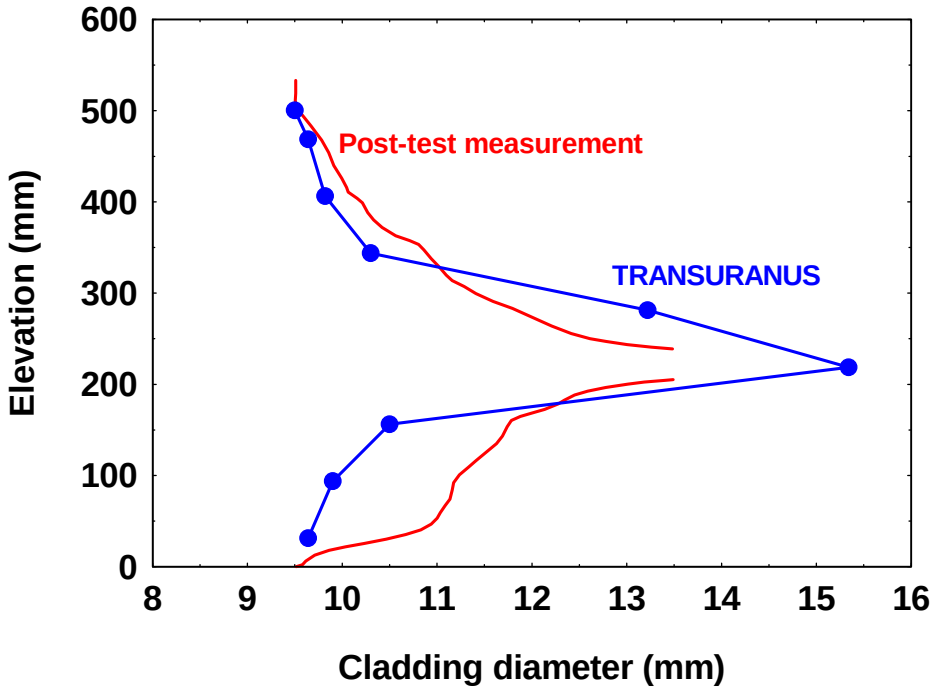
Examples of JRC research areas

Validation of the TRANSURANUS Code

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.

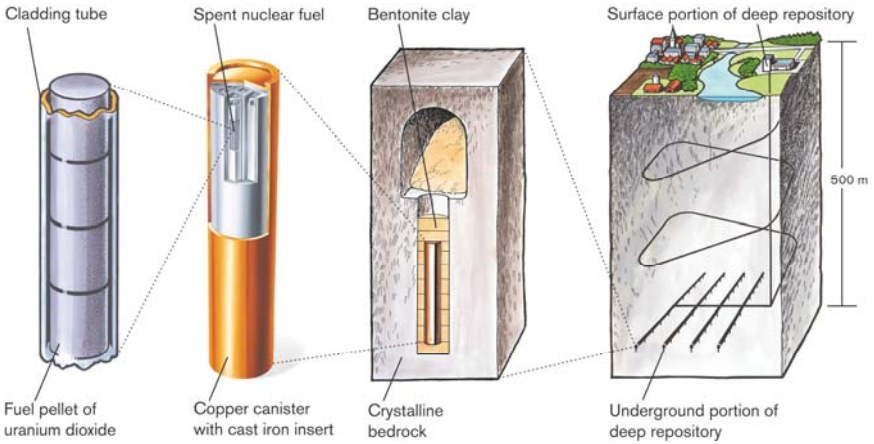


Validation of the TRANSURANUS Code
Integral test in OECD Halden Reactor

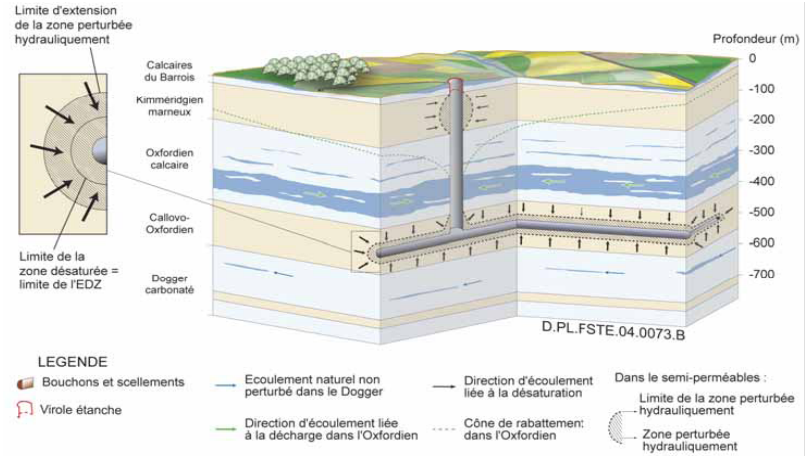
P. Van Uffelen et al., J. Nuclear Materials

Examples of JRC research areas
Nuclear Waste Management

Nuclear Waste Disposal

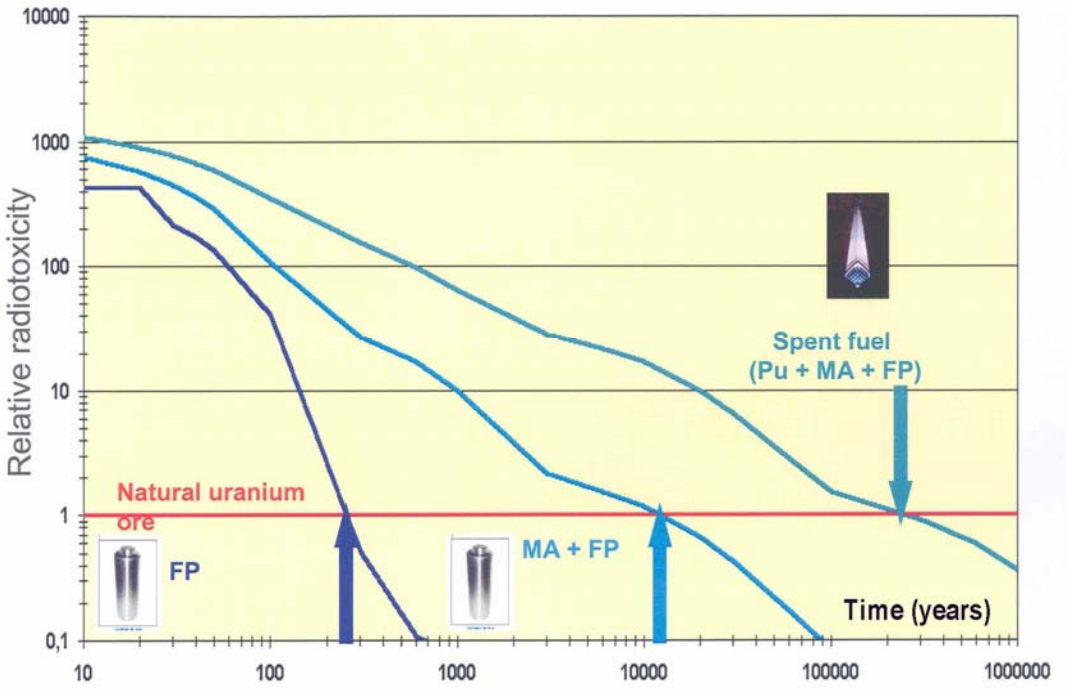


Geological disposal in crystalline rock (Sweden and Finland)



Geological disposal in clay (France)

Waste Radiotoxicity



Relative radiotoxicity vs. time a) spent fuel, b) processed waste with minor actinides and fission products and c) fission products only

Examples of JRC research areas

Knowledge Management, Education & training

- 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 loosing valuable knowledge.

Summer Schools

Trainees

PhD students, Post-Docs

Visiting scientists

User Facility

Network of excellence

Workshops

Conferences

Training courses

Nuclear databases

Information portals

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

A common EU binding framework on nuclear safety

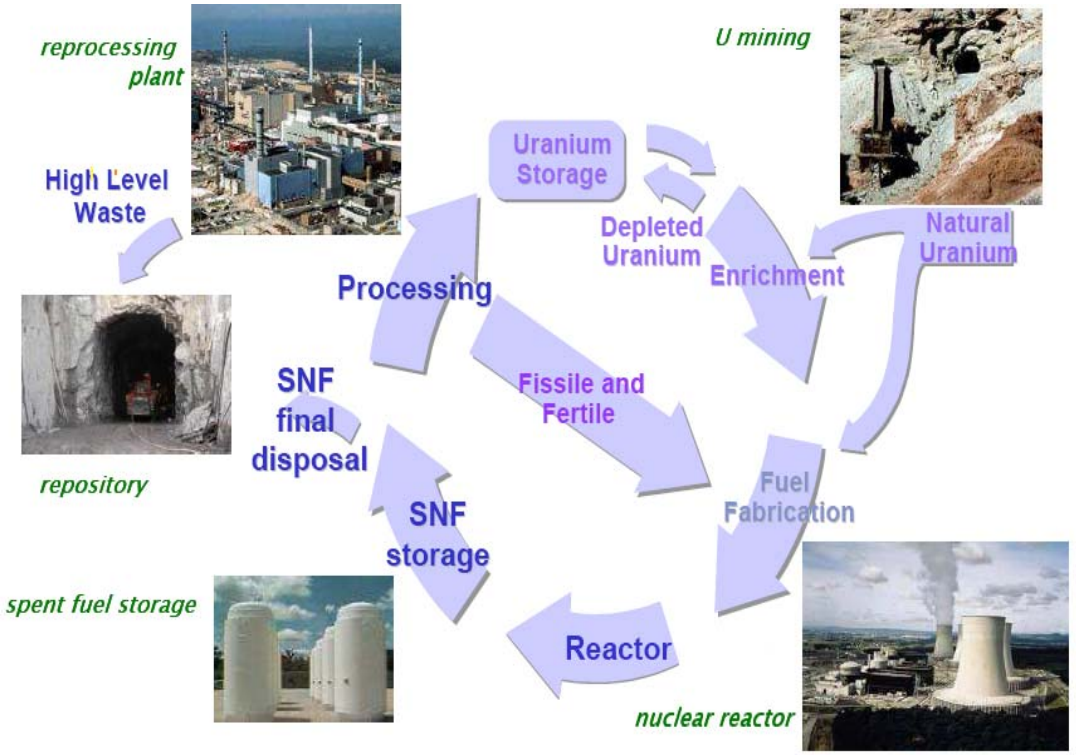
- Basic Principles
  - Legal certainty by EU binding nuclear safety rules
  - To reinforce role and autonomy of national regulatory bodies
  - Proposal anchored on obligations of the IAEA Convention on Nuclear Safety and Safety Fundamentals
  - Full subsidiarity
  - ENSREG principles on nuclear safety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

European Nuclear Energy Forum

- 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