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DE LA RECHERCHE À L'INDUSTRIE

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Nuclear Energy Innovation: a Necessity, a Challenge and an Asset for the Growth of a Low Carbon Economy

CONSEIL FRANÇAIS DE L'ÉNERGIE
WORLD ENERGY COUNCIL

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Outline

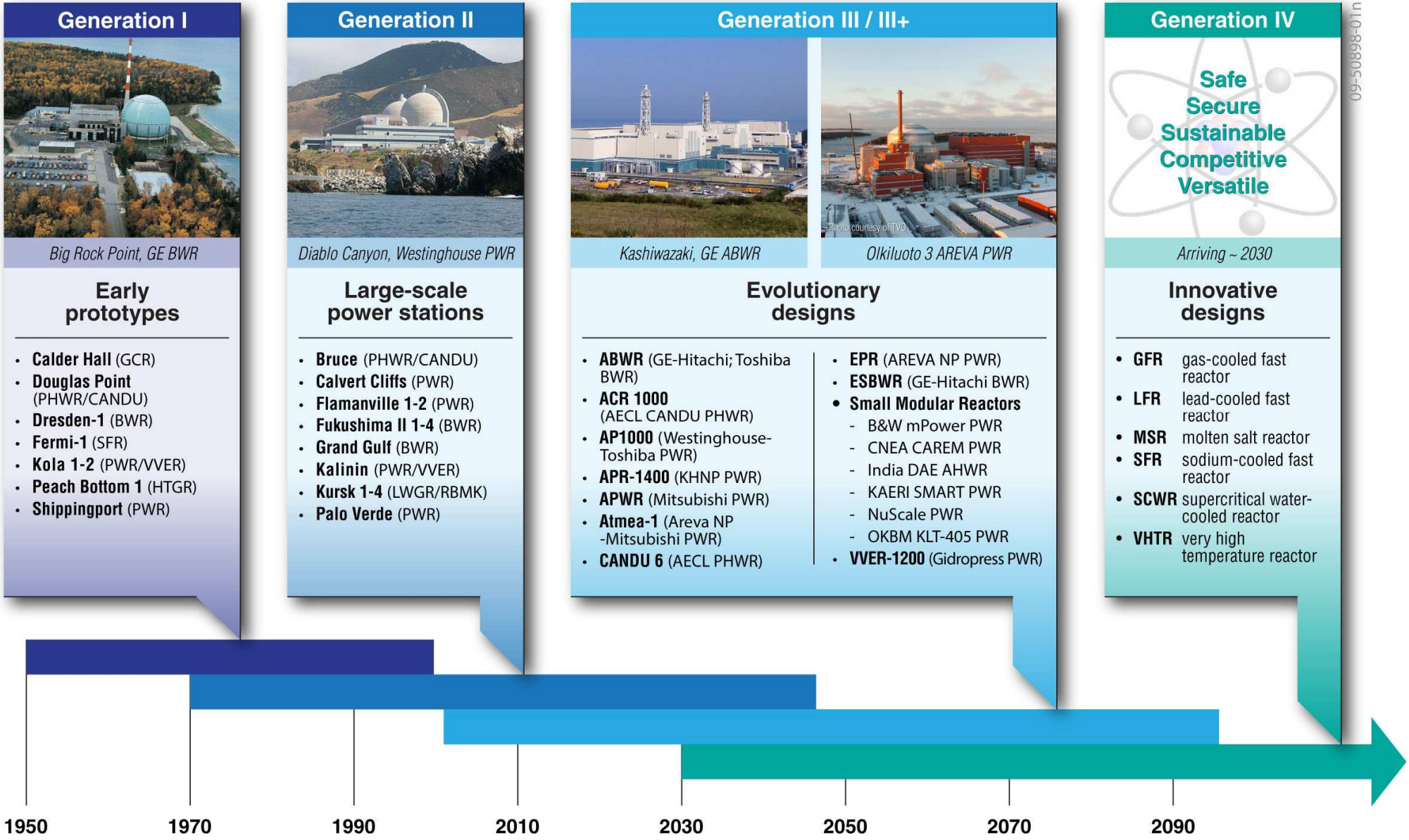
1 – Need for steady progress in safety, economic competitiveness and adaptation to a changing context

2 – Challenges related to development time and cost for new nuclear projects + Changes required at the international level

3 – Assets: energy security and stong pillar of low carbon energy policies as a supplement and support of variable renewable energies

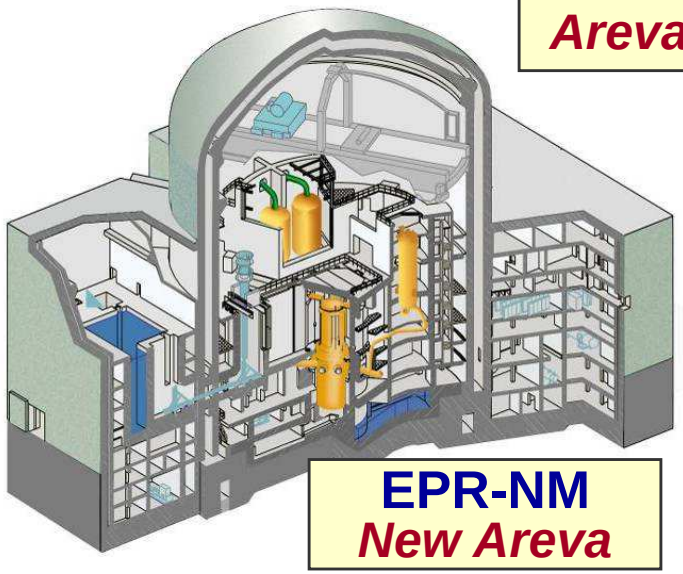
4 – Future Prospects

Generation IV International Forum



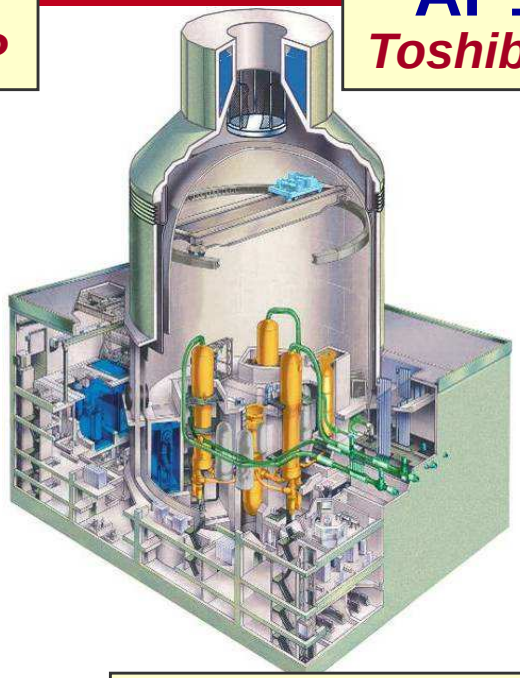
ALWRs from the USA, Japan, Russia & Europe

EPR
Areva NP

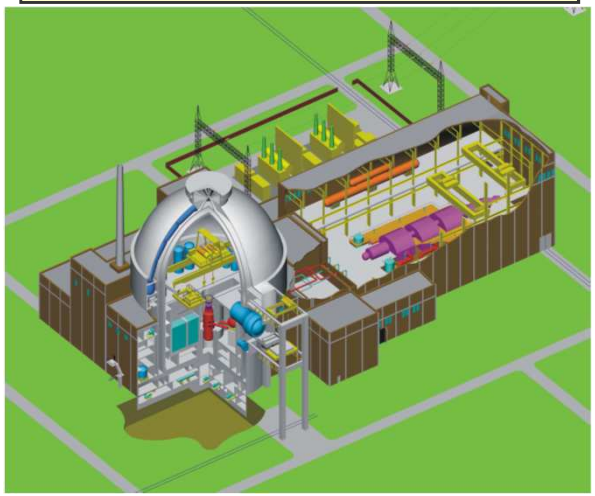


EPR-NM
New Areva

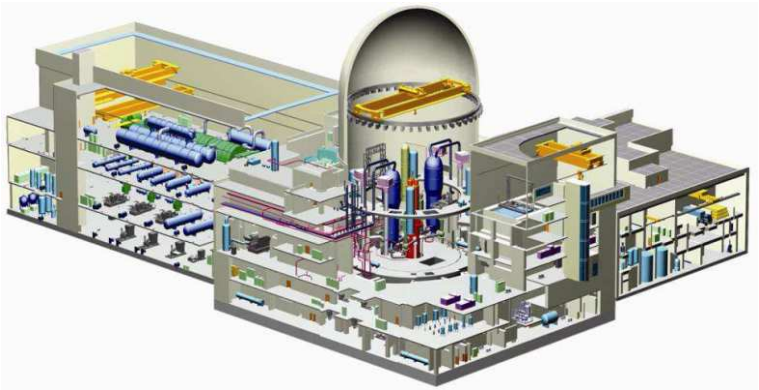
AP1000
Toshiba-West.



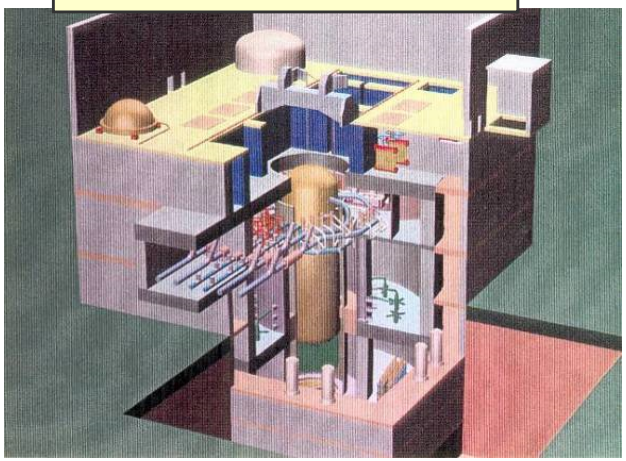
АЭС-92
с ВВЭР—1000
АСЭ РОСАТОМ



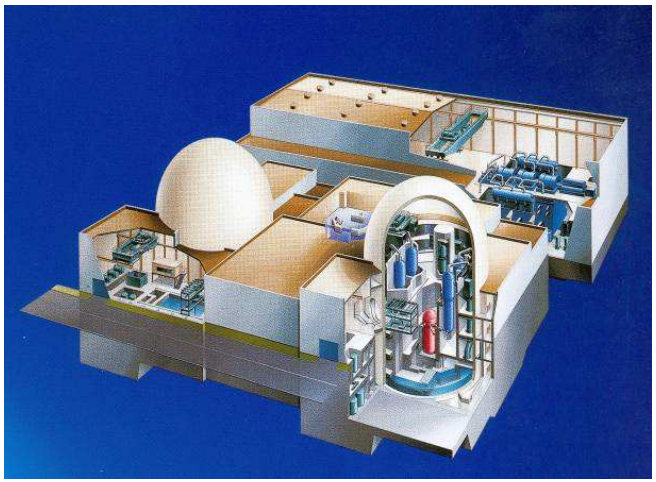
APR-1400
KHNP



ESBWR
GE & Hitachi



APWR
Misubishi



Challenges ahead: safety & economics

➢Lessons from Fukushima Dai-ichi

- ✓ *Very unlikelly events may happen*
  → *Reevaluation of natural events*
- ✓ *Enhance emergency preparedness*
  → *off-site power supply and cooling capabilities*
- ✓ *Revisit « beyond design basis accidents »*

➢Safety: more internationalization

- ✓ *Harmonizing safety requirements*
  + Assessing relevance to Gen-3 reactors
- ✓ *Enhancing cooperation on regulatory research on Safety & Radiation protection*
- ✓ *Progress of multinational evaluation towards international licensing convergence*

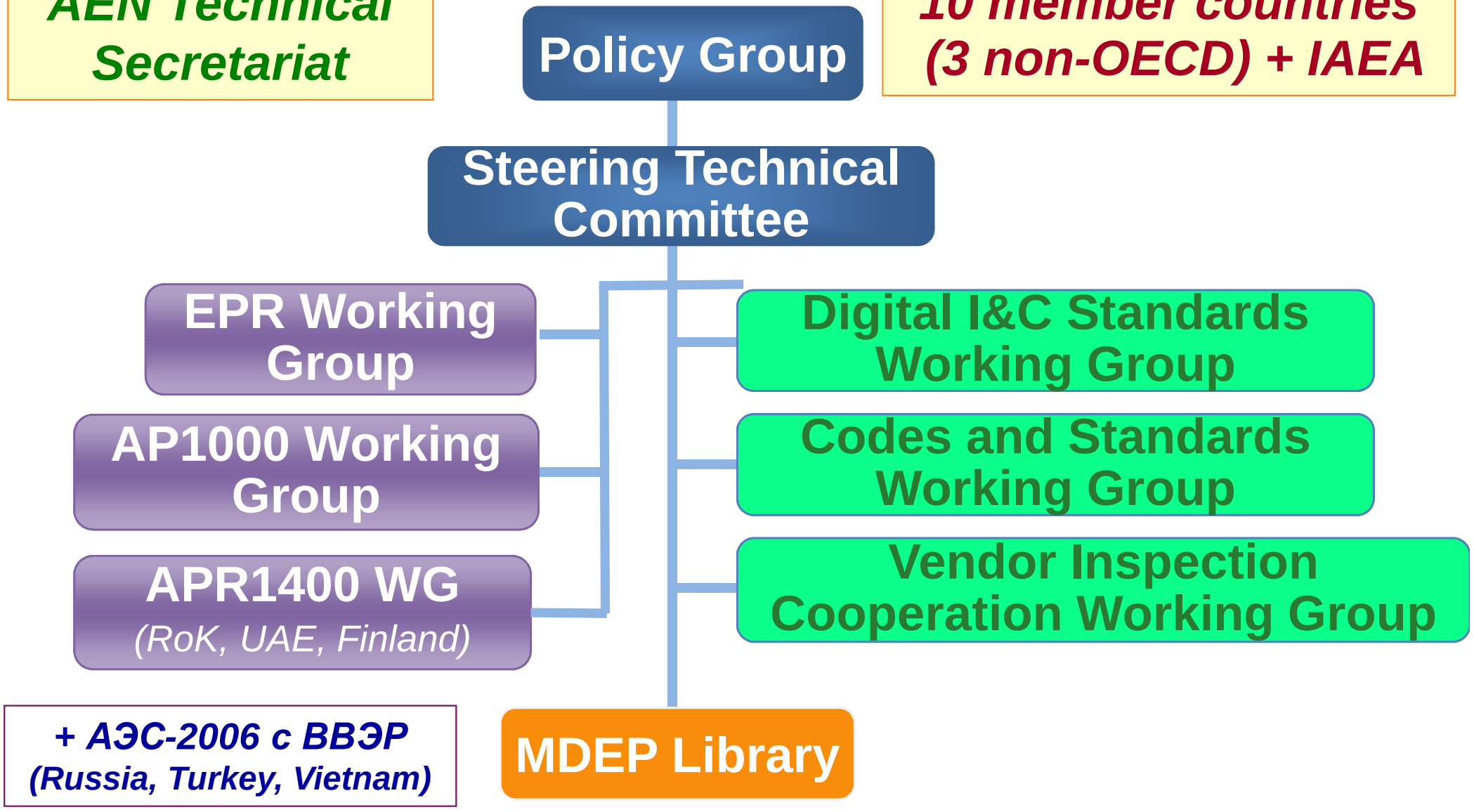
➢Economic competitiveness

- ✓ ***Nuclear: [42-60] €/MWh*** *(Court of auditors 2014 report)*
- → ***Innovative financing schemes*** *(by customers/vendors + BOT, BOO, BOOT contracts)*
- ✓ *Nuclear currently challenged by gas power stations in the USA (~50$/MWh) and possibly challenged by some renewable energies in the future*

Multinational Design Evaluation Program

AEN Technical Secretariat

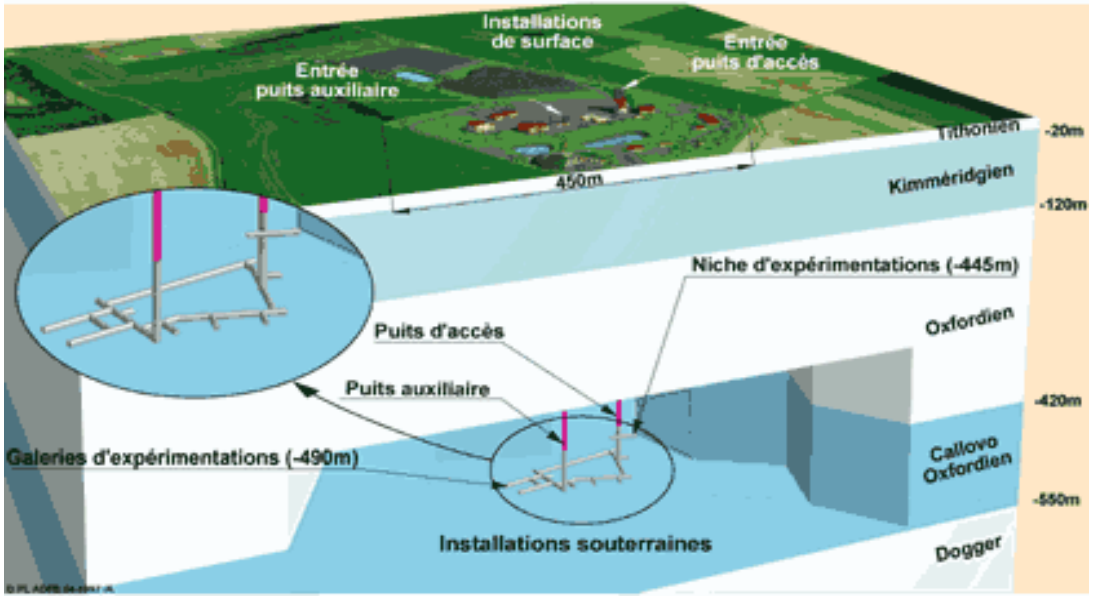
Creation in 2006
10 member countries
(3 non-OECD) + IAEA



+ АЭС-2006 с ВВЭР
(Russia, Turkey, Vietnam)

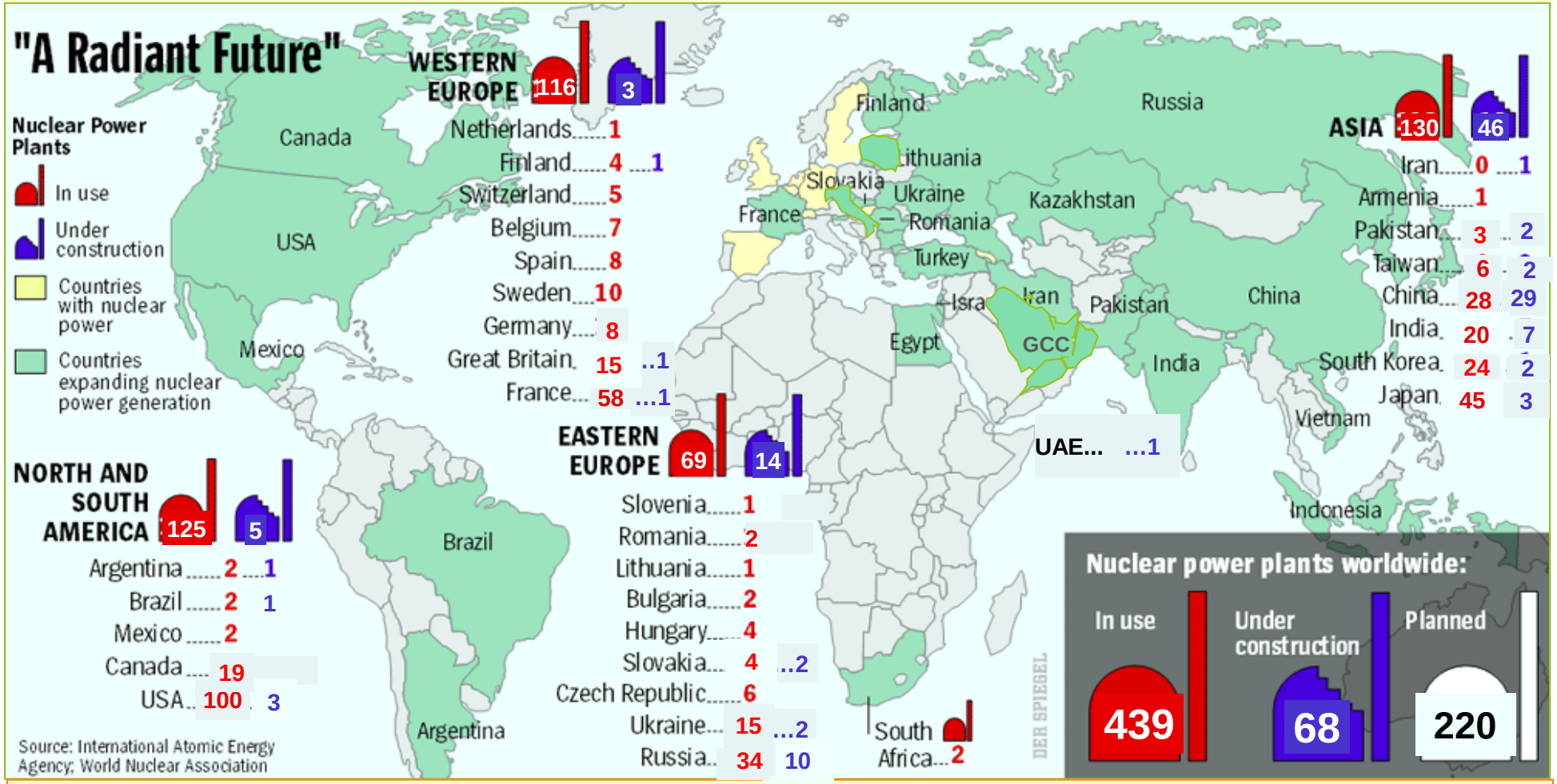
Laboratory of Bure for assessing the potential of the site as a repository for high level radioactive waste in France

- **French Act of June 28, 2006 for a sustainable management of nuclear matters and radioactive waste**
- **Appropriate properties of clay for confining radionuclides**
- **Assessment of the site for implementing a geological repository (CIGEO)**
- **Public debate in 2013 about the CIGEO project**



Operating & Planned Nuclear Power Plants in the World

An Increasing World Nuclear Electricity Demand ...



~382 GWe Installed Nuclear Power today

~243 GWe PWRs, ~83 GWe BWRs, ~21 GWe PHWRs, ~11 GWe GCRs, 11 GWe LWGRs, 1 GWe FBRs → 1000 – 1500 GWe by 2050?

Nuclear Power & Climate Change

Prof. James E. Hansen *(Univ. Columbia, US Academy of Science)*

Climate is changing 10 times faster than ever

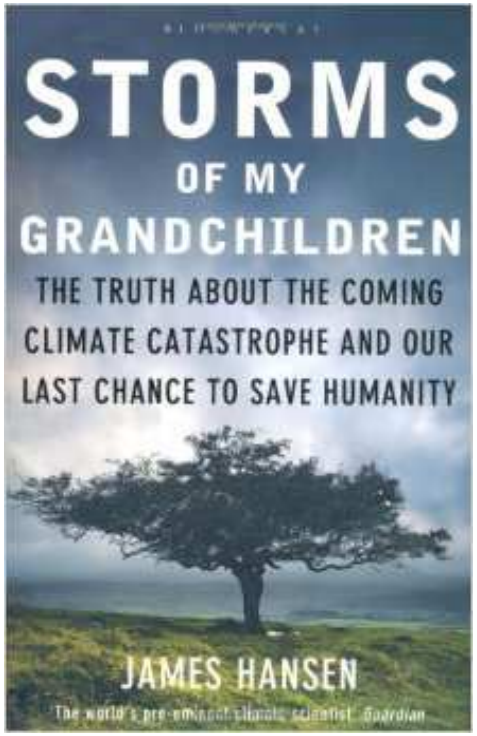
→***Extermination of species, Rising of sea level,***

Climatic extreme events *(storms, fires, floods…)*

→***Multiple Man-made stresses → Concerns for next generations***

"To those influencing environmental policy but opposed to nuclear power"

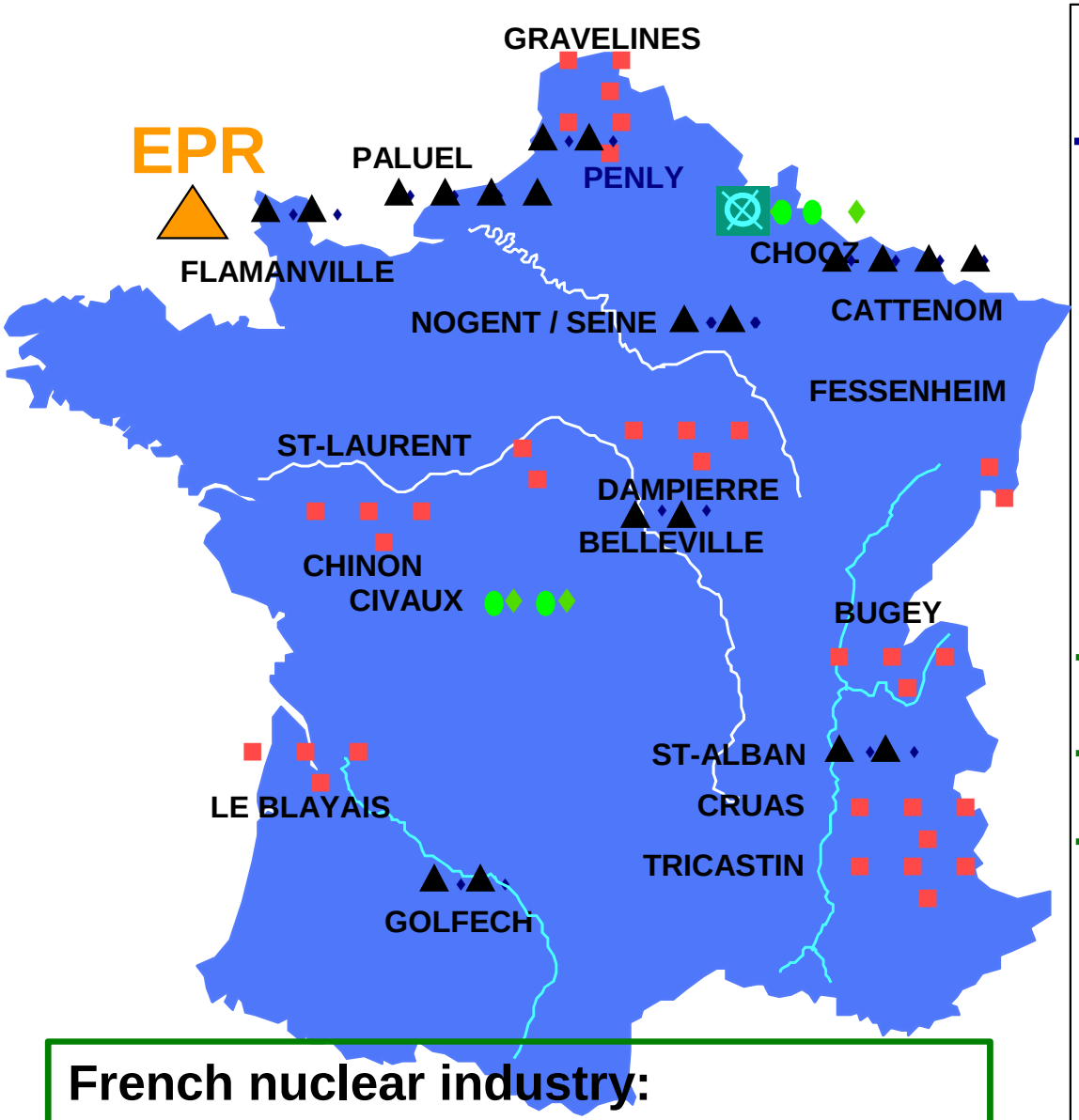
Open letter of 4 climate scientists (Nov. 17, 2013)
→A plea to fellow environmentalists that nuclear energy needs to be part of the global climate change solution
→ Confidence in technology progress to make nuclear safer, more efficient and more proliferation resistant



Prof. Hansen advocacies:

Need for a clean energy portfolio standards (not only renewables)
Urgency of a clean air act incentive
Modular reactors, largely factory built / Safety, reduction of cycle time
China to lead, West to cooperate

The French Nuclear Fleet



French nuclear industry:

- ✓ *125 000 direct employment (410 000 in total)*
- ✓ *~ 2% of National GDP*

58 reactors ***900-1450 MW***

+ EPR (~2018)

~420 TWh/y

76 % Power generation *(2015)*

145 €/MWh *(vs 206 UE)*

5,7 t_{CO2}/cap/y *(vs 7,4 UE)*

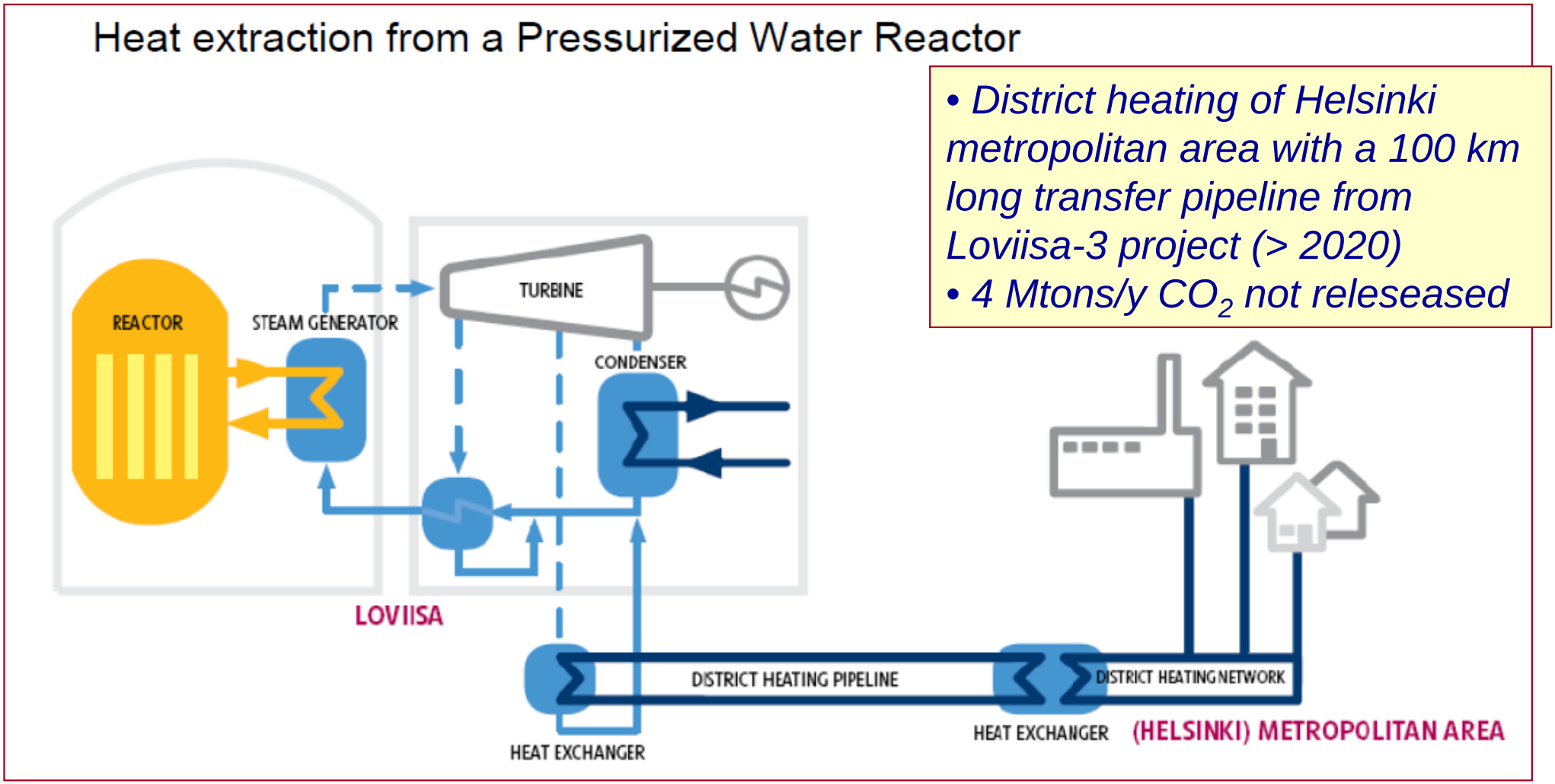
→ ***23/32 % RE 2020/2030***

→ ***50 % Nuc > 2025***

→ ***Nuc & RE integration towards a low-carbon economy***

ANCRE
Alliance Nationale de Coordination de la Recherche pour l'Énergie

District Heating from LWR Discharge Heat



from Harri Tuomisto, Fortum Power, Finland, Loviisa 3 project - October 2010

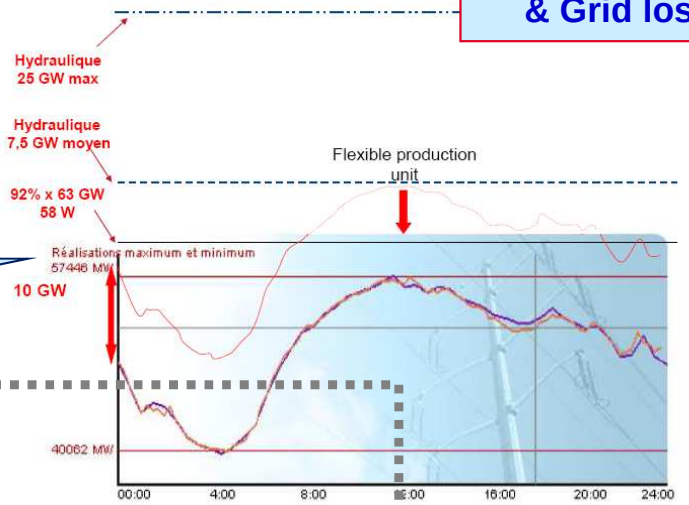
Towards Non-Electricity Products with LWRs

Low carbon electricity generation: nuclear, hydraulic, renewables… + Import

Offer and demand management

Electricity demand + Export & Grid losses

Decentralized and flexible units able to adapt their electricity consumption to electricity available on the grid



H_2 & syn-HyC fuels as storable & versatile energy carriers to supplement electricity

H_2O Electrolysis

H_2

Raw materials

Preparation

Petro-Chemistry, Recycle of CO_2 + …

Chemicals

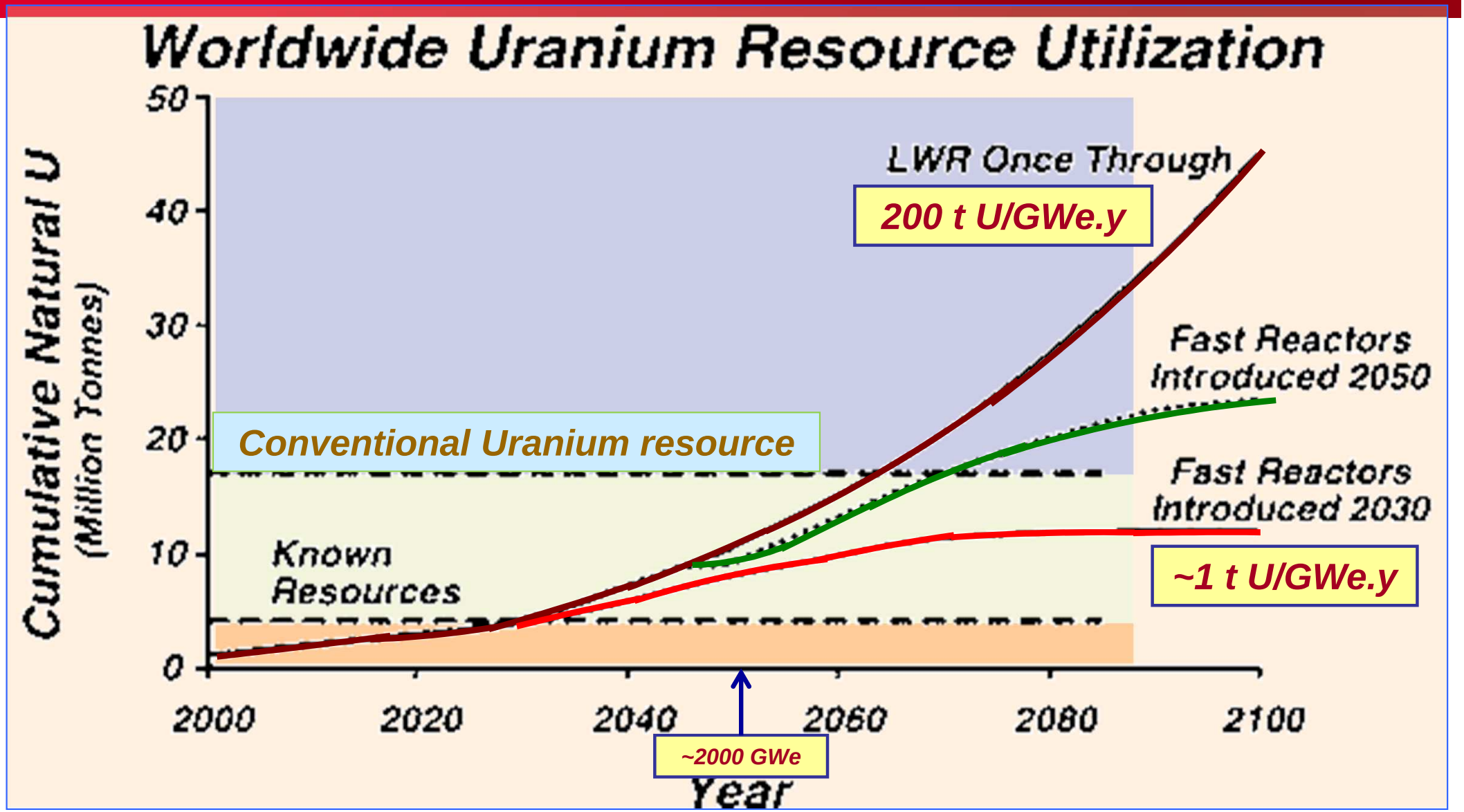
Syn-Fuels

Off-peak hours Production (electricity at marginal cost)
Production load following inversely the loads on the grid
Peak hours downturn (downturn valorization)

AREVA

N. Collignon & M. Lecomte

Durability of Uranium Resource



Source: "A Technology Roadmap for Generation IV Nuclear Energy Systems", December 2002

World Experience in Sodium Fast Neutron Reactors

➢**United States**
- *EBR-1 1951*
- *EBR-II (20 MWe) 1963 → 1994*
- *FFTF (400 MWth) 1980 → 2000*
- *Clinch River Project cancelled 1983*

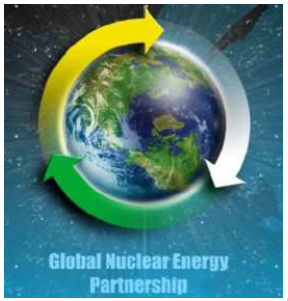
+ R&D on fuel cycle
+ Strategy under development

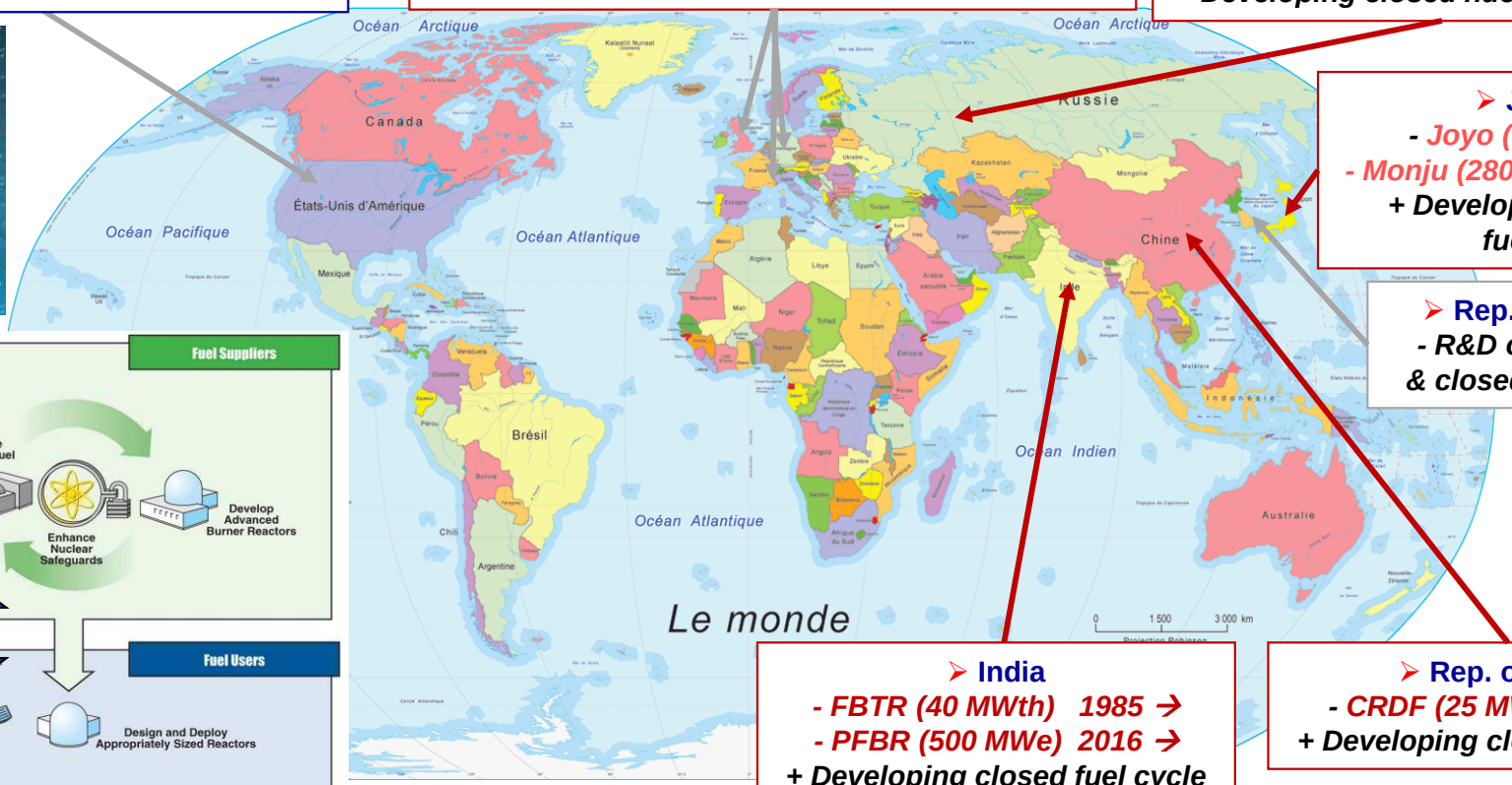
➢**Europe** *(France, Germany & UK)*
- *Rapsodie (20 MWth) 1967 → 1983*
- *DDFR (60 MWth), KNK II (17 MWe) 1978 → 1991*
- *Phenix (250 MWth) 1973 → 2009*
- *PFR (250 MWe) 1975 → 1994, SNR300*
- *Superphenix (1200 MWe) 1986 → 1998*

+ Industrial nuclear fuel cycle in France & the UK
+ ASTRID Next Generation SFR Project

➢ **Russian Federation**
- *BOR-60 (60 MWth)*
- *BN350 (90 MWth) 1973 → 1999*
- *BN600 (600 MWth) 1980 →*
- *BN800 (800 MWth) 2015 →*

+ Developing closed nuclear fuel cycle





➢ **Japan**
- *Joyo (140 MWth)*
- *Monju (280 MWth) 1994 →*

+ Developing closed fuel cycle

➢ **Rep. of Korea**
- **R&D on reactor & closed fuel cycle**

➢ **India**
- *FBTR (40 MWth) 1985 →*
- *PFBR (500 MWe) 2016 →*

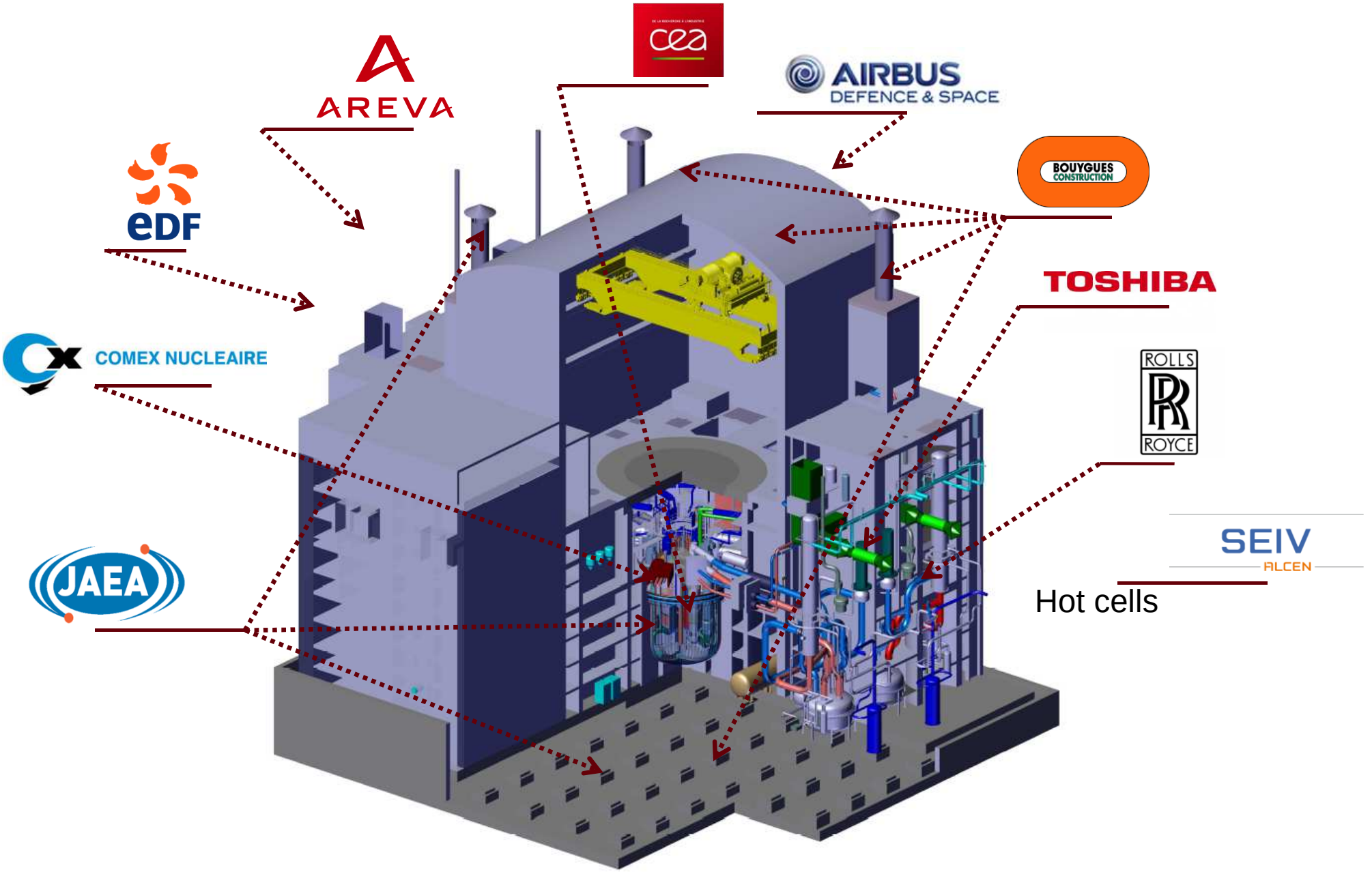
+ Developing closed fuel cycle

➢ **Rep. of China**
- *CRDF (25 MWe) 2010 →*

+ Developing closed fuel cycle

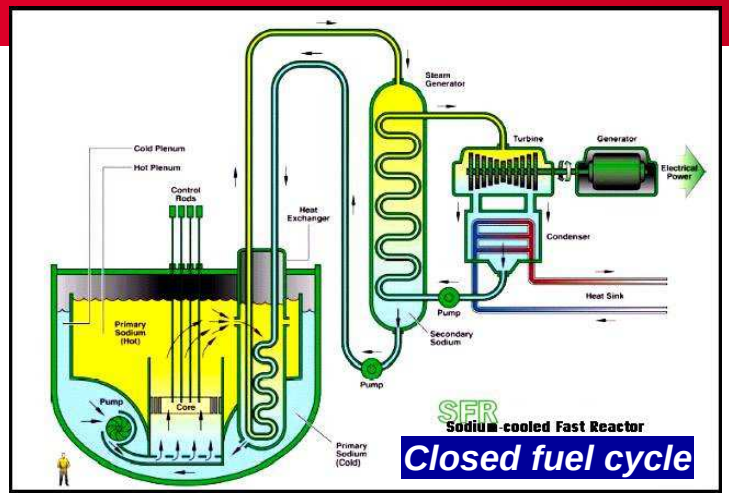
GNEP: a strategy to enable expansion of nuclear power in the U.S. and around the world, promote nuclear nonproliferation goals, and help resolve nuclear waste disposal issues

ASTRID : Involvement of Industry

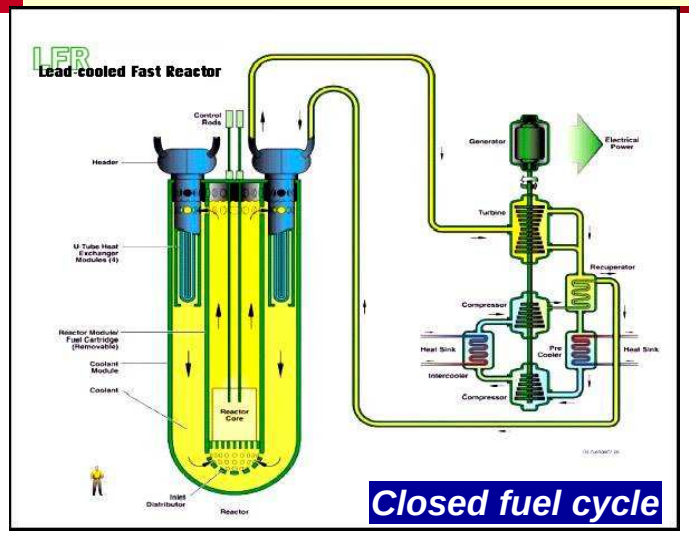


Generation IV International Forum: Six Systems for R&D

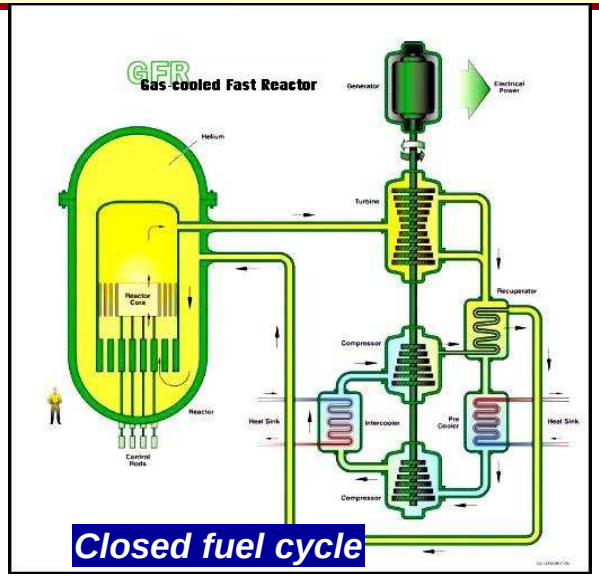
GIF Selection of six Nuclear Systems



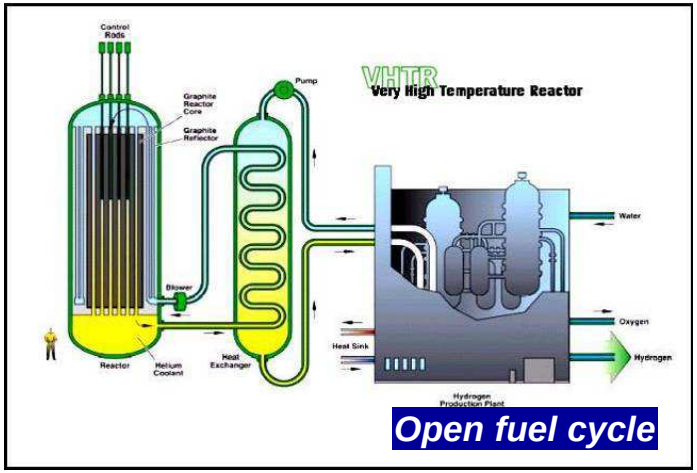
Sodium Fast Reactor



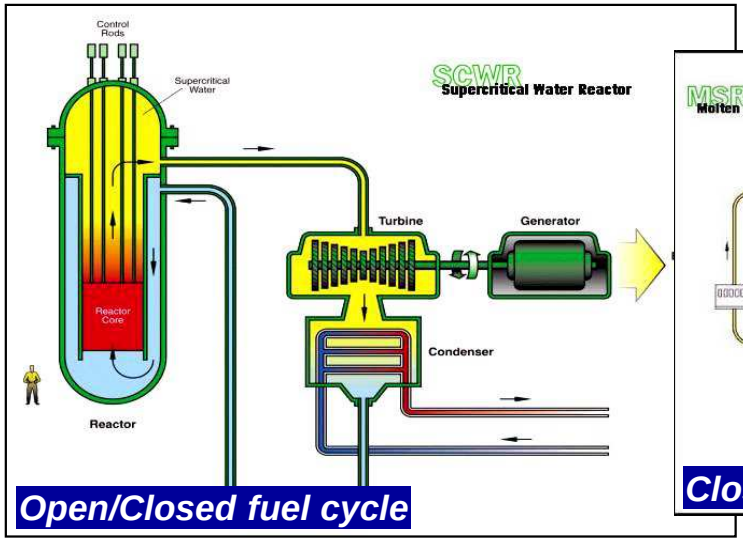
Lead Fast Reactor



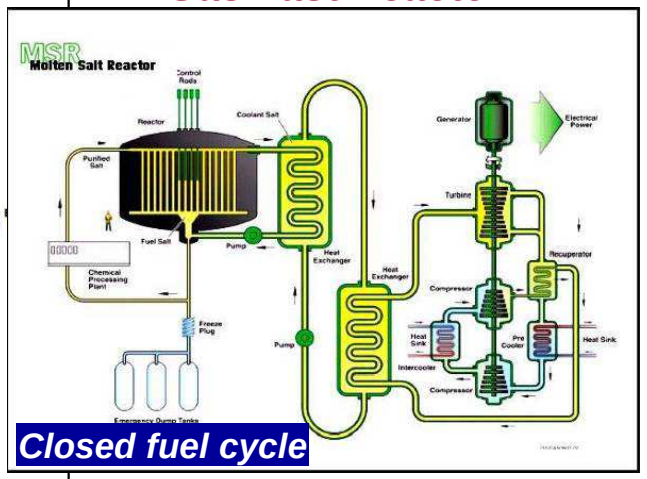
Gas Fast Reactor



Very High Temperature Reactor



Super Critical Water Reactor



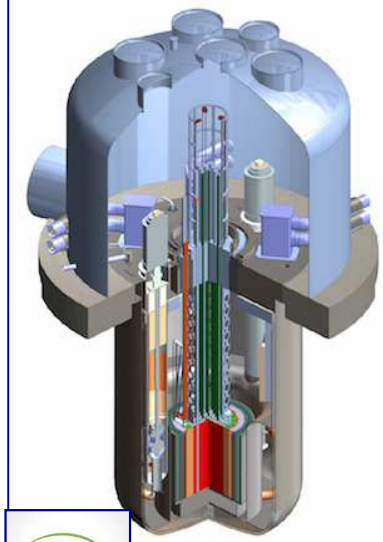
Molten Salt Reactor

The recognition of the major potential of fast neutron systems with closed fuel cycle for breeding (fissile re-generation) and waste minimization (minor actinide burning)

Game Changers for Sustainable Nuclear Growth?

TWR: A reactor for initiating the deployment of FNRs in a NTP member country without fuel cycle industry?

Traveling Wave Reactor



Turns depleted uranium into electricity, using a simple fuel cycle without requiring separations.

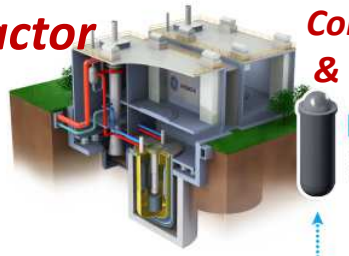
SIZE	600 MWe (Prototype Plant) 1150 MWe (Commercial Plant)
TEMPERATURE	510°C
PRESSURE	Low (Atmospheric)
PRIMARY FUEL	Depleted Uranium
COOLANT	Sodium
ENERGY CONVERSION	Steam (Rankine Cycle)
WASTE REPROCESSING	Not Required

TerraPower

Transportable sealed & retrievable SMR with a long lifetime: An option for moderately reliable /stable newcomer nuclear countries?

Integral Fast Reactor

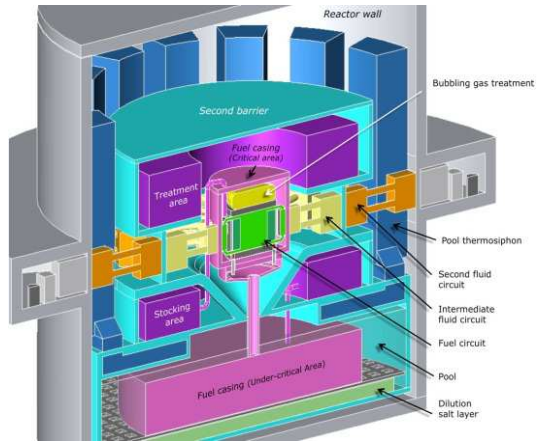
Sodium Reactor Evolution



Colocated Reactor & Recycle Facility

PRISM 1980s
Power Reactor Innovative Small Module
General Electric

Nuclear systems with reactor & recycle facilities recycled: IFR? MSFR?... From fresh fuel to ultimate waste on the same site?



Molten Salt Fast Reactor

Nuclear Energy Innovation: Necessity, Challenge and Asset

Summary and perspectives

- **Nuclear energy is a vital component of a low-carbon economy**
- **Make the marketing of *Gen-III* a success** *(> 20% World Power Gen)*
  - ✓*Towards more internationally harmonized safety regulations*
  - ✓*Economic competitiveness, Financing arrangements, Symbiosis with Renewable Energies, Widened range of applications…*
  - ✓*Secured services for nuclear fuel supply and management of used fuels*
- **Conduct R&D today for breakthrough innovation needed for *Gen-IV* nuclear systems in the perspective of a sustainable world low-carbon economy**
  - ✓*Fast neutron reactors with a closed nuclear fuel cycle for a durable nuclear production and mitigation of long term radioactive waste burden*
  - ✓ *Production of H_2, synthetic hydrocarbon fuels, district and process heat…*
- **Innovations: Technology, Financing, Regulations, Integration with renewable energies and a low carbon economy…**
- **Stakes of international collaboration** *(GIF, IAEA/INPRO, EU/SNE-TP…)*
  - ✓ *To share costs of R&D & large demonstrations (system technologies, recycling, applications)*
  - ✓*Towards more internationally harmonized safety regulations and visions of security measures*