GEN IV International Forum[SM]
Expertise | Collaboration | Excellence

Introduction to Nuclear Reactor Design

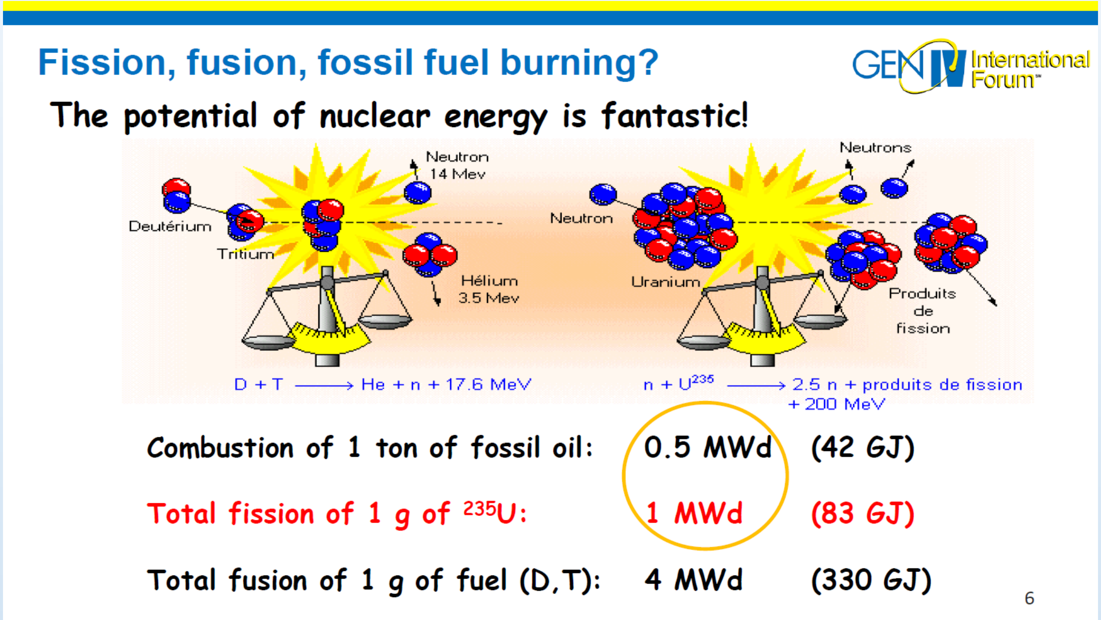
Summary / Objectives:

Why is a 4th generation of nuclear reactors needed? And what are the most promising reactor technologies? The GIF initiative has led to reconsider some of the options adopted in the past and stimulated the investigation of new tracks for long term sustainable nuclear energy. To grasp the rationale for selecting Generation IV reactor systems, and their main characteristics, requires some basic knowledge in the fundamentals of nuclear reactor design. What is behind the terms "criticality," "breeding," and "fast or thermal neutrons"? How to select the coolant, moderator, neutron spectrum, fuel materials and composition and to choose the ad hoc combinations to design nuclear reactors in line with Generation IV criteria, in particular sustainability? This is the objective of this rather technical webinar targeting civil society stakeholders.

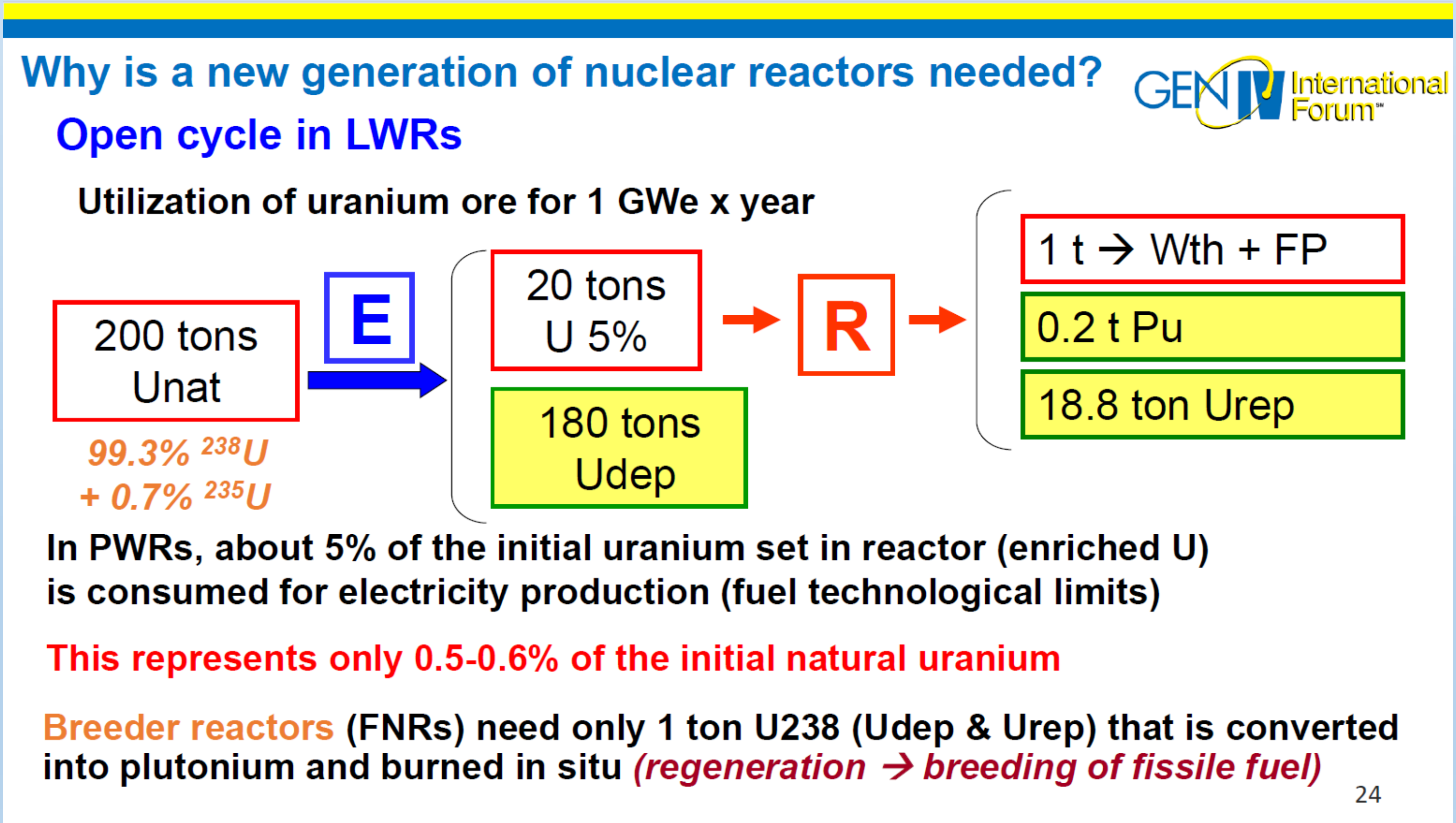
Meet the Presenter:

Dr. Claude Renault has been working at CEA for more than 30 years in R&D and E&T. He is a senior expert at CEA and professor. In 2010, he joined the INSTN where he is currently the International Project Leader. His expertise and teaching experience mainly cover thermal-hydraulics, design and operation of nuclear reactors, including the different families of reactors in particular the concepts of 4th generation. Claude Renault came to CEA in 1984 in the development team of CATHARE, the reference CEA-EDF-AREVA-IRSN computer code for the simulation of accidental transients in Pressurized Water Reactors (PWR). He was subsequently responsible, at national and international level, for several R&D projects in the areas of severe accidents (ASTEC) and nuclear fuel behavior (PLEIADES).
Between 2001 and 2009, he was heavily involved in R&D programs devoted to future nuclear reactors. He intervened at the Directorate of Nuclear Energy (CEA/DEN) in the definition and monitoring of research programs on the different concepts of 4th generation reactors. He chaired the Steering Committee of the Molten Salt Reactor in Generation IV.

Why Generation IV, especially fast reactors?



2,000,000 times energy from fission than fossil energy like coal, oil, gas.



200 tons U for 1GWe electricity in PWRs, **1 ton U238** in FNRs.
EBR-1 , 1951 USA Idaho: Uranium metal fuel and NaK primary coolant, Fast neutron power reactor.
(BORAX-III, 1955 Thermal neutron power reactor for BWR type.)

What is the condition for self-sustained reaction?

A necessary condition for criticality is that the reproduction factor η is significantly larger than 1

$$k = \frac{\bar{\nu}\frac{\Sigma_f}{\Sigma_a}}{1 + \frac{AR_{other} + LR}{AR_{fuel}}}$$

Reproduction factor η for uranium fuel (fissile fraction e):

Fissile fraction e	0.71 % (U nat)	3 %	10 %	15 %	100 %
For fast neutrons	0.10	0.35	0.85	1.07	1.88
For « thermal » neutrons	1.33	1.84	2.00	2.02	2.07

The chain reaction is not possible with natural uranium <u>and</u> fast neutrons.

Therefore 2 solutions:

- **to <u>slow down neutrons</u> (criticality possible whatever the fissile content, Unat possible for strict neutron economy)**
  → ***Thermal Neutrons Reactors, TNR* (PWR, BWR, CANDU,…)**
- **to use fast neutrons and subsequently increase the fissile fraction in the fuel**
  → ***Fast Neutrons Reactors, FNR***

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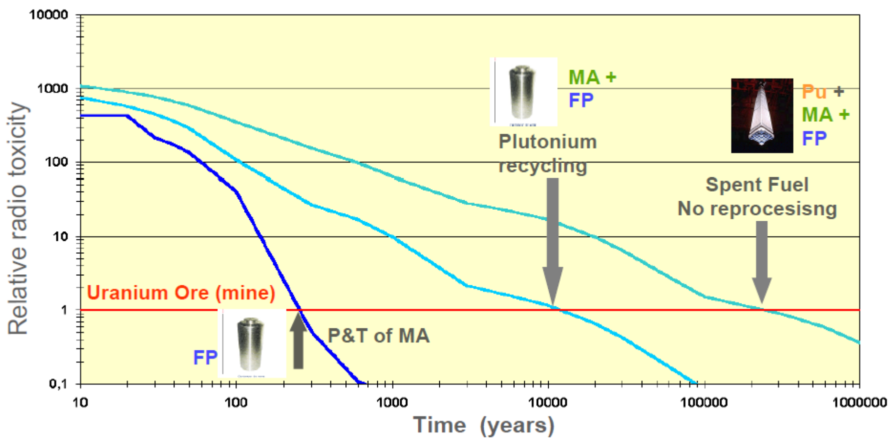
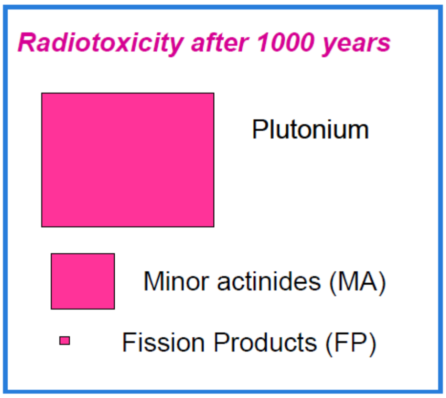
Adequate fissile fraction for thermal neutron reactors and fast neutron reactors.

Why Fast Neutron Reactors?
The waste management issue

- Plutonium is the major contributor to the long term radiotoxicity of spent fuel → ***Plutonium recycling***
- After plutonium, MA (Am, Cm, Np) have the major impact to the long term radiotoxicity → ***MA transmutation***





The ratio fission/capture is favourable to MA fission with fast neutrons

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Comparison of radiotoxicity in spent fuel after 1000 years.
Pu for recycling, MA for transmutation.

Nuclear reactors today

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General characteristics of nuclear reactors in operation

Reactor type	Fuel type	Moderator	Coolant	Core power density (MW/m^3)	Pressure (bar)	Temperature (°C)	Efficiency (%)
UNGG	**Unat**	C	CO_2	1	41	400	30
Magnox							
PHWR		D_2O	D_2O	12	130	300	30
LWGR	**U 1-2%**	C	H_2O	2	70	284	31
AGR		C	CO_2	3	40	645	40
BWR	**U 3-5%**	H_2O	H_2O	50	72	288	37
PWR				100	155	330	35
FBR (FNR)	**Pu 20-30%**	-	Na	500	1	550	40

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	SFR	LFR	GFR	VHTR	SCWR	MSR	*PWR*
Neutron spectrum (T/F)	F	F	F	T	T/F?	T/F	*T*
Moderator	[illegible]	[illegible]	[illegible]	graphite	H_2O (or D_2O)	graphite (or none)	*H_2O*
Coolant	Na	Pb (or Pb-Bi)	He	He	H_2O	molten salt	*H_2O*
Fuel type	MOX (pins)	nitride (pins)	carbide	carbide (particles)	UOX, MOX	liquid fuel (U, Pu, Th)	*UOX, MOX*
Core outlet t° (°C)	550	500	850	> 900	550	700	*330*
Primary pressure (MPa)	0.1	0.3-0.4	7	5-8	25	0.1-0.2	*15.5*
Core power density (MW/m^3)	240	140	100	4-6	100	20-300	*100*

The values given in the table are fairly indicative!

The design of Gen IV systems is ongoing (R&D development work) 36

Comparison of core power density and plant parameters.

GIF and a new generation of nuclear systems

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Nuclear is a CO_2-free option for sustainable energy

New requirements for sustainable nuclear energy

Search innovative solutions for:

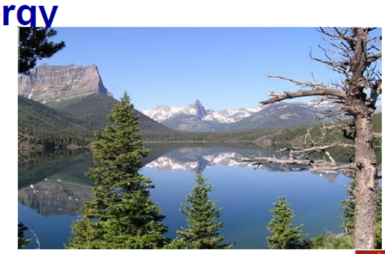
- Waste minimisation
- Natural resources conservation
- *Proliferation resistance*

Perform continuous progress on:

- Competitiveness
- Safety and reliability

Develop the potential for new applications:

hydrogen, syn-fuels, desalinated water, process heat



➔ Systems marketable from 2040 onwards

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