The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2473-3

Joint ICTP-IAEA School on Nuclear Energy Management

15 July - 3 August, 2013

Basic Principles

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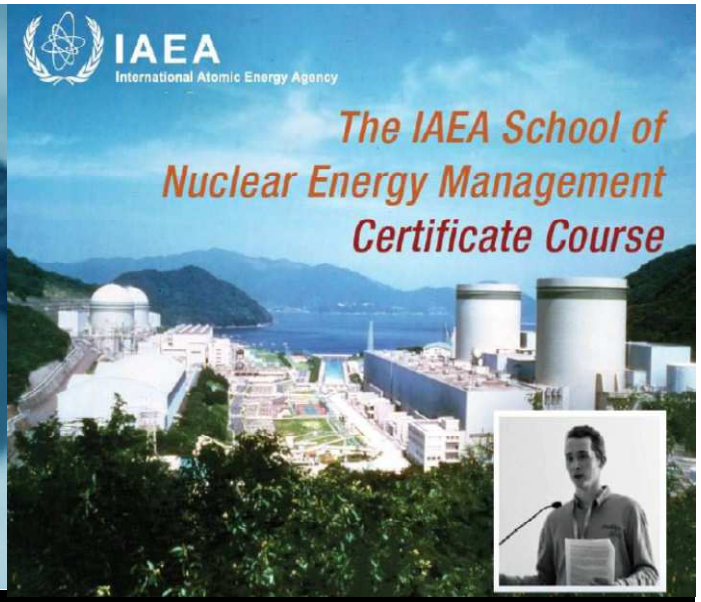


Nuclear Energy

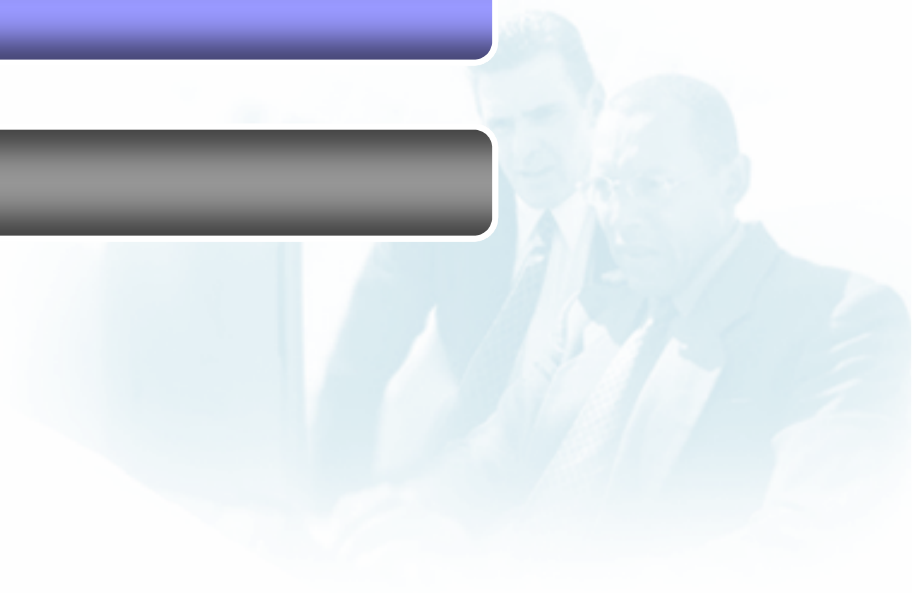
Basic Principles

Yanko Yanev

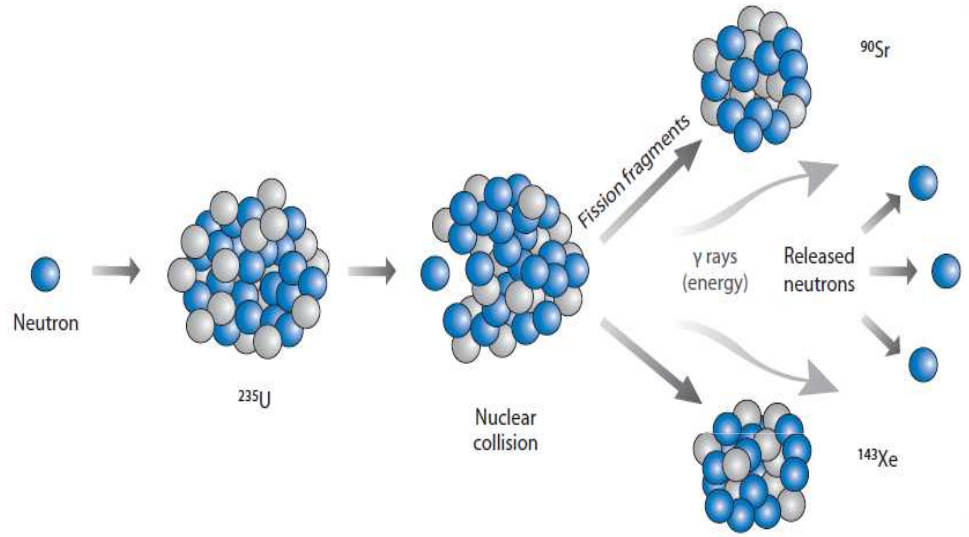
NEM School, ICTP 2013

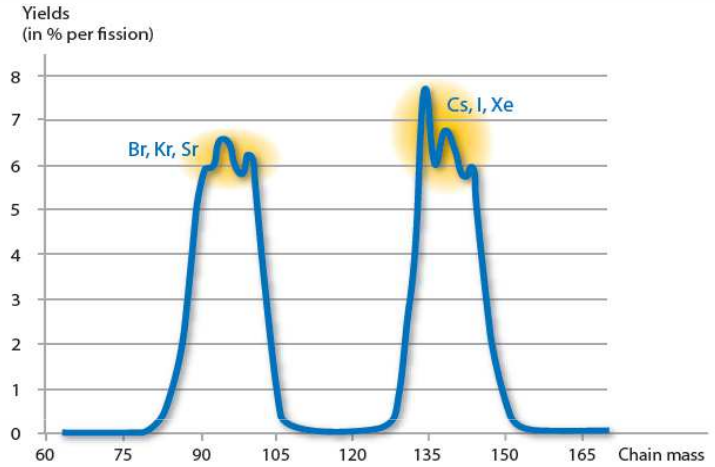
Agenda

1. Science and Policy
2. The Basic Principles
3. Understanding
4. Discussion

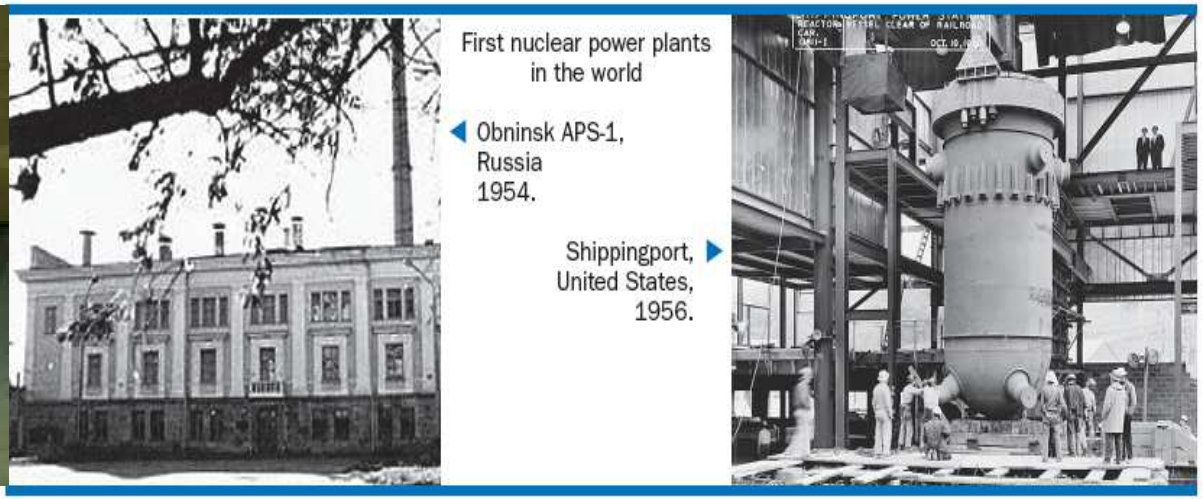


The Beginning

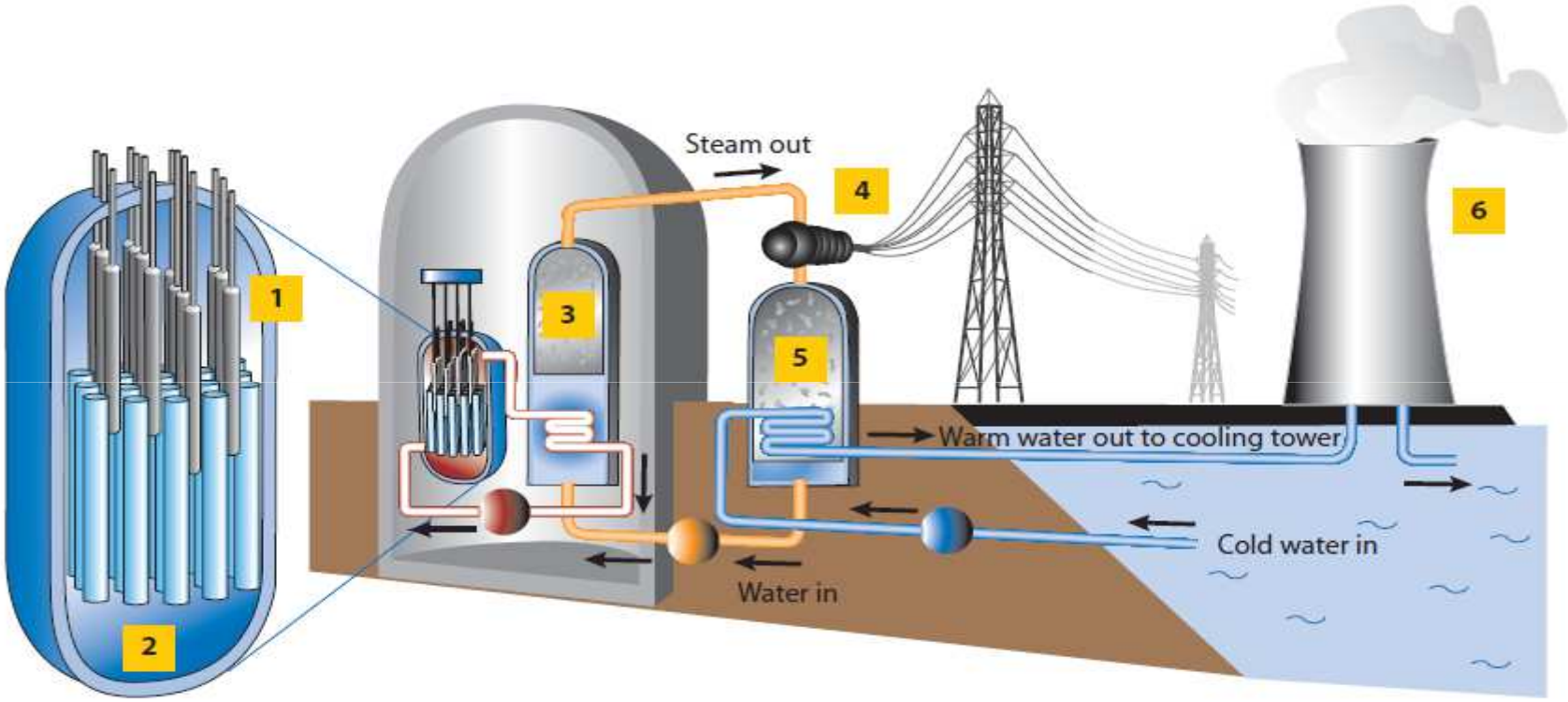




Hahn and Strassmann - 1938



Nuclear Power Plant



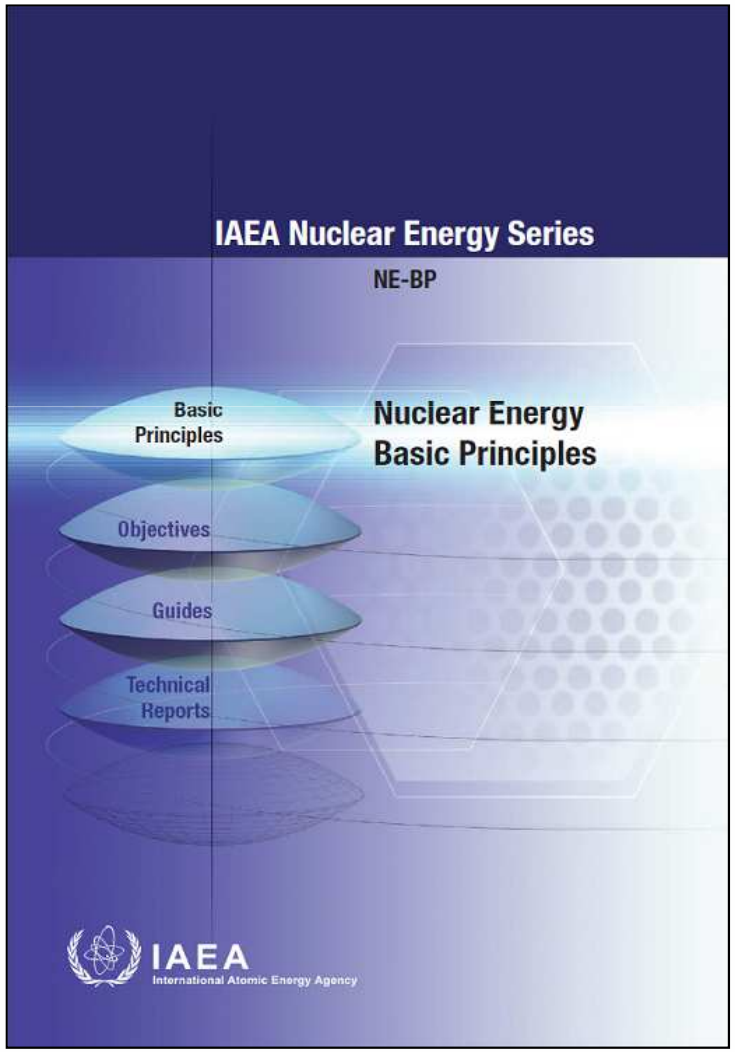
Source: *New Scientist.*

1 – Reactor : fuel (light blue) heats up pressurised water. Control rods (grey) absorb neutrons to control or halt the fission process.
2 – Coolant and moderator: fuel and control rods are surrounded by water (primary circuit) that serves as coolant and moderator.
3 – Steam generator: water heated by the nuclear reactor transfers heat through thousands of tubes to a secondary circuit of water to create high-pressure steam.
4 – Turbo-generator set: steam drives the turbine, which spins the generator to produce electricity.
5 – Condenser: removes heat to convert steam back to water, which is pumped back to the steam generator.
6 – Cooling tower: removes heat from the cooling water that circulated through the condenser, before returning it to the source at near-ambient temperature.

NUCLEAR ENERGY MATH

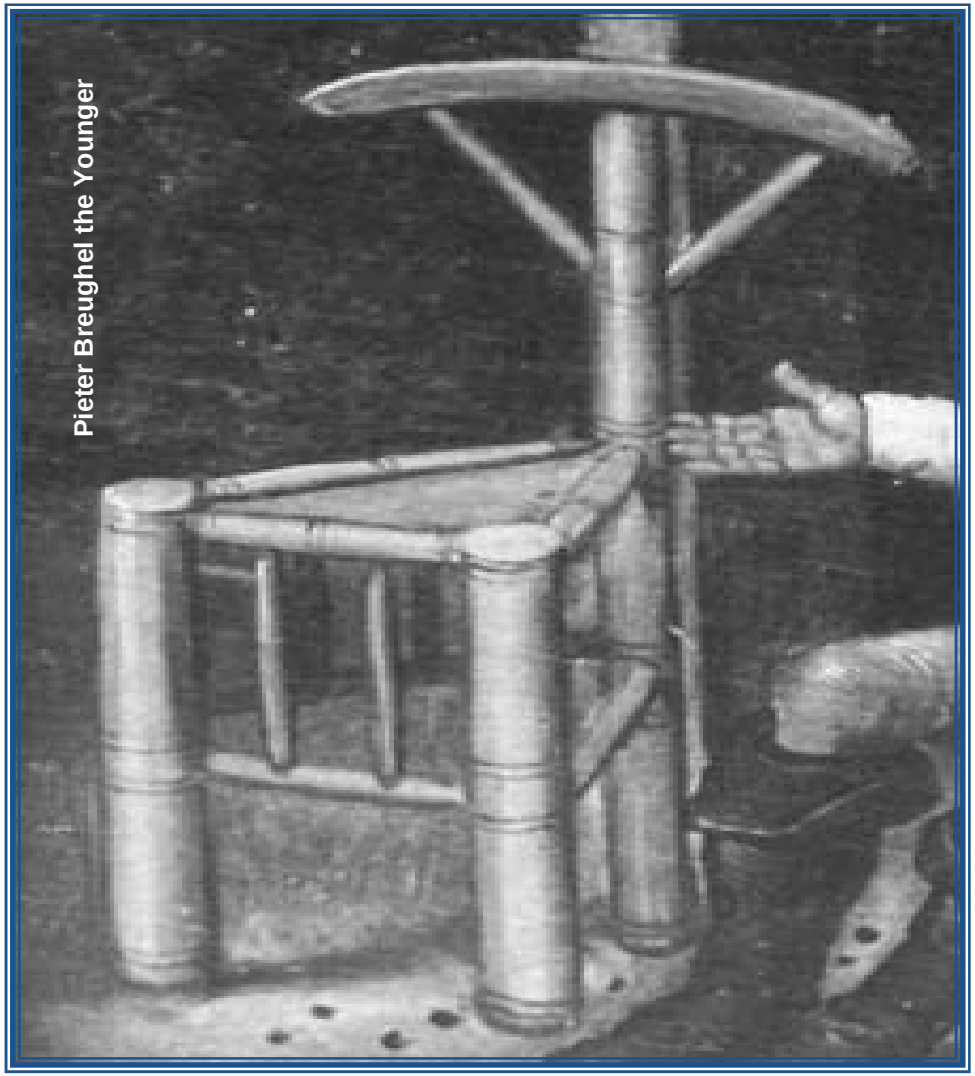
- **Scientifically and Technically sound!**
- **Politically correct!**

Nuclear Energy Basic Principles



- The Basic Principles describe the **rationale and vision for the peaceful uses of nuclear energy** on which nuclear energy systems should be based to fulfil nuclear energy's potential to help meet growing global energy needs.
- The basic principles are intended to provide a **holistic approach to the use of nuclear energy** and to be equally applicable to all elements of nuclear energy systems, including human resources and technical, management and economic aspects, with due regard to the protection of people and the environment, security, and non-proliferation.

BALANCE



1. Society must be convinced in the **benefit** of nuclear energy.
2. Nuclear energy should be used with high **responsibility.**
3. Nuclear energy must be developed in **sustainable way**.

BENEFICIAL USE

PRINCIPLE 1 — BENEFITS

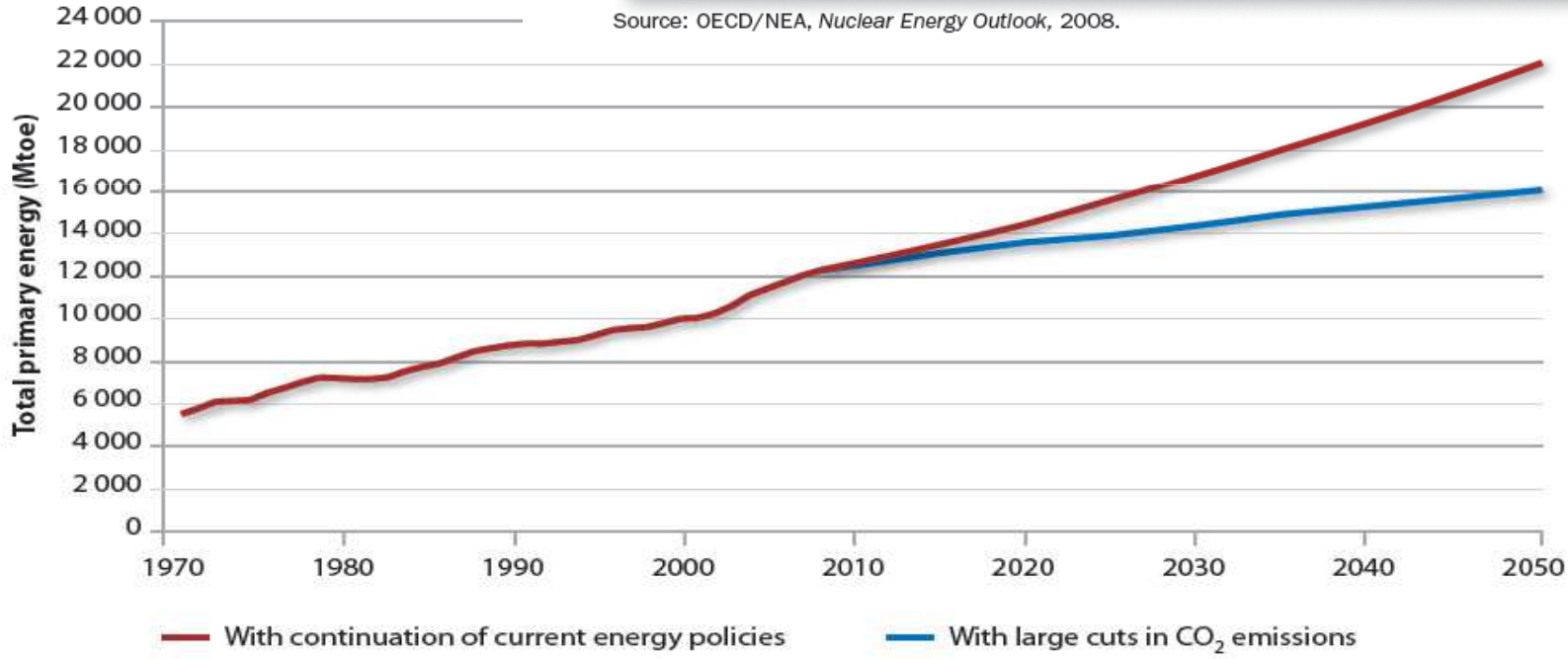
"The use of nuclear energy should provide benefits that outweigh the associated costs and risks."

- Large, low-carbon, scalable energy source
- Energy security
- Human development (science, R&D, E&T, Industrial development, etc.
- Environmental protection.

Energy projections

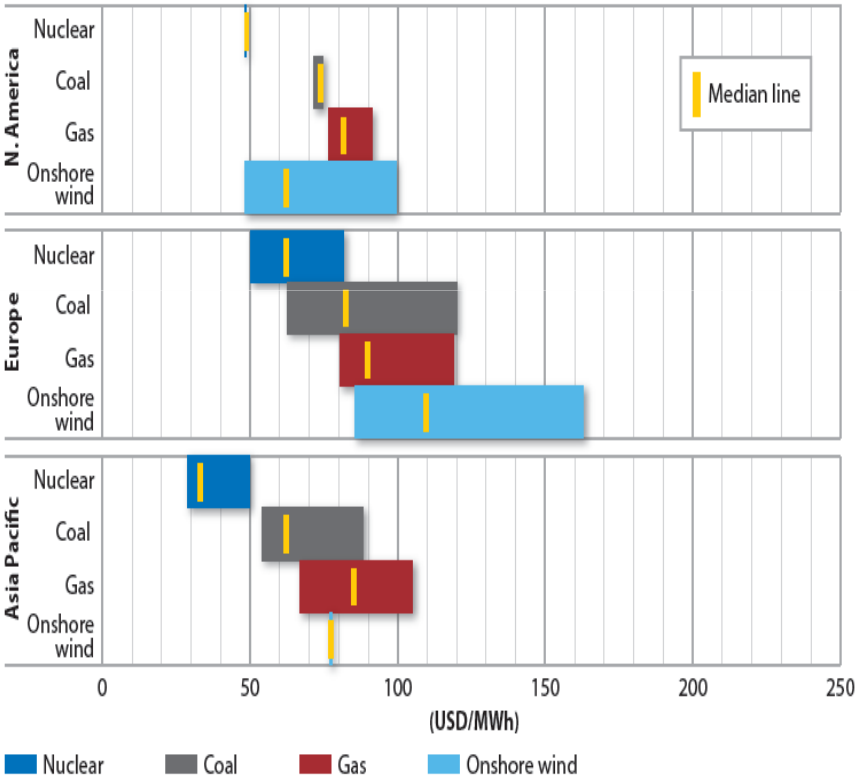
	Identified resources	Total conventional resources	Total conventional and unconventional resources
Present reactor technology	100	300	700
Fast neutron reactor systems	> 3 000	> 9 000	> 21 000

Source: OECD/NEA, *Nuclear Energy Outlook*, 2008.

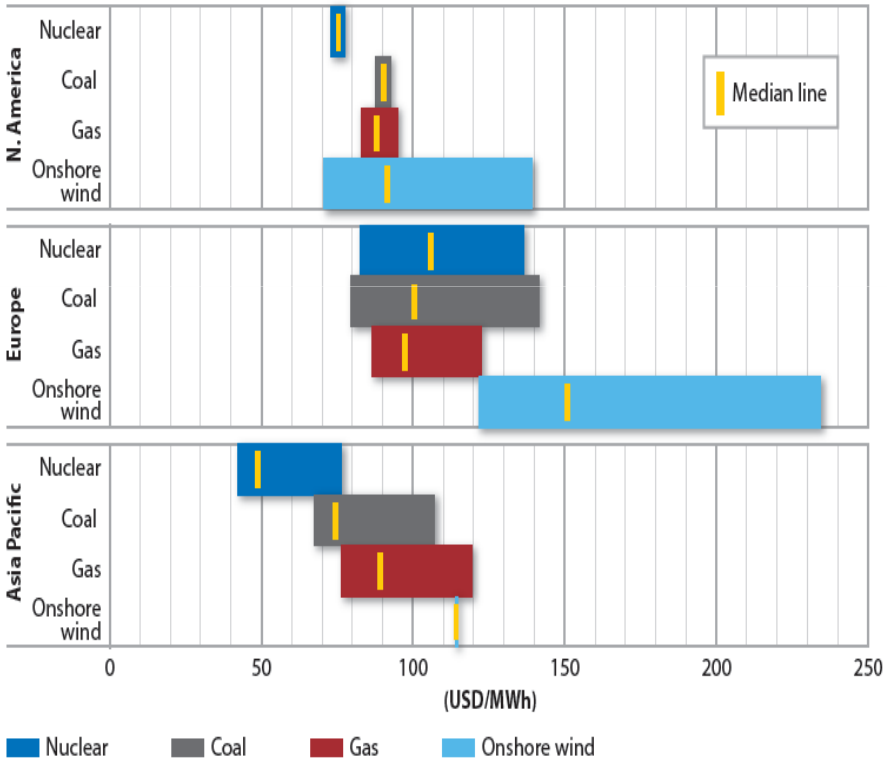


Sources:
Historical data: *OECD Factbook 2010*.
Projections: Based on IEA Baseline and Blue Map scenarios (*Energy Technology Perspectives*, 2010).

Costs

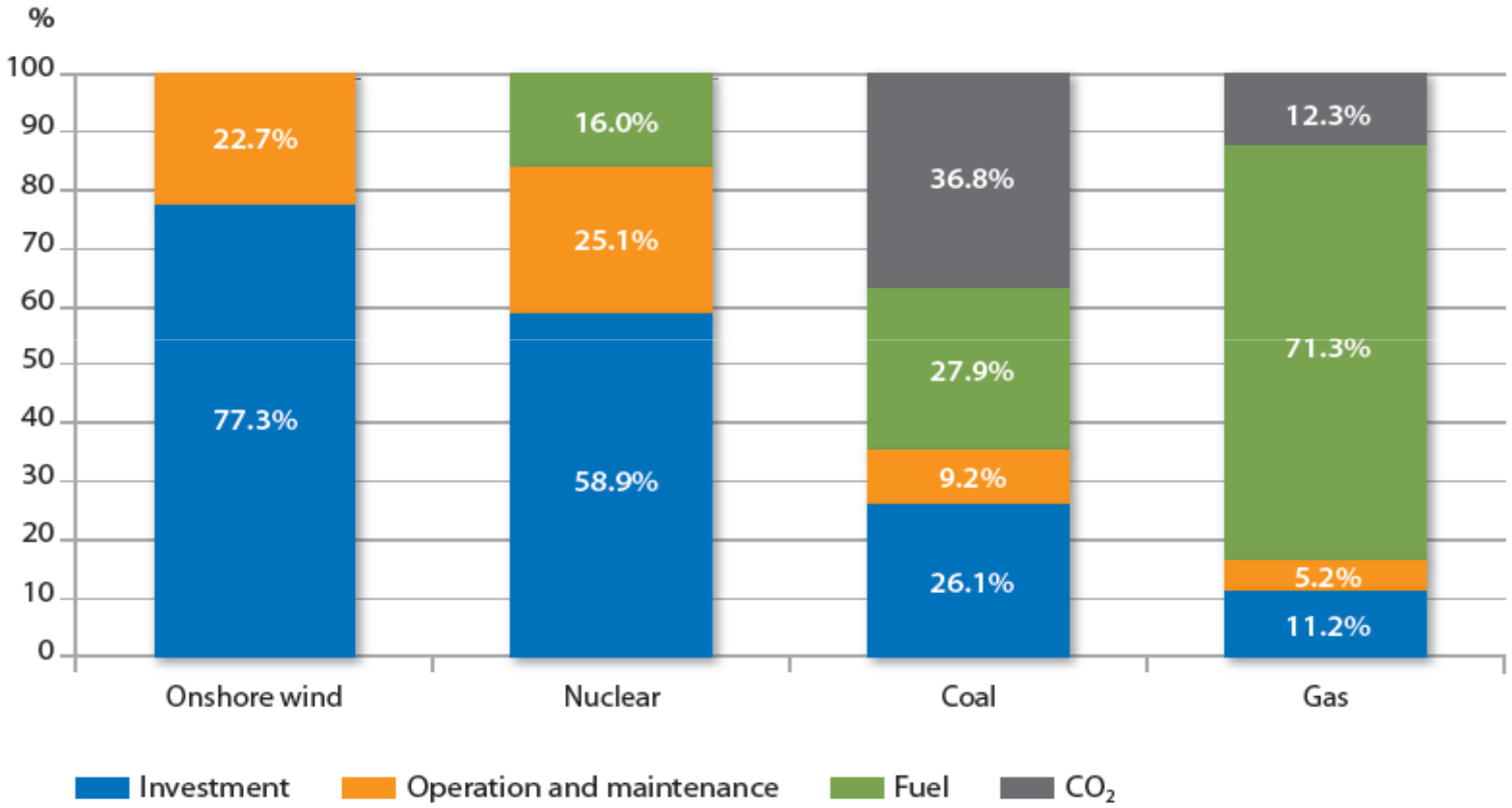


Source: IEA/NEA, *Projected Costs of Generating Electricity*, 2010.



Source: IEA/NEA, *Projected Costs of Generating Electricity*, 2010.

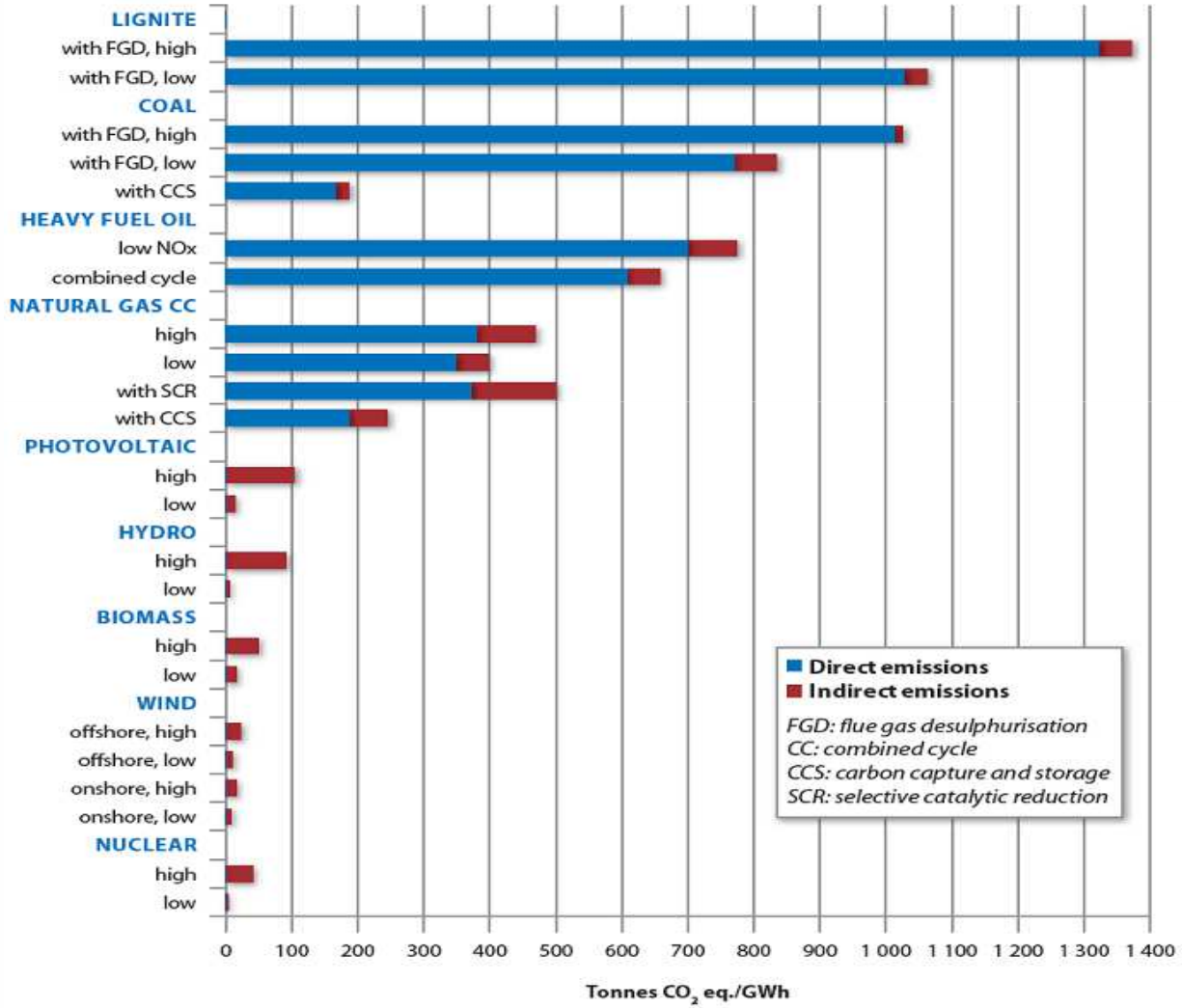
Comparison



Notes: Investment: includes decommissioning costs. Fuel: includes waste management for nuclear.

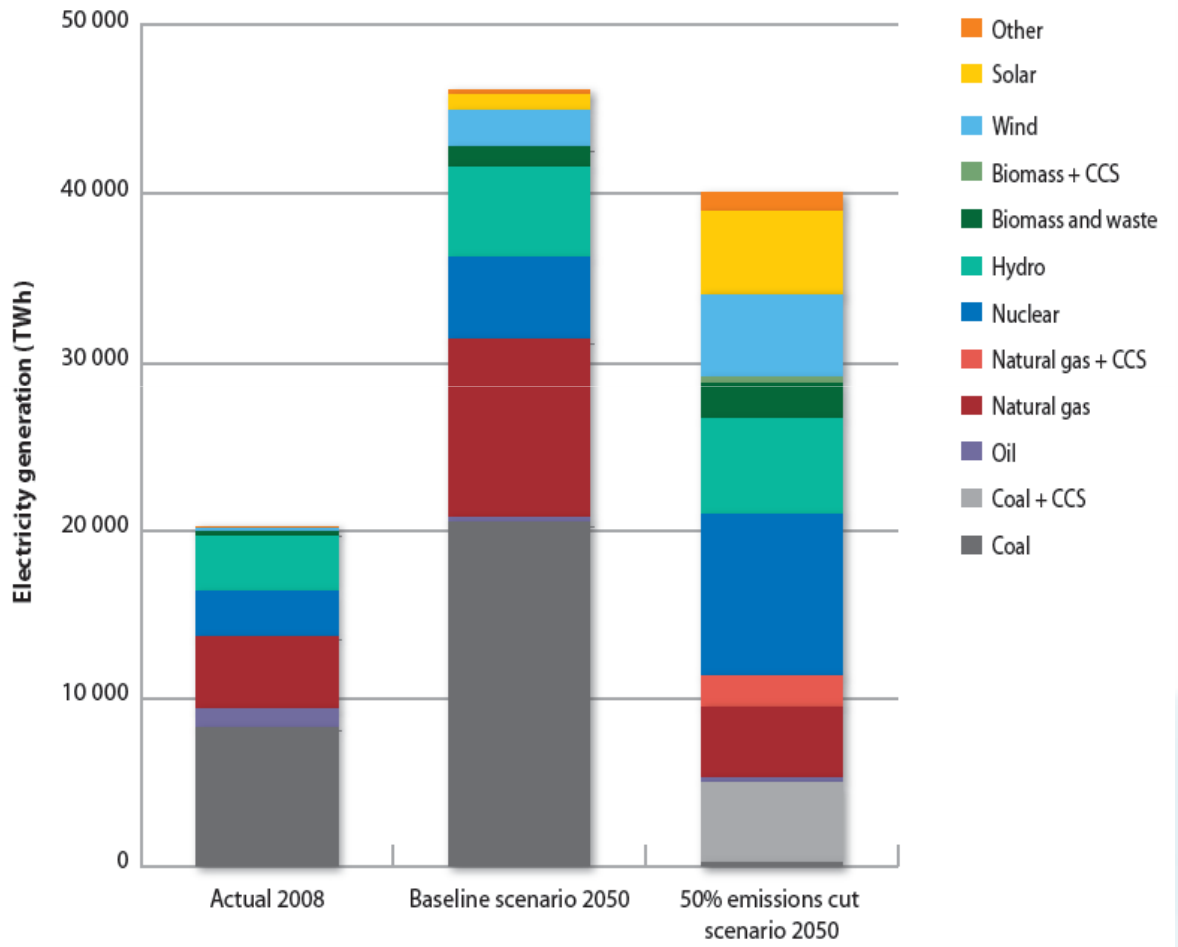
Source: IEA/NEA, *Projected Costs of Generating Electricity*, 2010.

CO2 emissions



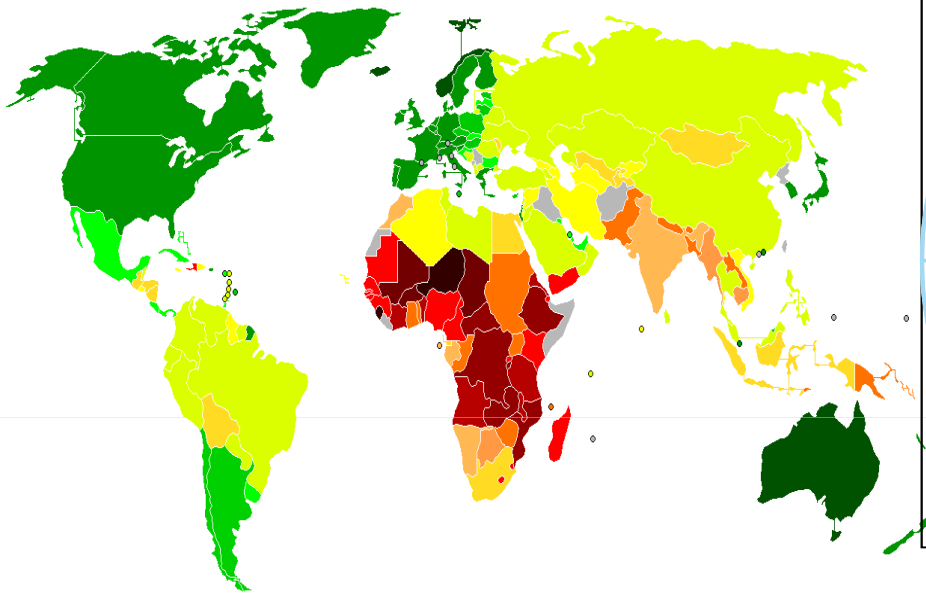
Source: Intergovernmental Panel on Climate Change, *Mitigation of Climate Change*, 2007.

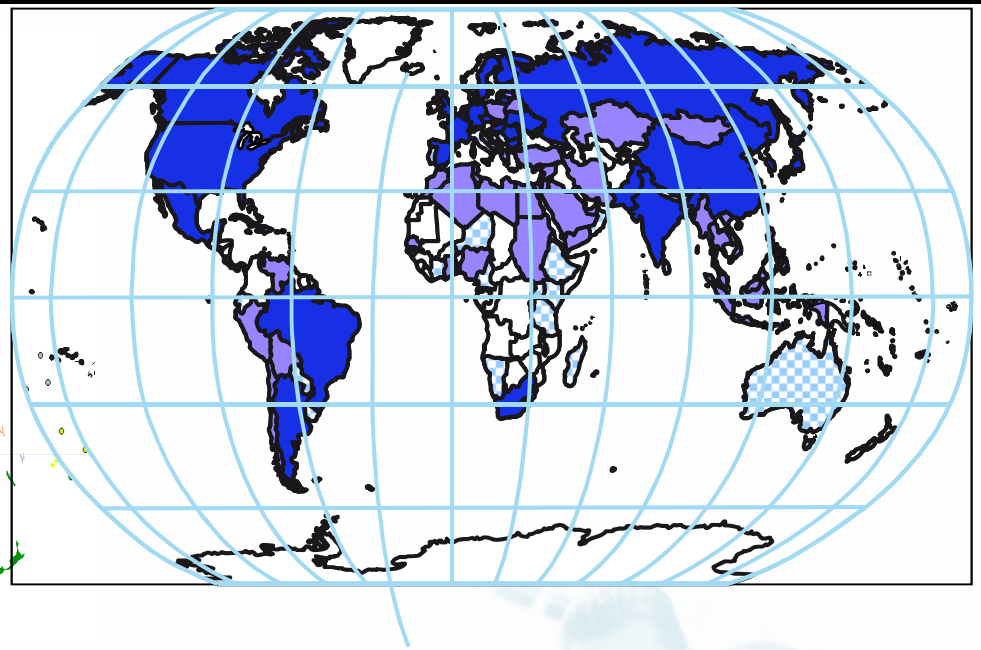
Fight Climate Change



Note: CCS is carbon capture and storage. "Other" includes geothermal, tidal and wave power.
Source: IEA, *Energy Technology Perspectives*, 2010.

Human development





HDI=(GDP/Edu/Health)

over 0.95	0.75-0.799	0.55-0.599	0.35-0.399
0.90-0.949	0.70-0.749	of 0.50-0.54	0.30-0.349
	0.65-0.699	of 0.45-0.49	<0.30
0.85-0.899	0.60-0.649		N/A
0.80-0.849		0.40-0.449	

- Using nuclear energy
- Planning a nuclear program
- Interested in the future

BENEFICIAL USE

PRINCIPLE 2 — TRANSPARENCY

"The use of nuclear energy should be based on open and transparent communication of all its facets."

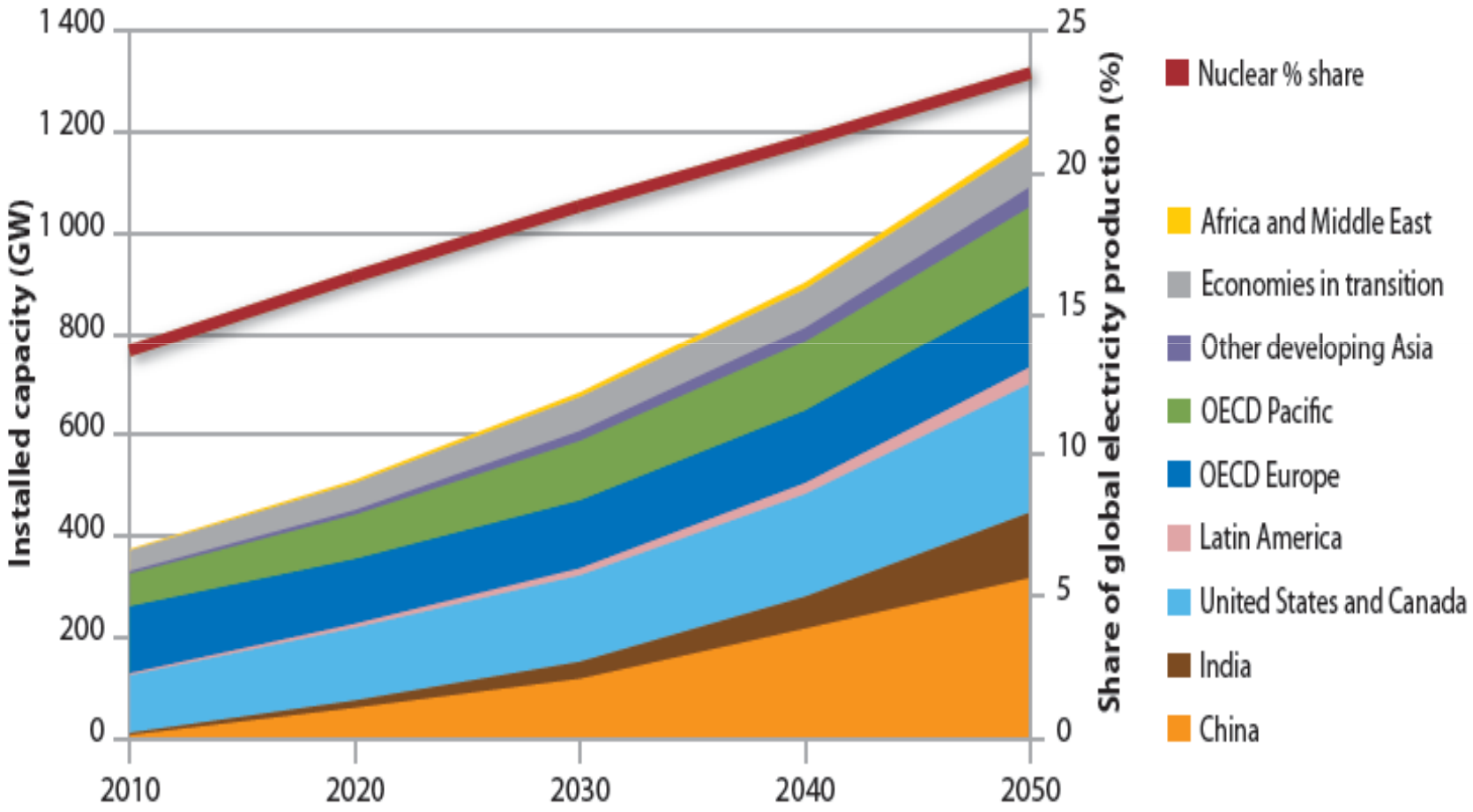
- Social understanding
- Stakeholder involvement
- Public relationship
- Peaceful use
- Risks

Social understanding

Social Problems of Nuclear Energy

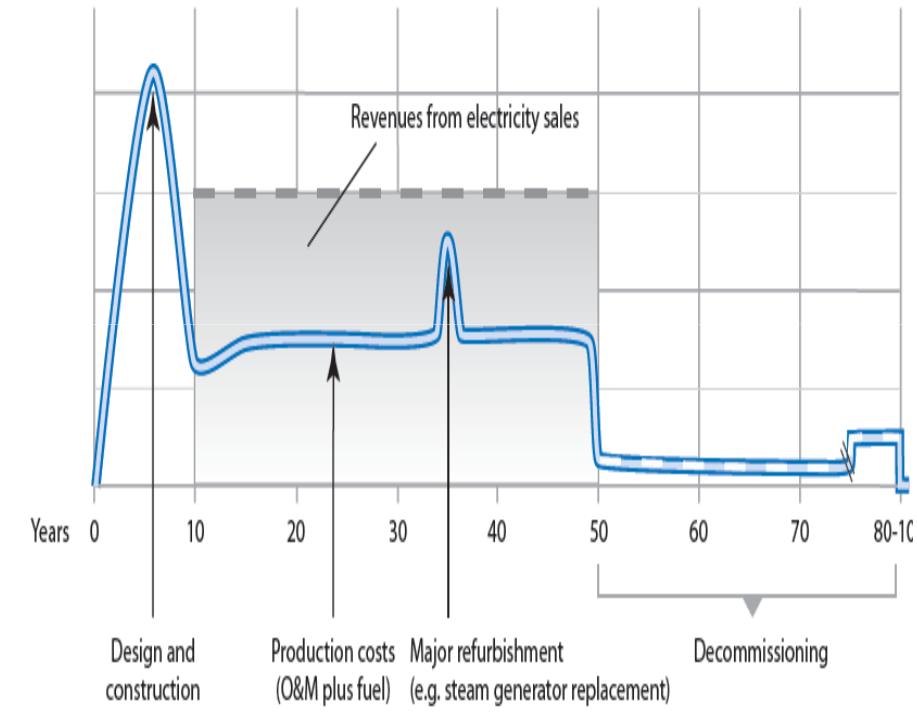
NEW FOR SPRING 2013

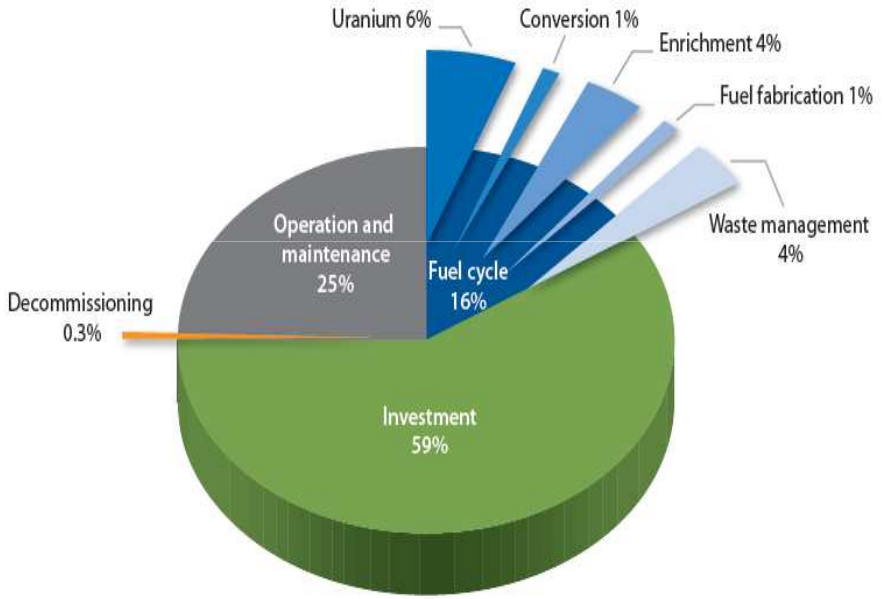
NUCLEAR SHARE



Source: IEA/NEA, *Nuclear Energy Technology Roadmap*, 2010.

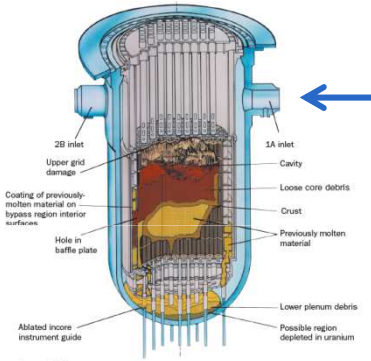
MONEY – When and How

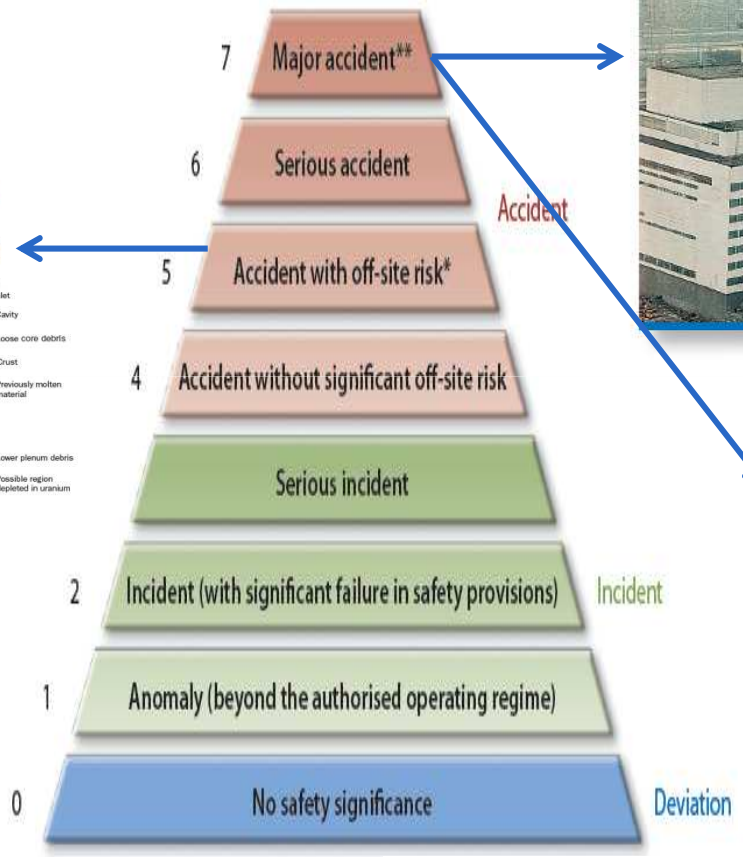




Source: IEA/NEA, *Projected Costs of Generating Electricity*, 2010.

THE RISKS?





*Three Mile Island, United States, 1979.

** Chernobyl, Ukraine, 1986 – Fukushima, Japan, 2011

Chernobyl unit 4 after the accident.

Source: De Cort *et al.*, 1998.

Tsunami wave overrunning the sea walls and flooding the Fukushima Daiichi nuclear power plant on 11 March 2011 (photo taken from unit 5).

Source: TEPCO.

Table 4.1: ^{131}I and ^{137}Cs releases and INES equivalent release in the Chernobyl accident

Nuclide	Half-life	Core inventory ($x10^{15}$ Bq)	Release fraction (%)	Activity released ($x10^{15}$ Bq)	Equivalence factor	Equivalent release ($x10^{15}$ Bq)
^{131}I	8.05 days	3 200	55	1 760	1	1 760
^{137}Cs	30 years	280	30	85	40	3 400
						5 160

Source: NEA (1996).

Table 4.2: ^{131}I and ^{137}Cs releases (estimations from TEPCO, May 2012) and INES equivalent release in the Fukushima Daiichi accident

Nuclide	Half-life	Activity released ($x10^{15}$ Bq)	Equivalence factor	Equivalent release ($x10^{15}$ Bq)	Ratio to Chernobyl releases
^{131}I	8.05 days	500	1	500	28%
^{137}Cs	30 years	10	40	400	12%
				900	**17%**

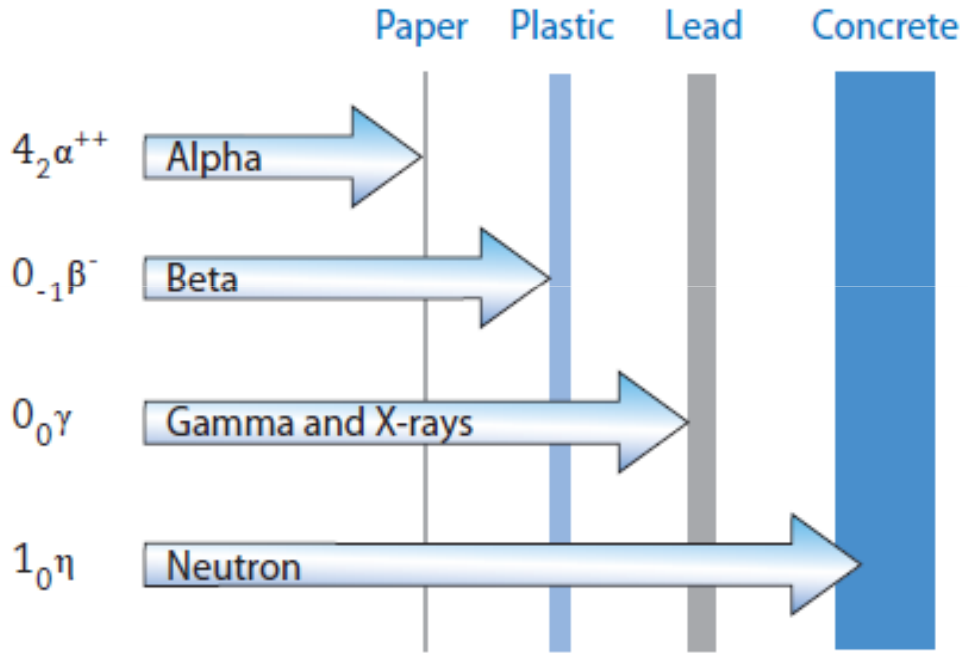
RESPONSIBLE USE

PRINCIPLE 3 — PROTECTION OF PEOPLE AND THE ENVIRONMENT

"The use of nuclear energy should be such that people and the environment are protected in compliance with the IAEA safety standards and other internationally recognized standards."

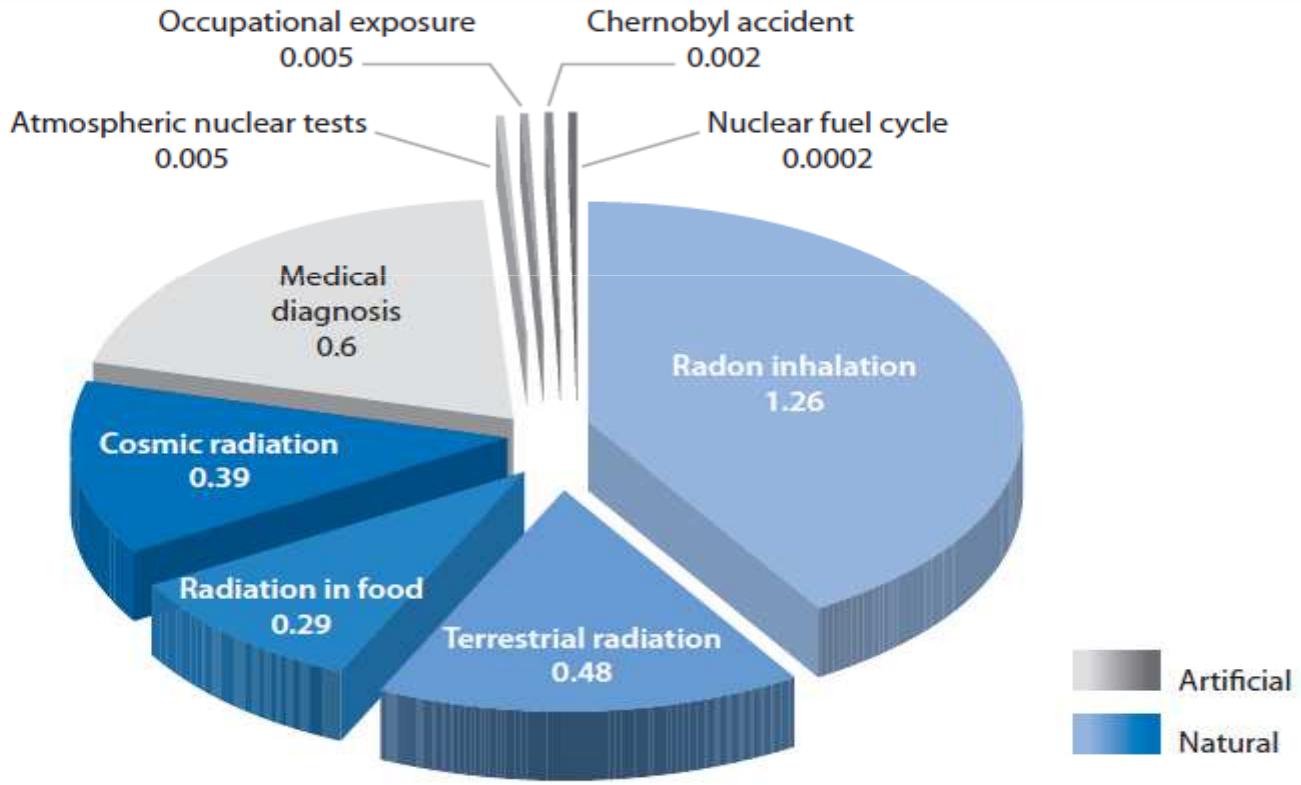
- IAEA Safety Standards
- Technological development
- Engineering solutions
- Knowledge management

Radiation



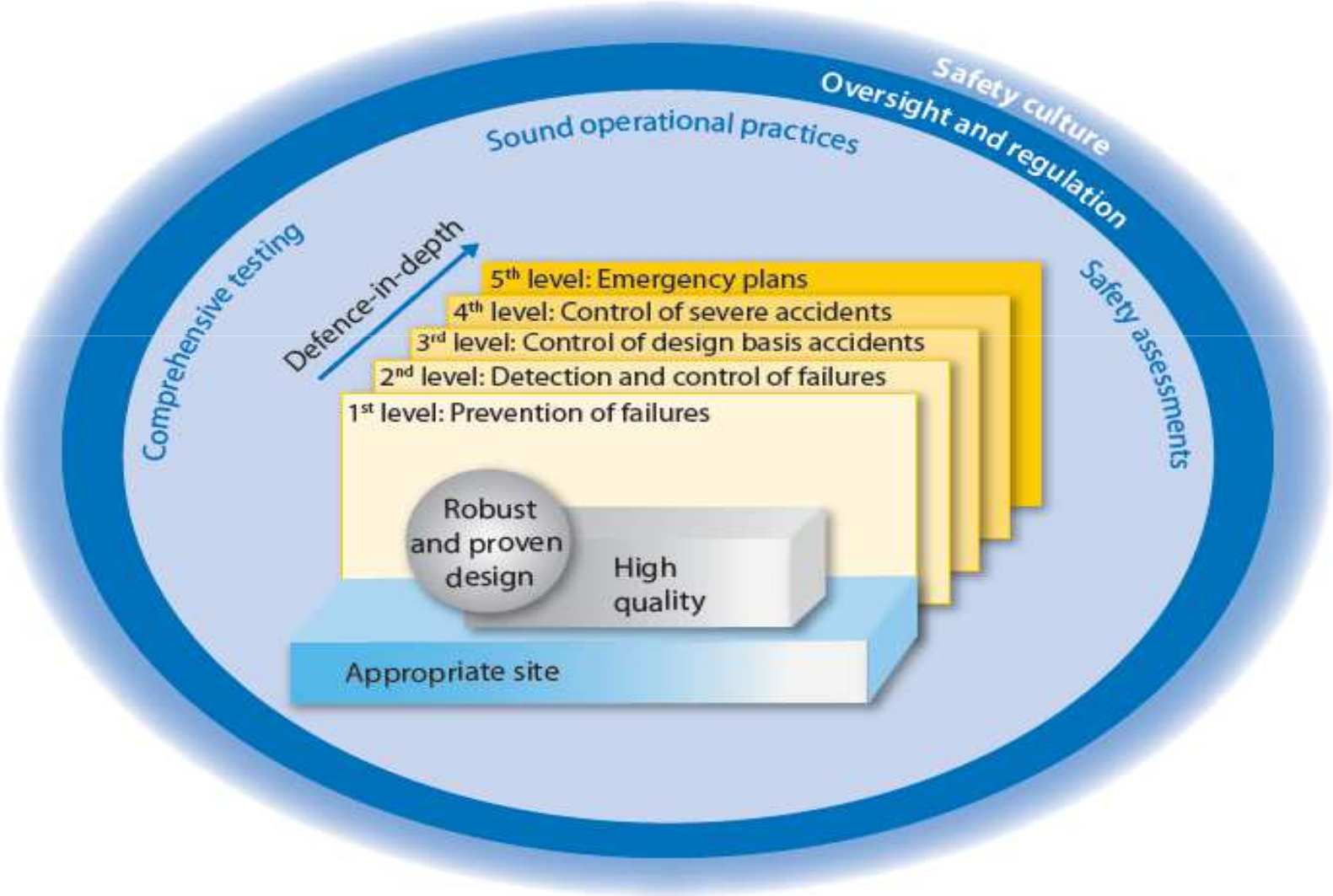
Source: University of Michigan Student Chapter of the Health Physics Society, United States.

Radiation exposure?

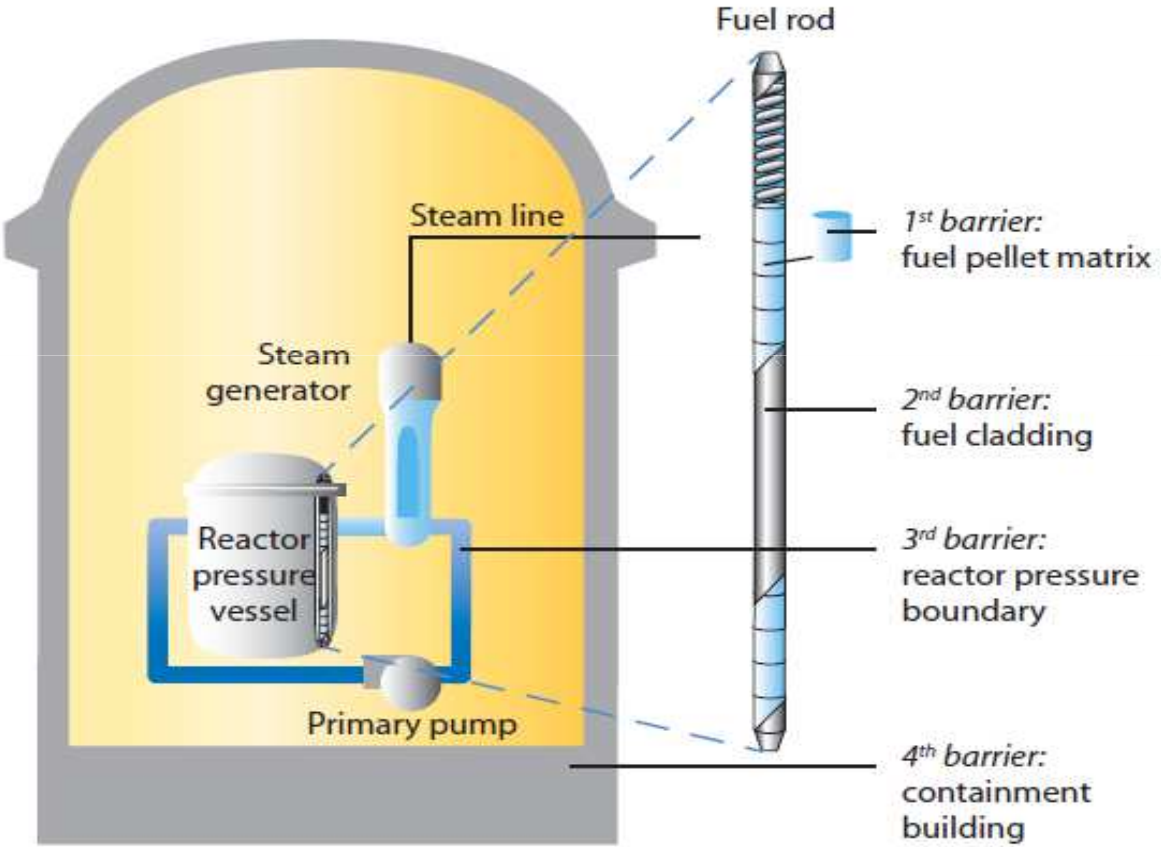


Source: UNSCEAR, *Sources and Effects of Ionizing Radiation*, Vol. 1, United Nations, 2008.

Nuclear Safety



Defence in Depth



RESPONSIBLE USE

PRINCIPLE 4 — SECURITY

"The use of nuclear energy should take due account of the risk of the malicious use of nuclear and other radioactive material."

- Physical protection
- Sabotage and theft
- Nuclear terrorism
- Legal measures

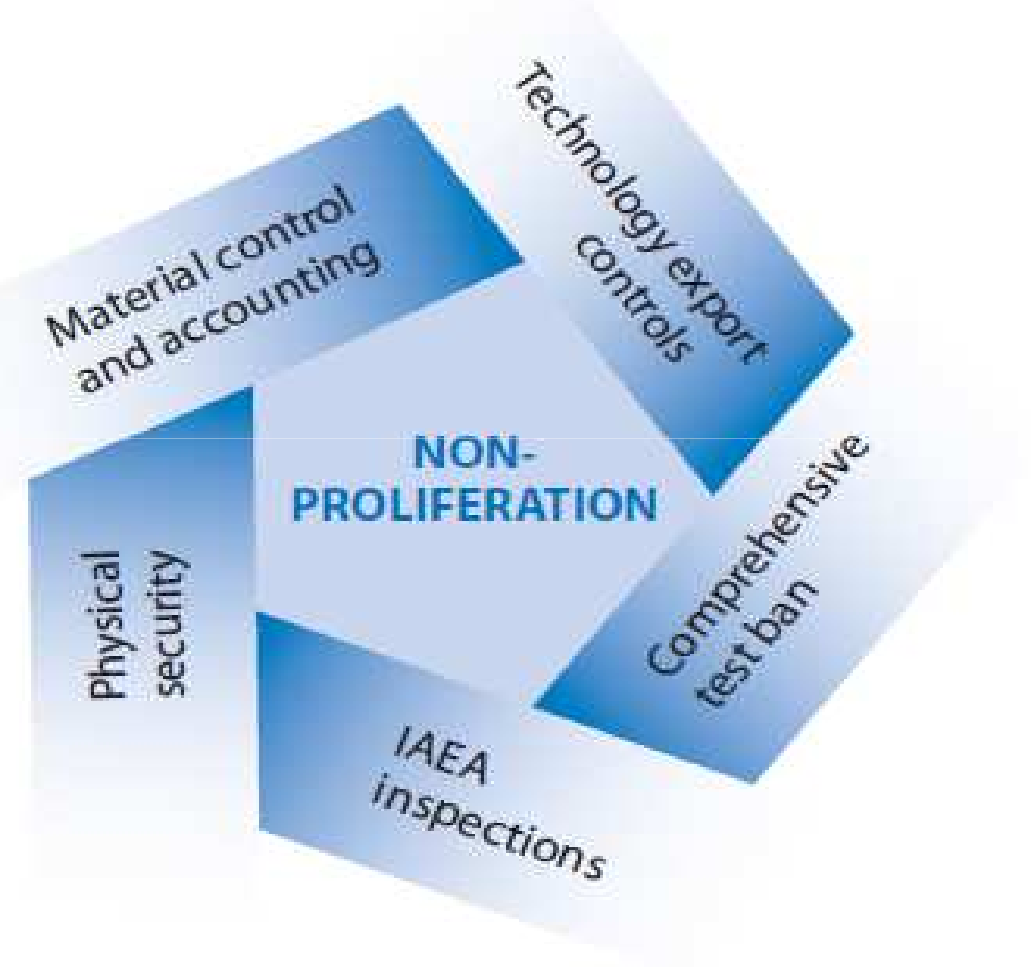
RESPONSIBLE USE:

PRINCIPLE 5 — NON-PROLIFERATION

"The use of nuclear energy should take due account of the risk of the proliferation of nuclear weapons."

- Technological solutions
- Proliferation resistance

Non-proliferation



NPT Treaty - entered into force in 1970

- Safeguards to prevent diversion from peaceful uses
- Balanced obligations between NNWS and NWS
- Full access to peaceful uses of nuclear energy
- Security assurances

What are IAEA Safeguards?

IAEA

Secretariat

- Verifies compliance
- Draws safeguards conclusions

Board of Governors

Reviews safeguards implementation and takes action

UN Security Council

Addresses cases of non-compliance

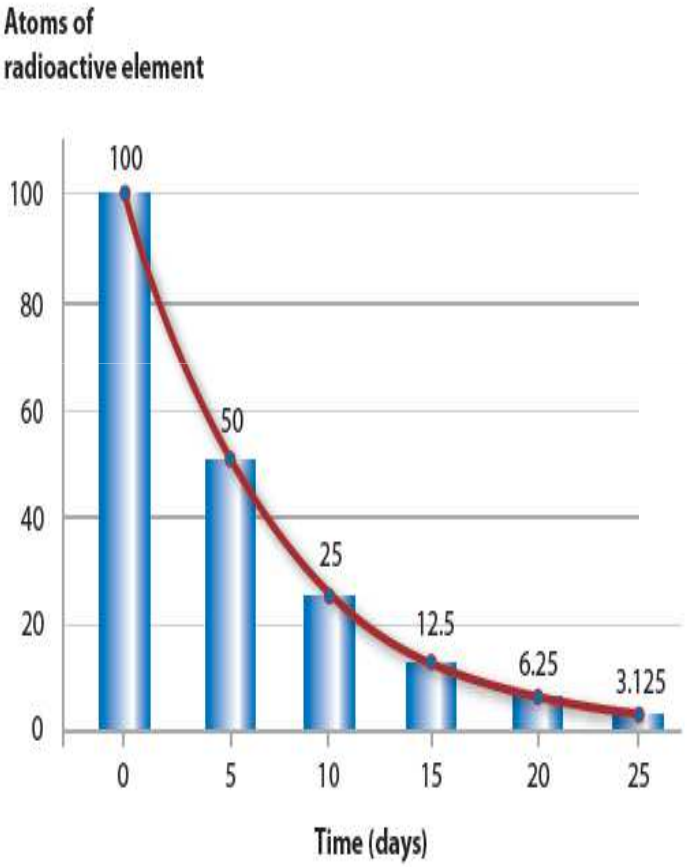
RESPONSIBLE USE

PRINCIPLE 6 — LONG TERM COMMITMENT

"The use of nuclear energy should be based on a long term commitment."

- Acceptance of International legal requirements and instruments,
- National legal framework,
- Commitment on RAW and SF management.

Radioactive Wastes

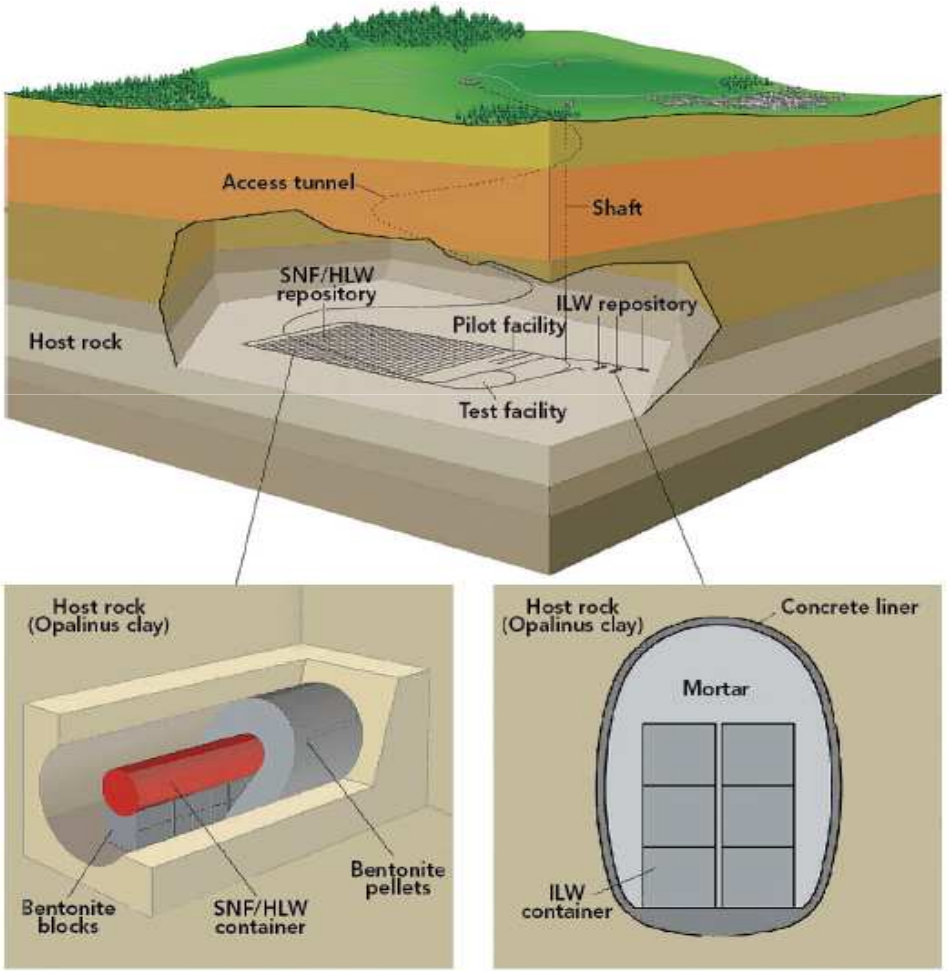


Isotope	Approximate half-life
Strontium-90	29 years
Cesium-137	30 years
Americium-241	430 years
Americium-243	7 400 years
Plutonium-239	24 000 years
Technetium-99	213 000 years

Waste type	Once-through fuel cycle	Recycling fuel cycle
LLW/ILW	50-100	70-190
HLW	0	15-35
SNF	45-55	0

Source: European Commission, *Radioactive Waste Management in the European Union* (1998).

High level waste

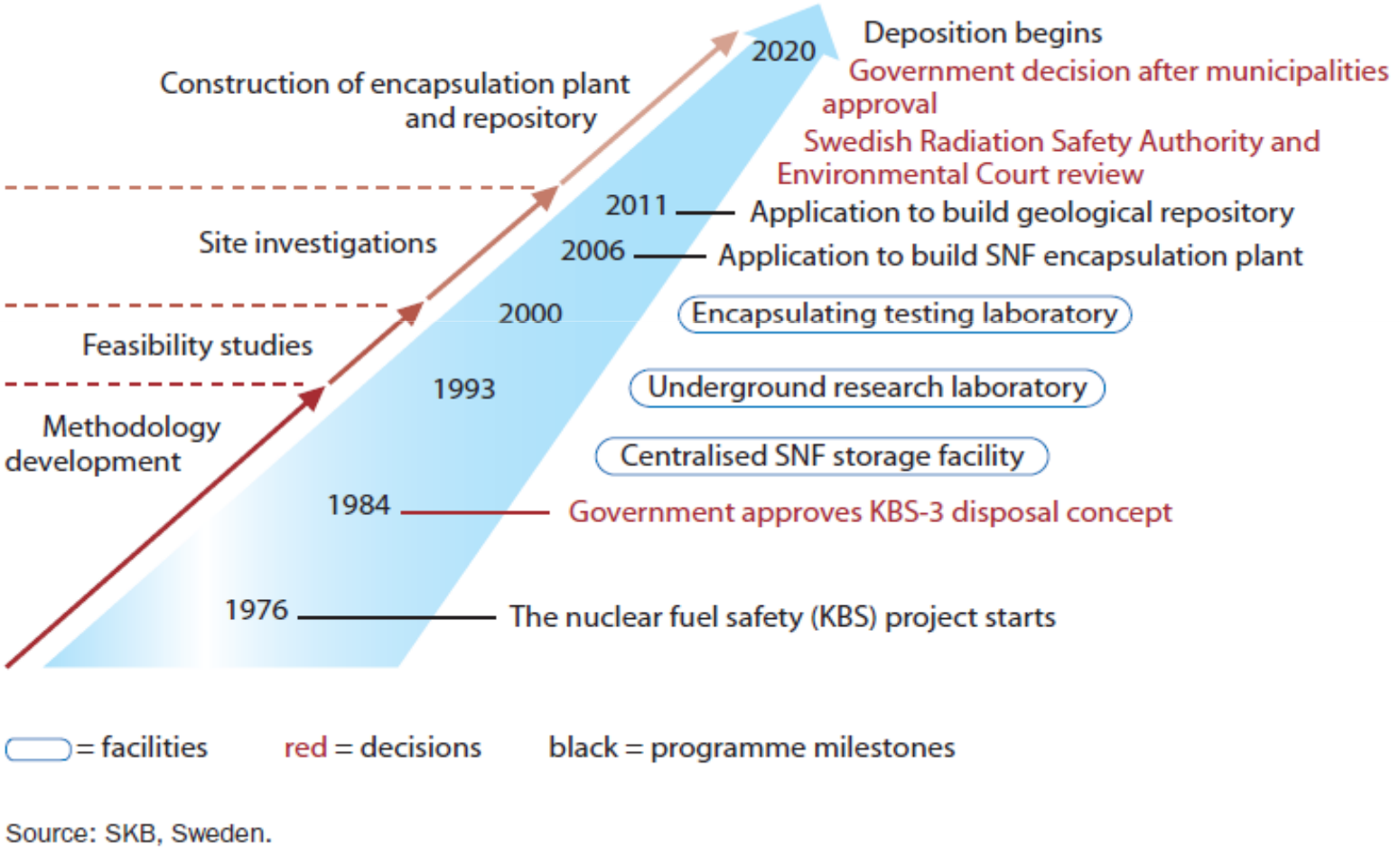


Emplacement drift for SNF/HLW

Emplacement tunnel for ILW

Note: Based on the Swiss concept.
Source: Nagra.

When and How



Source: SKB, Sweden.

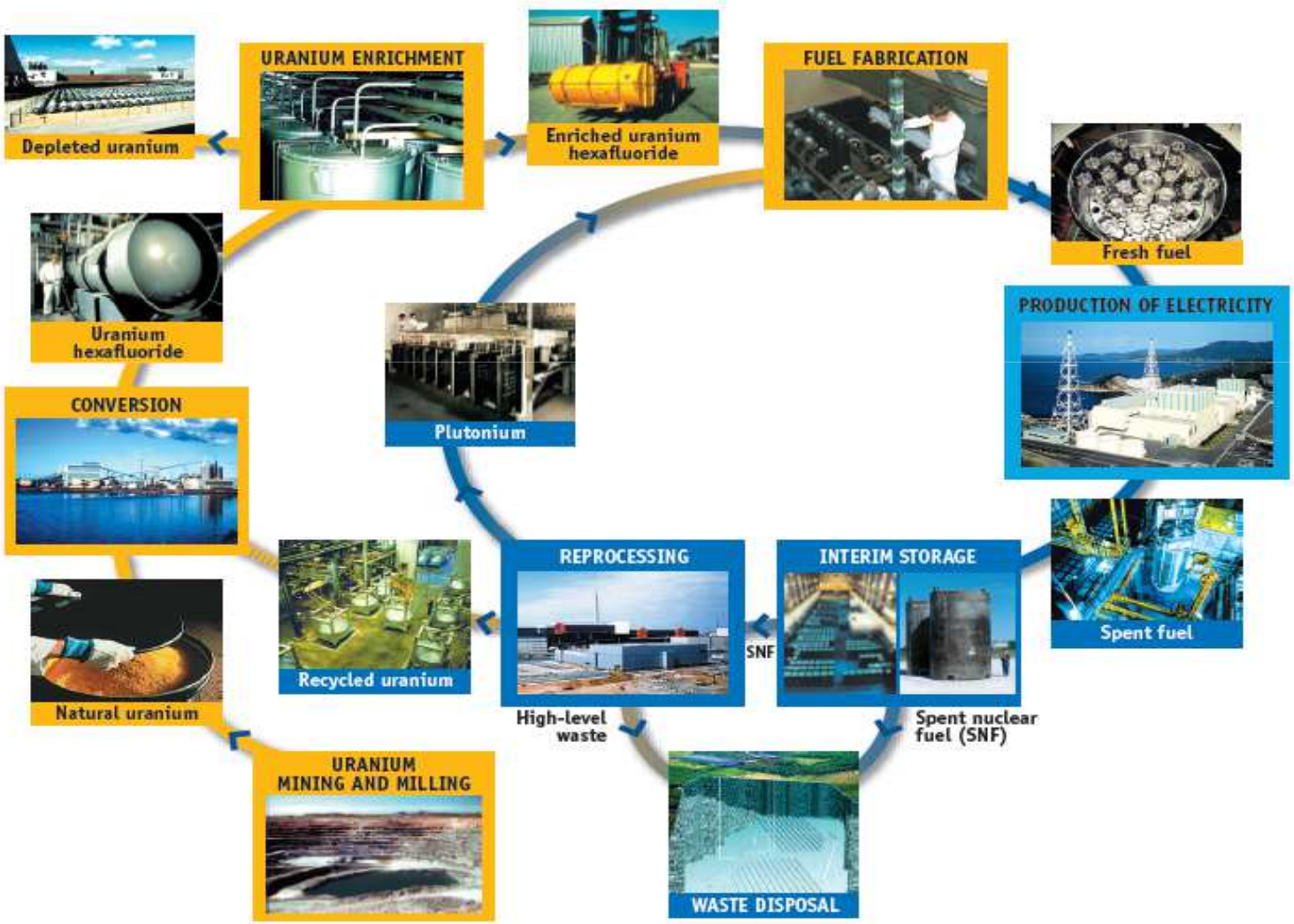
SUSTAINABLE USE

PRINCIPLE 7 — RESOURCE EFFICIENCY

"The use of nuclear energy should be efficient in using resources."

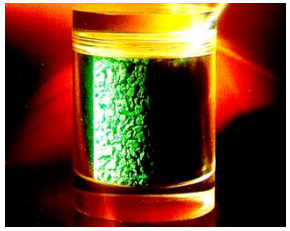
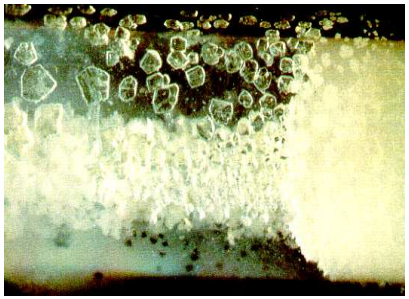
- ***Efficient management of materials***
- ***Efficient management and renewal of fuel resource***
- ***Efficient management and renewal of knowledge***

The Fuel Cycle



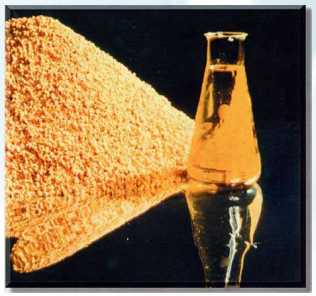
Nuclear Materials










Uranium

	Uranium production (tonnes)
Australia	5 918
Brazil	148
Canada	9 775
China	1 350
Czech Republic	254
India	400
Kazakhstan	17 803
Malawi	681
Namibia	4 503
Niger	4 197
Russia	3 562
South Africa	582
Ukraine	837
United States	1 630
Uzbekistan	2 874
Others	156
Total	**54 670**

	Site	Nominal capacity (tonnes U/yr)
Canada	Port Hope, Ontario	12 500
China	Lanzhou	3 000
France	Pierrelatte	14 000
Russian Federation	Irkutsk and Seversk	25 000
United Kingdom	Springfields	6 000
United States	Metropolis, Illinois	15 000

Source: WNA, 2011.

Enrichment capacity

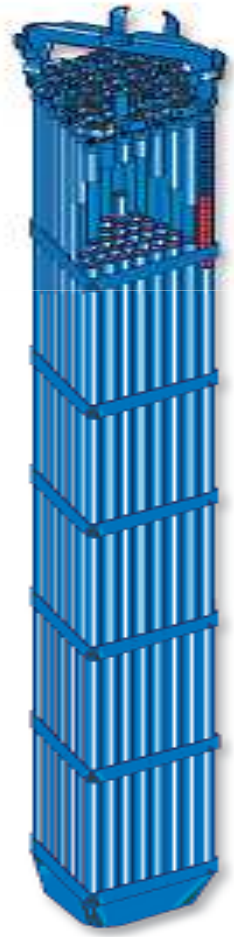
Country	Supplier	Site	Nameplate capacity 2010 (tSWU/yr)	Effective supply 2010 (tSWU/yr)	Planned capacity 2015 (tSWU/yr)
Operational centrifuge plants					
China	CNNC	Hanzhun and Lanzhou	1 300	1 300	3 000
Germany, Netherlands, United Kingdom	URENCO	Gronau (D), Almelo (NL), Capenhurst (UK)	12 800	12 800	12 300
Japan	JNFL	Rokkasho	Refurbishment	0	150
Russian Federation	ROSATOM/TVEL	Angarsk, Novouralsk, Zelenogorsk and Seversk	28 600	24 350	30 000
United States	URENCO	Eunice, New Mexico	Test operation	–	5 700
Gaseous diffusion plants, expected to close before 2015					
France	AREVA	Georges Besse	10 800	8 500	Closed
United States	USEC	Paducah, Kentucky	11 300	6 000	Undecided
New centrifuge plants, expected to be in operation by 2015					
France	AREVA	Georges Besse II	Inaugurated Dec. 2010	–	7 000
United States	USEC	Piketon, Ohio	Under construction	–	1 000
United States	AREVA	Eagle Rock, Idaho	Planned*	–	–

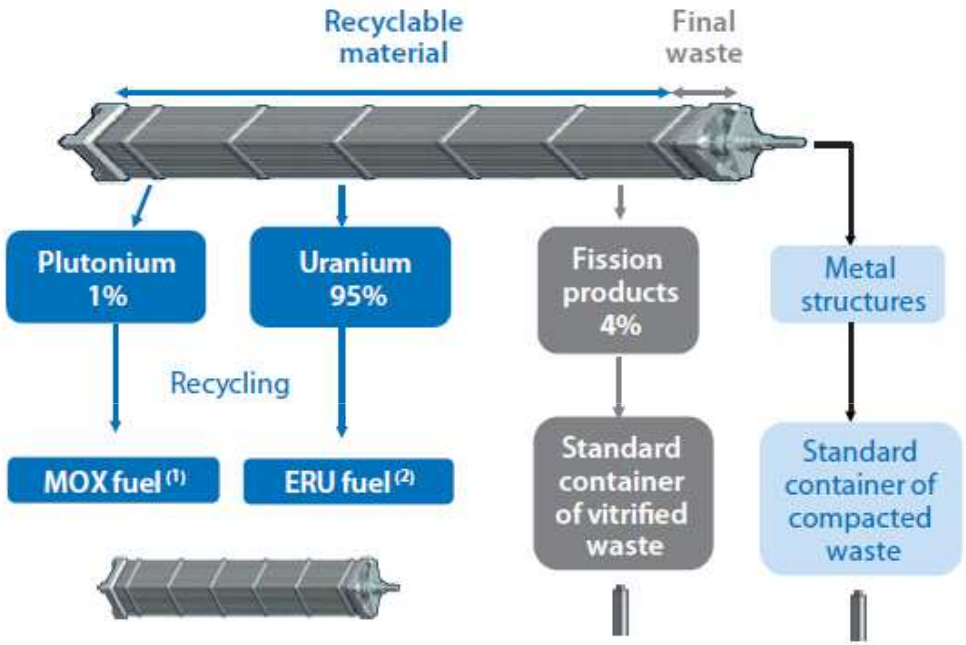
* Construction suspended in December 2011, AREVA press release.

Source: WNA, 2011.

MOX

Typical BWR fuel assembly
(about 4 m tall and about 15 cm on each side; weighs about 300 kg)





(1) MOX : mixed oxide.
(2) Enriched recycled uranium.
Source: AREVA.

	Site	Nominal capacity (tonnes U/yr)
France	La Hague	1 700
Japan	Rokkasho*	800
Russian Federation	Ozersk	400
United Kingdom	Sellafield	900

* In commissioning, start up expected in 2012.

Source: WNA.

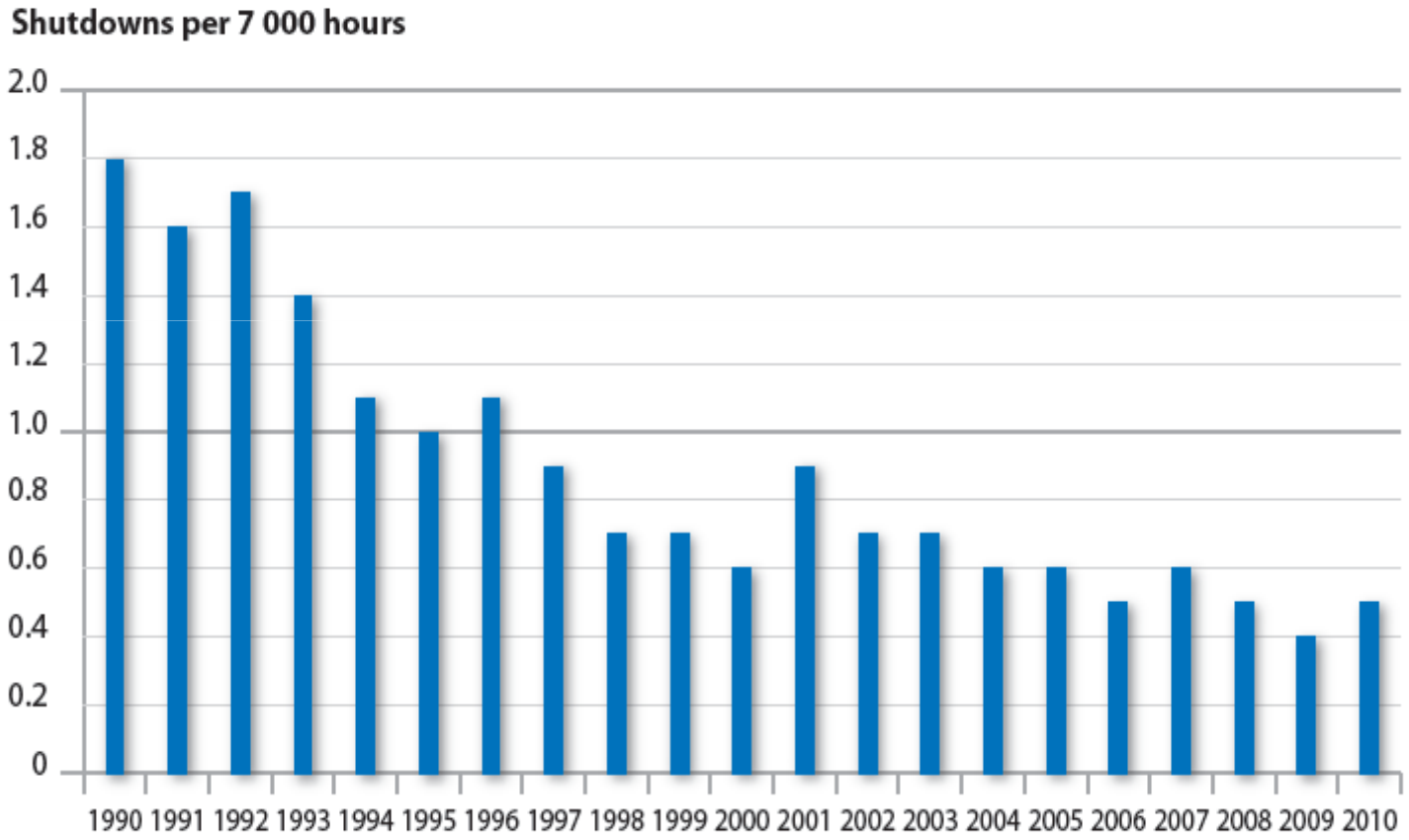
SUSTAINABLE USE

PRINCIPLE 8 — CONTINUAL IMPROVEMENT

"The use of nuclear energy should be such that it pursues advances in technology and engineering to continually improve safety, security, economics, proliferation resistance, and protection of the environment."

- Continuous improvement in technology, leadership and management,
- Continuous development and innovation.

Safety Performance



Source: WANO Performance Indicators.

Technology innovation

Generation I

Early prototype reactors

- Shippingport
- Dresden
- Magnox

Generation II

Commercial power reactors

- PWRs
- BWRs
- CANDU

Generation III

Advanced LWRs

- CANDU6
- System 80+
- AP600

Generation III+

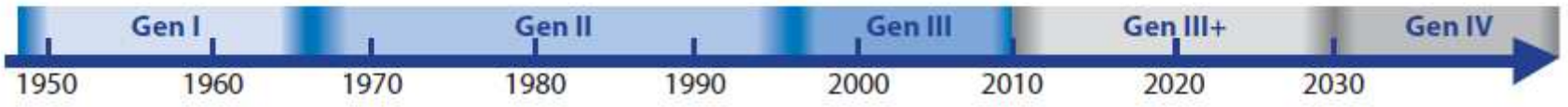
Evolutionary designs

- ABWR
- ACR 1000
- AP 1000
- APWR
- EPR
- ESBWR

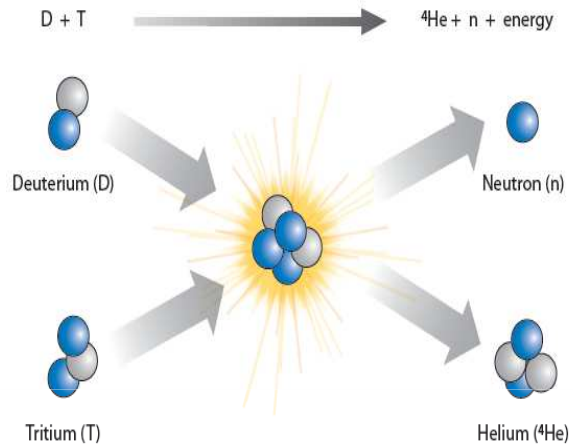
Generation IV

Revolutionary designs

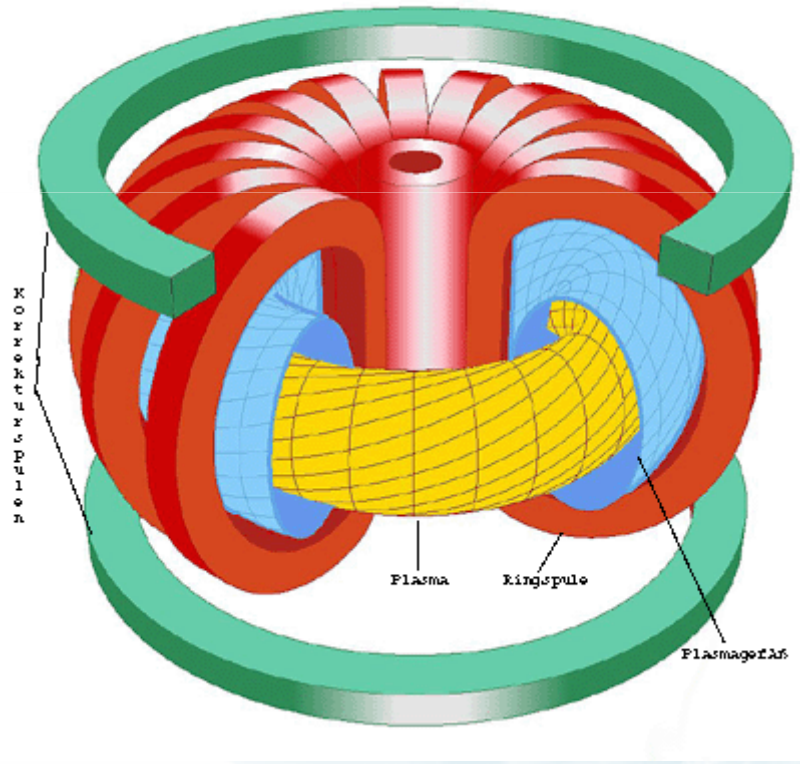
- Enhanced safety
- Minimisation of waste and better use of natural resources
- More economical
- Improved proliferation resistance and physical protection



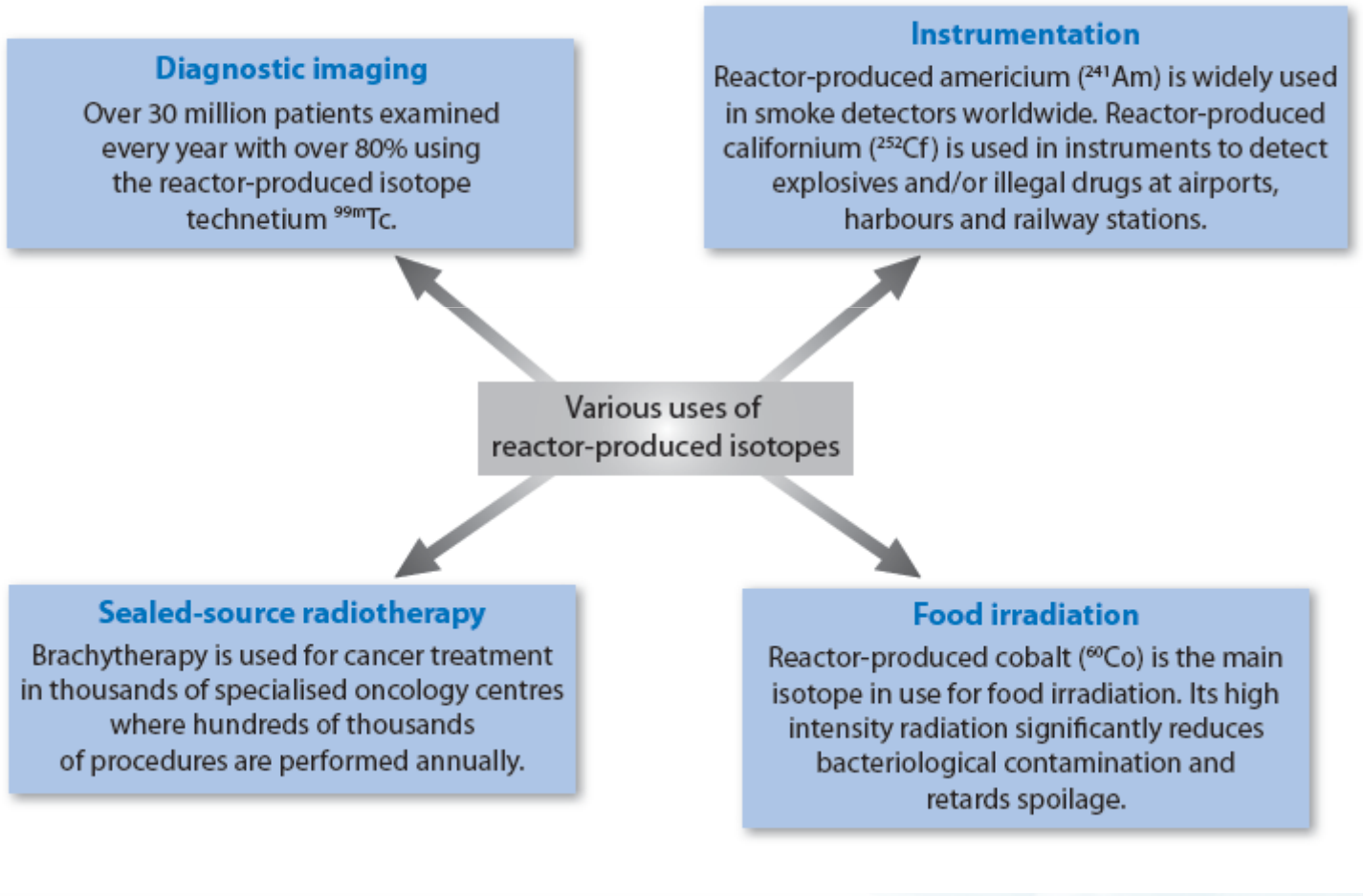
Fusion?



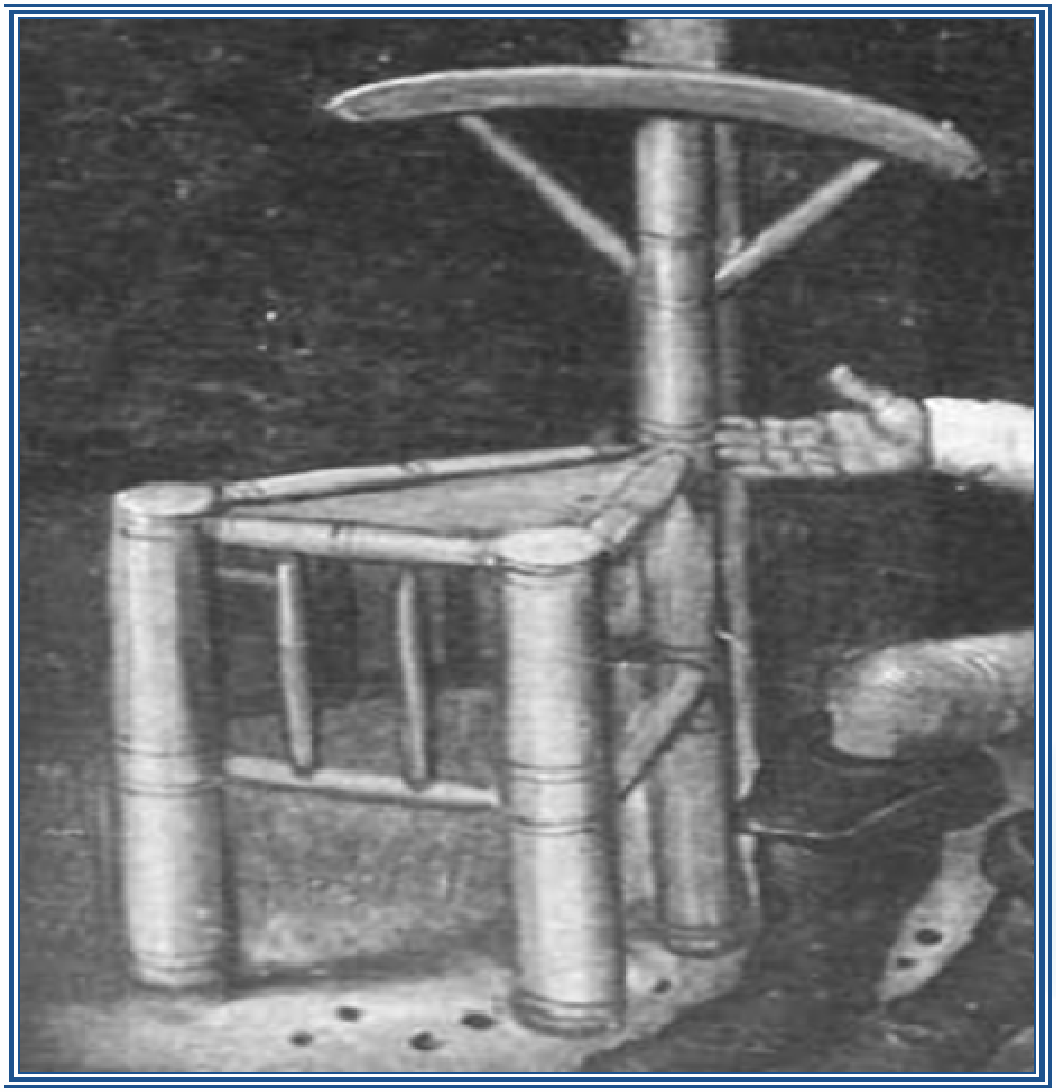
Source: Joint European Torus.



Humanitarian objectives



Questions



Remember
the Balance.