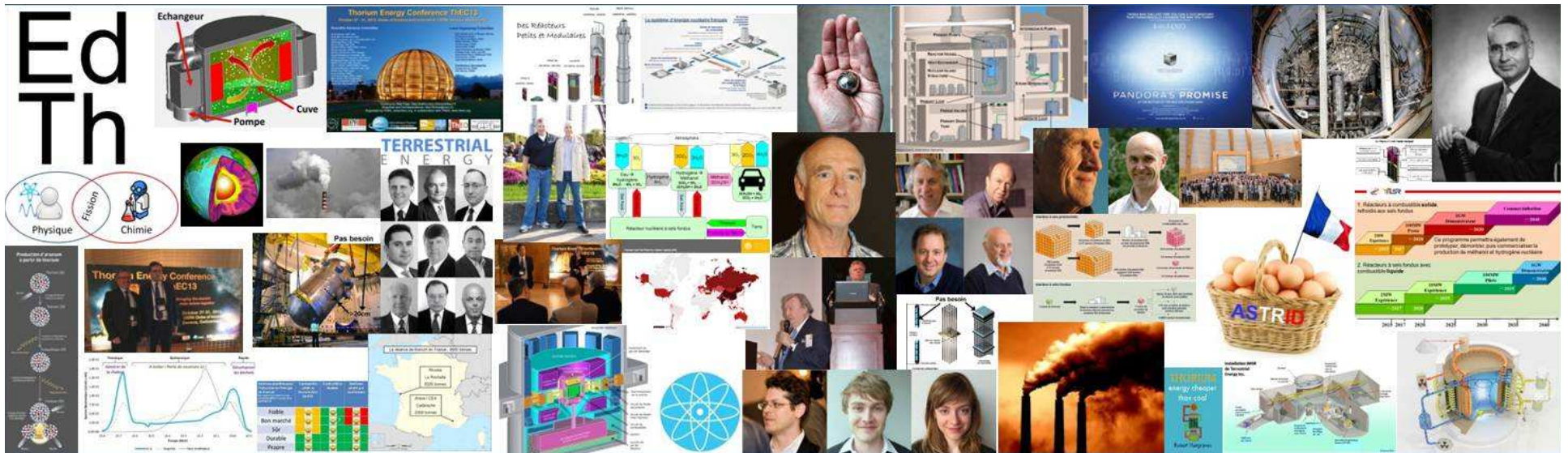


# La Voiture Nucléaire



John Laurie

<http://energieduthorium.fr>

Samedi 13 septembre 2014

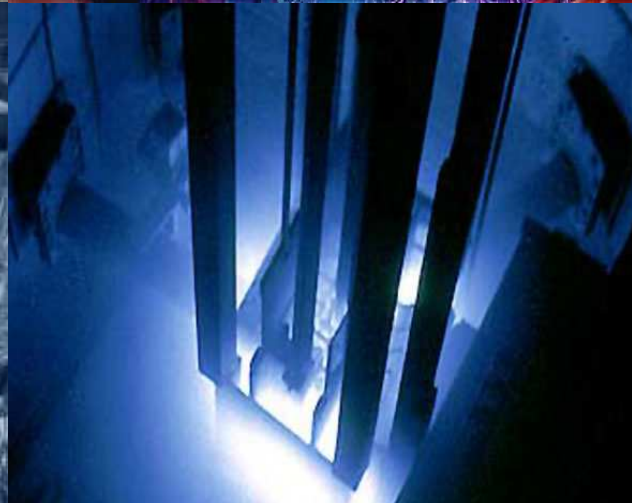
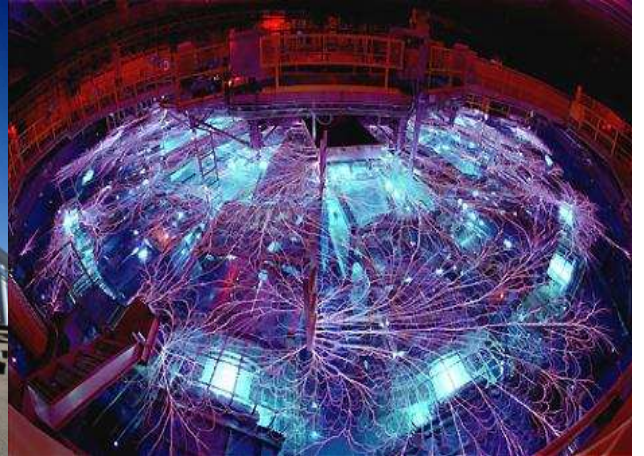


Car !









**FIABLE**

**BON MARCHÉ**

**SÛRE**

**DURABLE**

**PROPRE**



**FIABLE** 😊

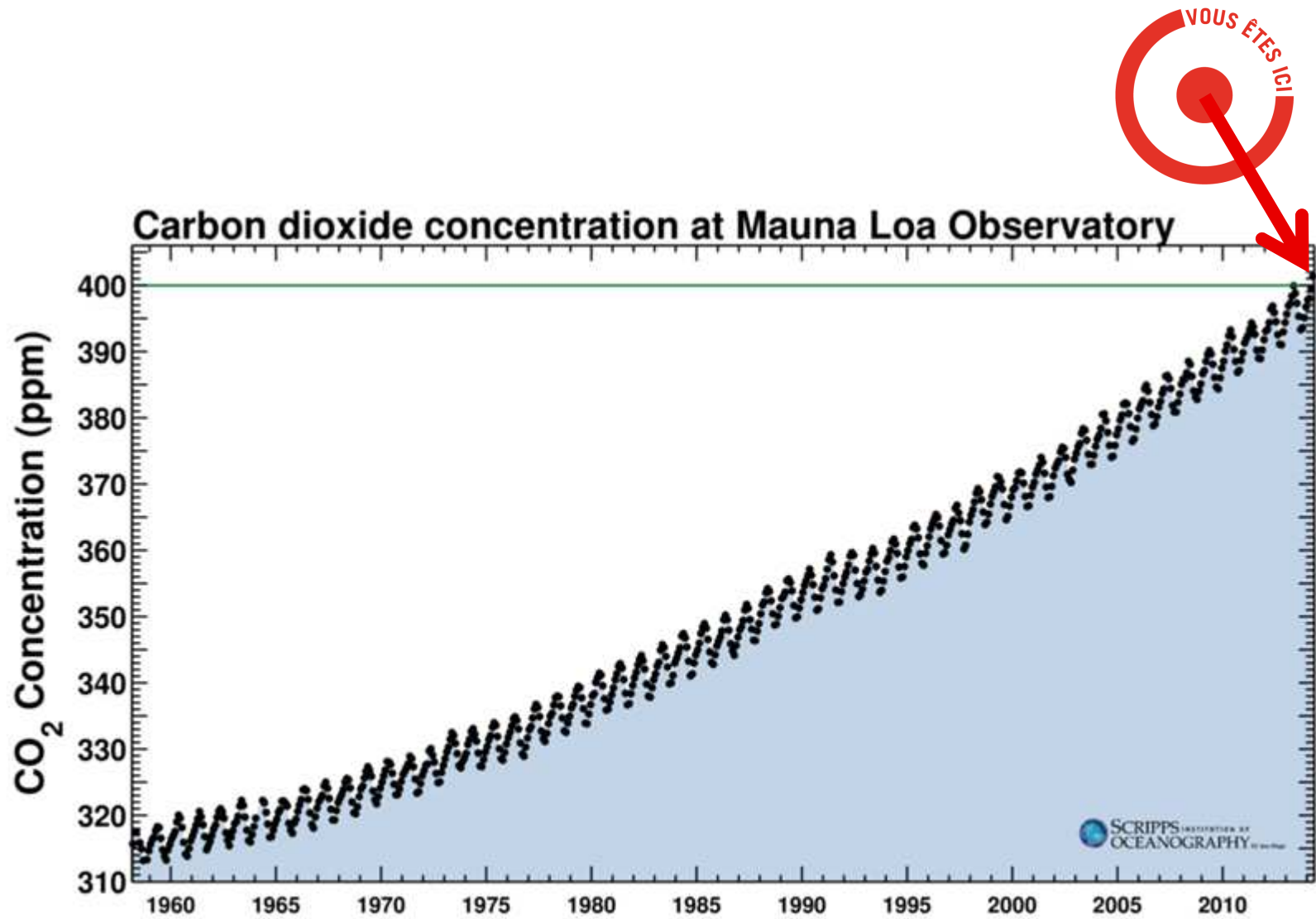
**BON MARCHÉ** 😊

**SÛRE** 😞

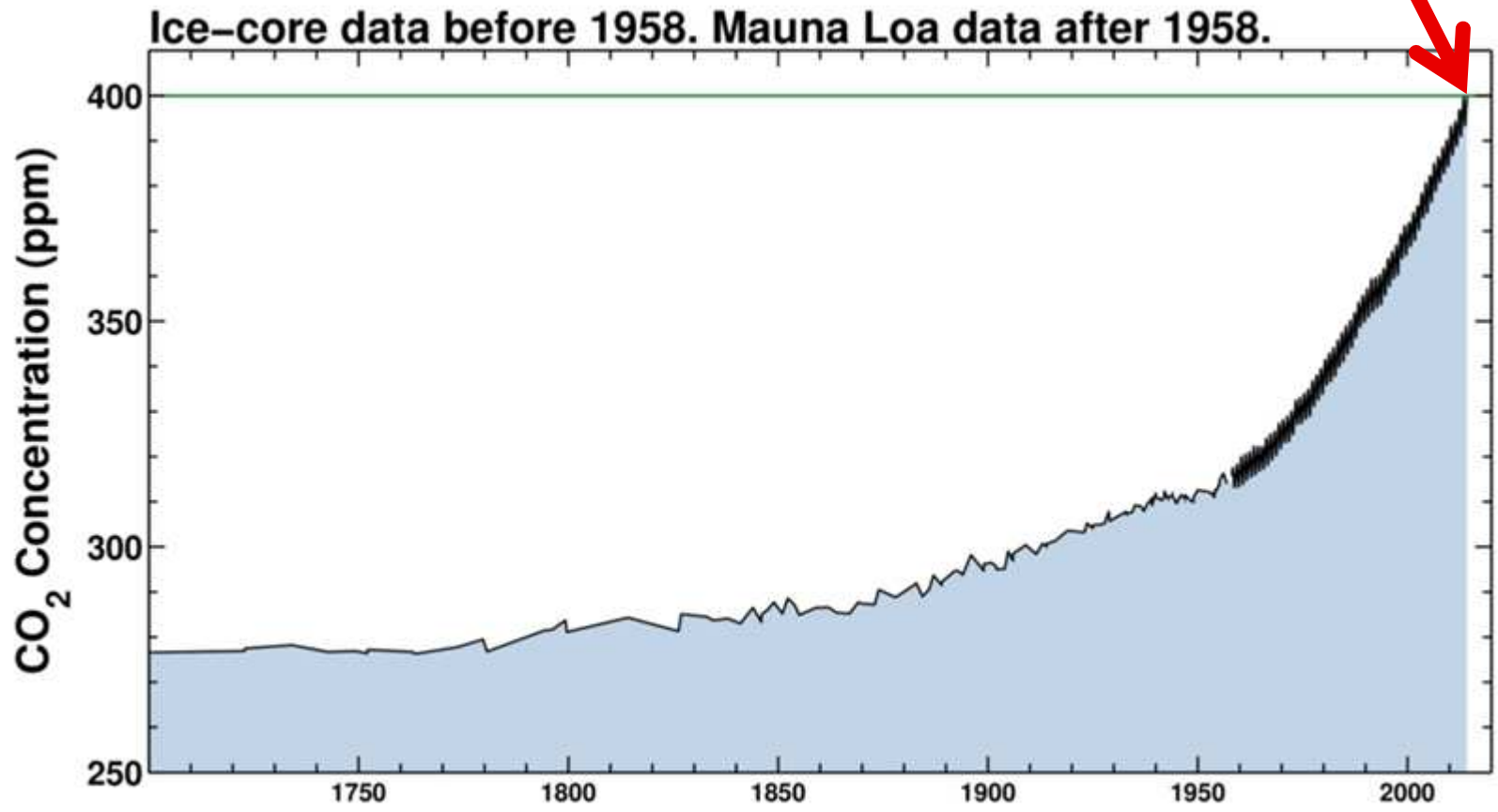
**DURABLE** 😞

**PROPRE** 😞

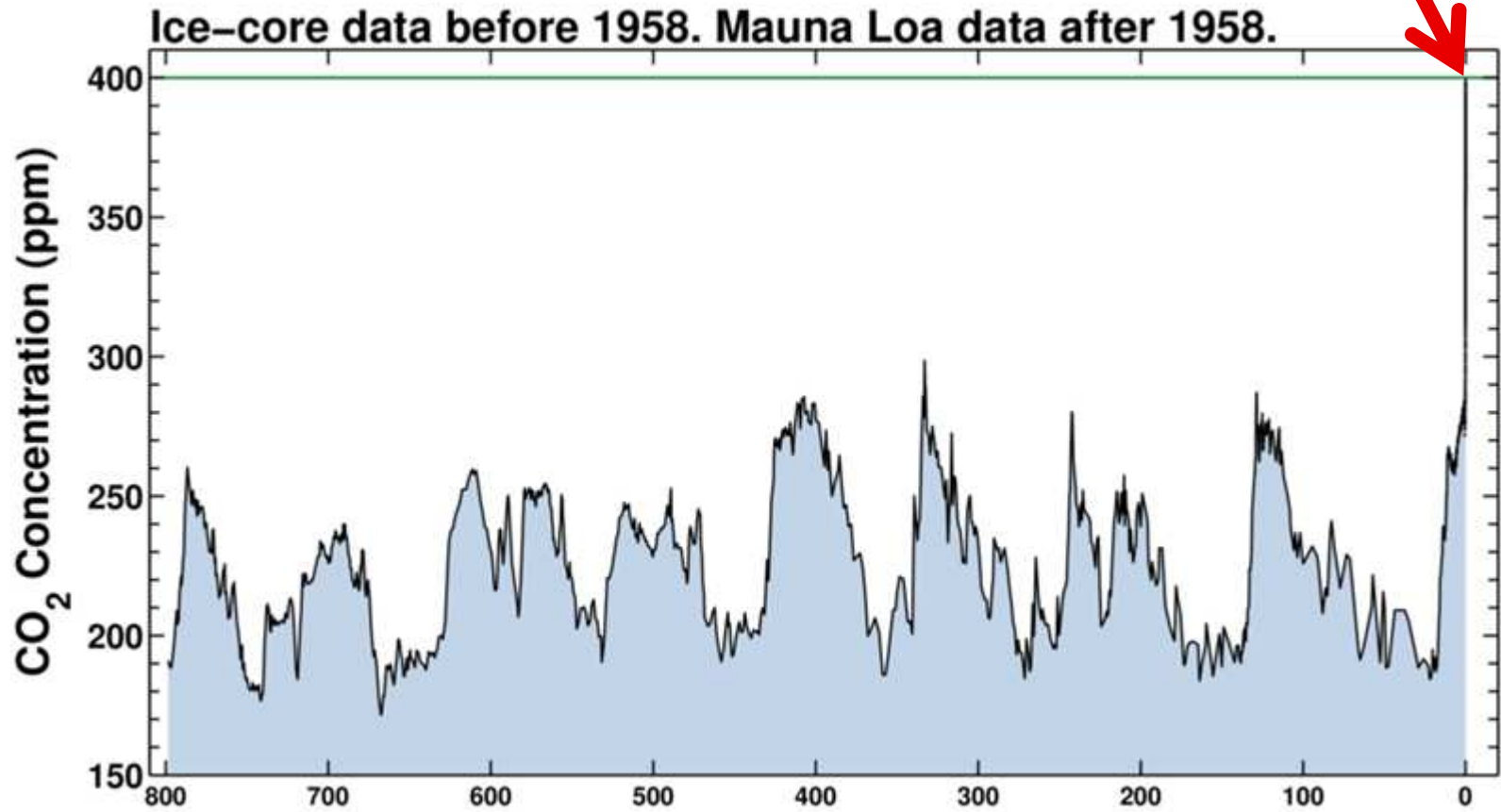




Source : [Keeling Curve](#)



Source : [Keeling Curve](#)

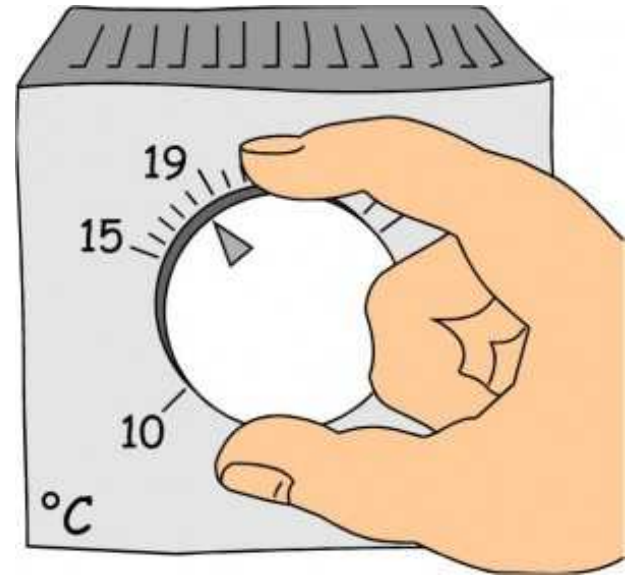


Source : [Keeling Curve](#)

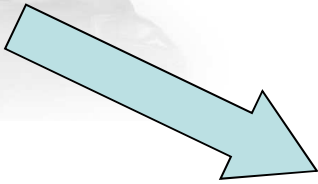
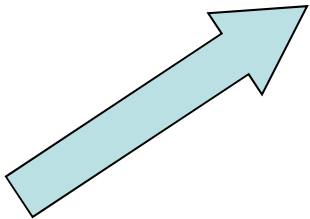


**NÉGA-WATTS**



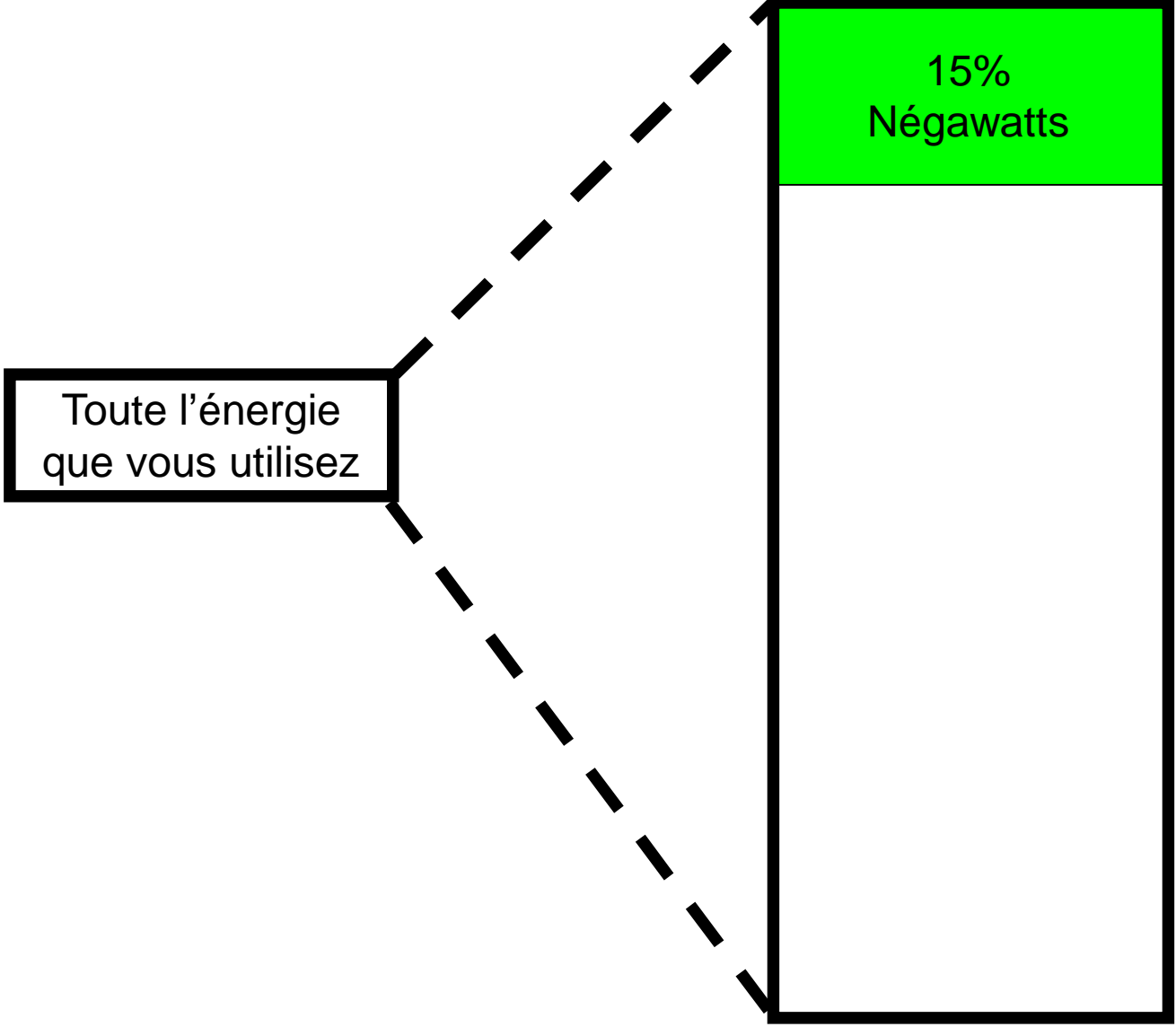














**FIABLE** 🙄

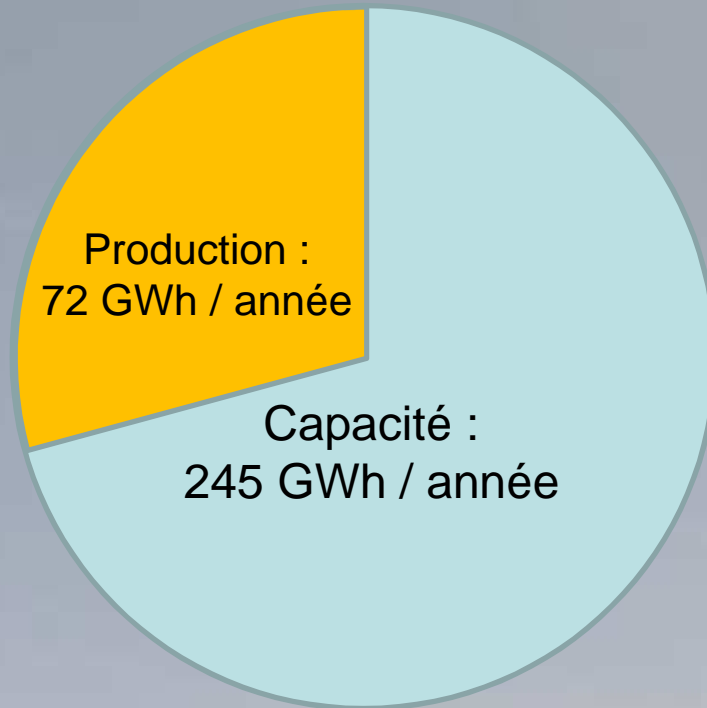
**BON MARCHÉ** 🙄

**SÛRE** 😊

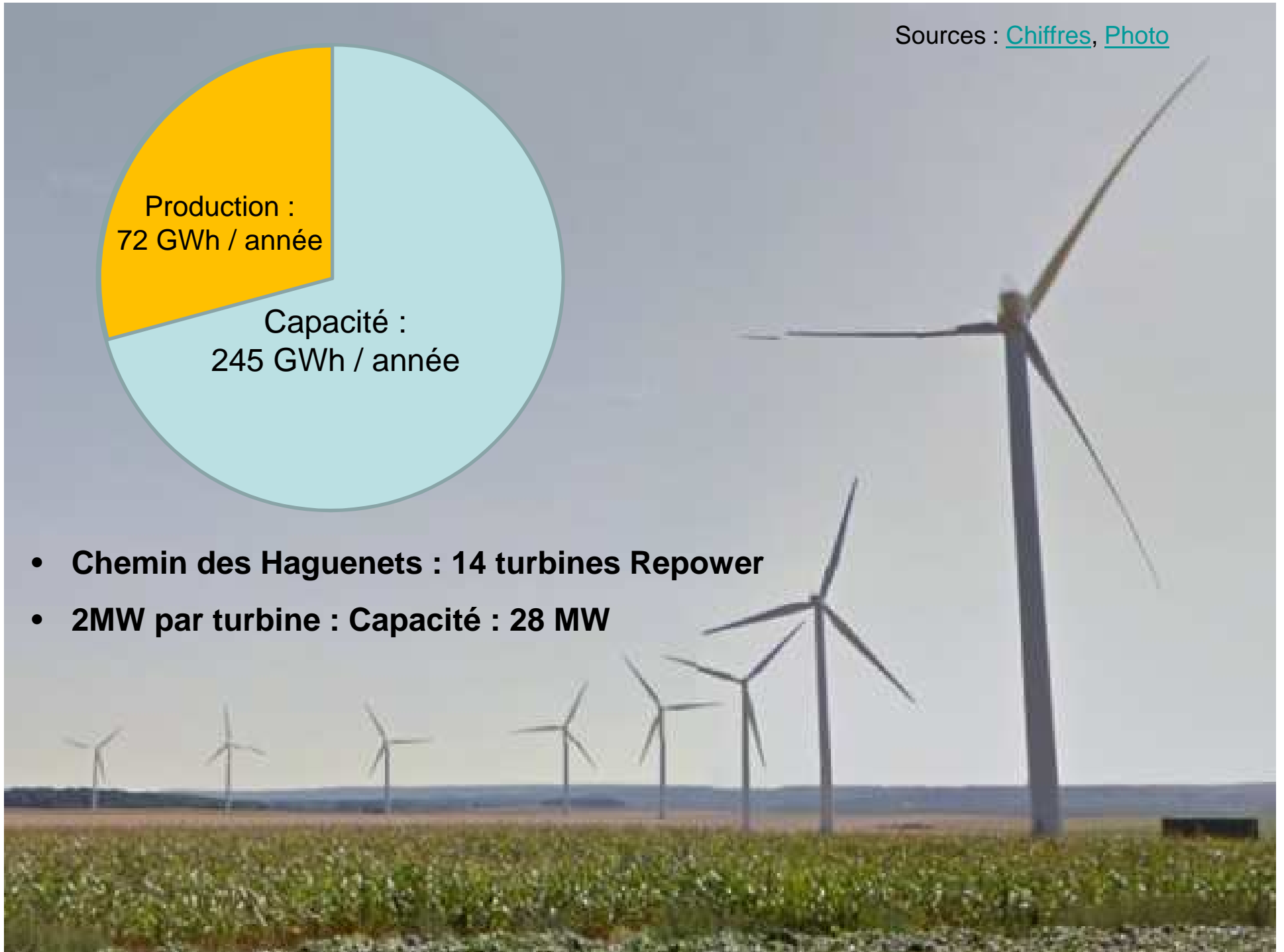
**DURABLE** 😊

**PROPRE** 😊

Sources : [Chiffres](#), [Photo](#)



- **Chemin des Haguenets : 14 turbines Repower**
- **2MW par turbine : Capacité : 28 MW**

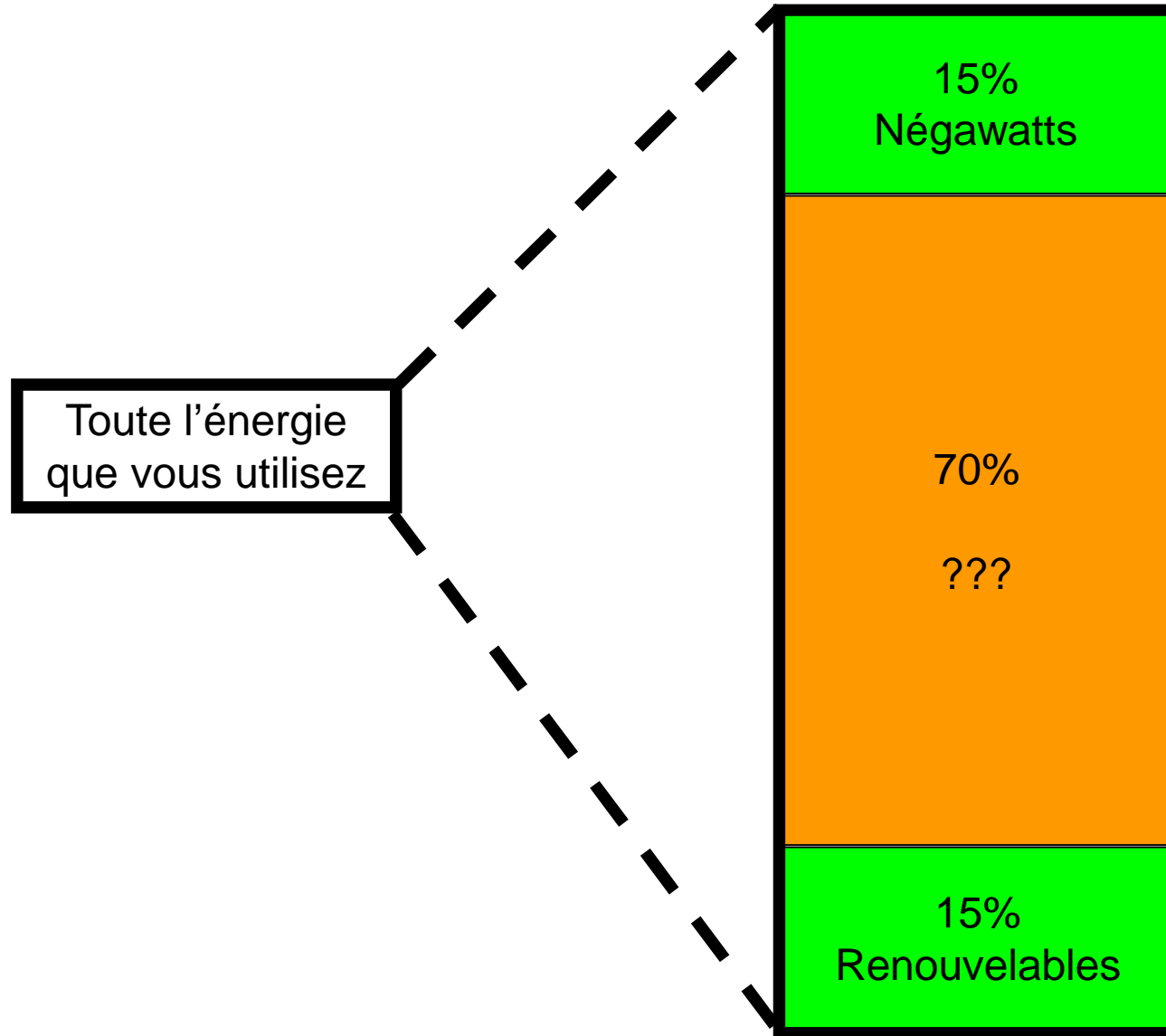


**INTERMITTENTE**

**DIFFUSE**

**CHÈRE**

# Le sandwich de l'énergie





**Zero EMISSION**

**( au point d'utilisation )**

Source : Autotest ADAC, Octobre 2013. Rapport complet .pdf (voir pages 10&12)



# Autotest



## ADAC-URTEIL



## Zielgruppencheck



Testverbrauch Schnitt pro 100 km

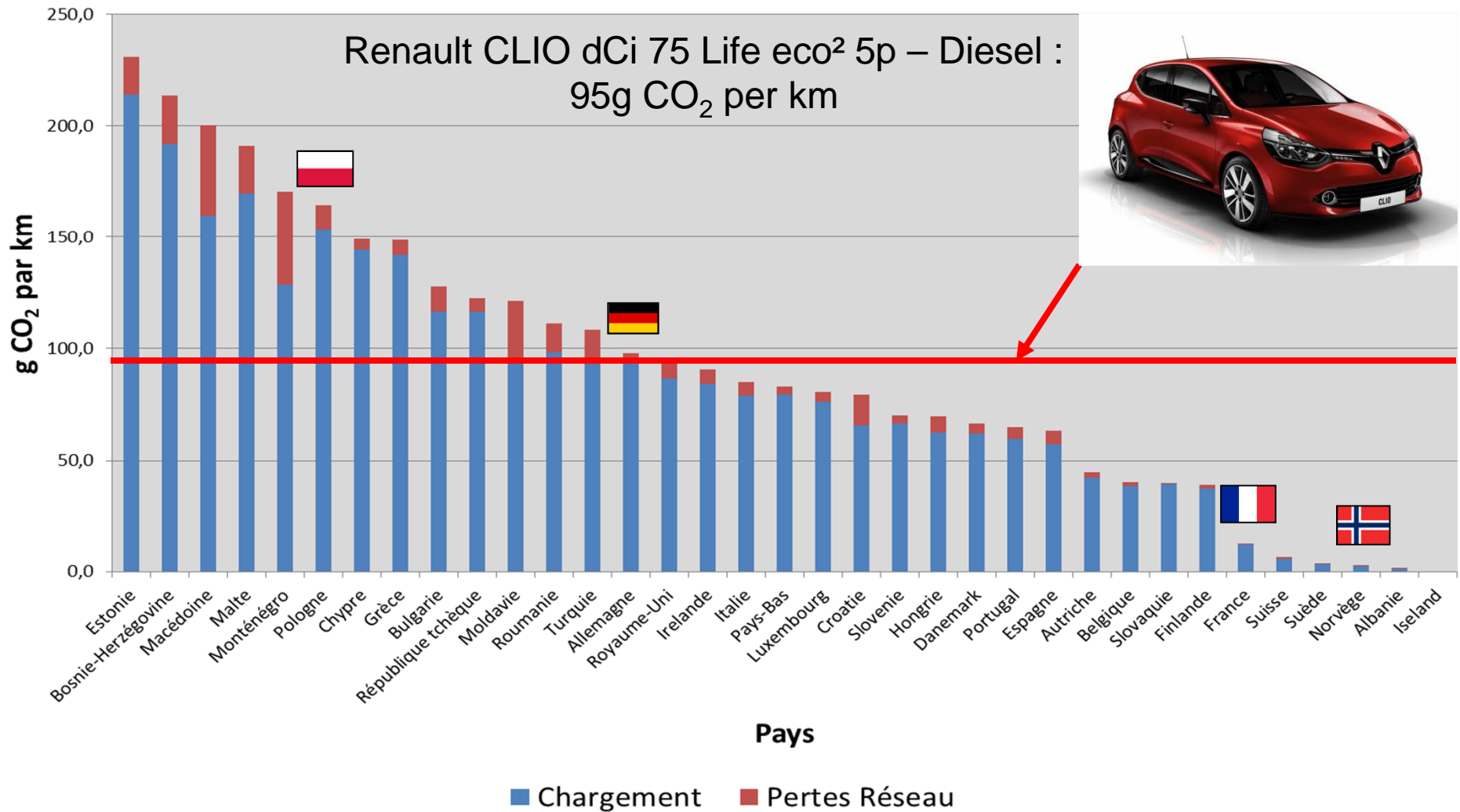
**19,7 kWh**

Testverbrauch pro 100 km Stadt/Land/BAB 14,0/17,0/28,3 kWh

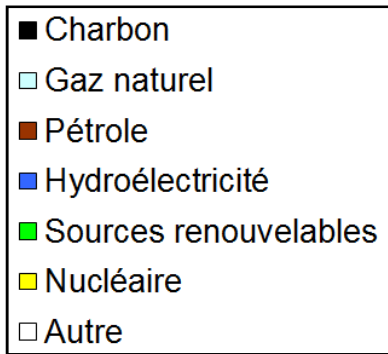


Sources : [CO2 par kWh \(IEA\)](#), [Pertes réseau](#), [ZOE](#), [CLIO](#), [Calcul et graphique](#)

### Renault ZOE : g CO<sub>2</sub> par km 2011 - Pays européens

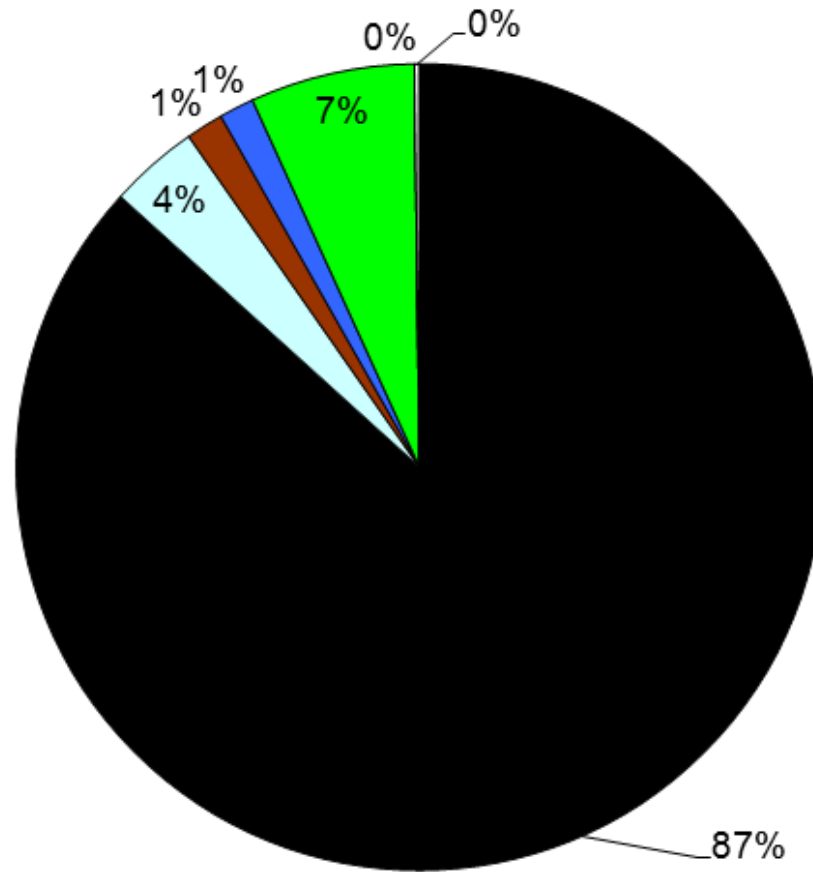






Pologne

Population : 38.544.513



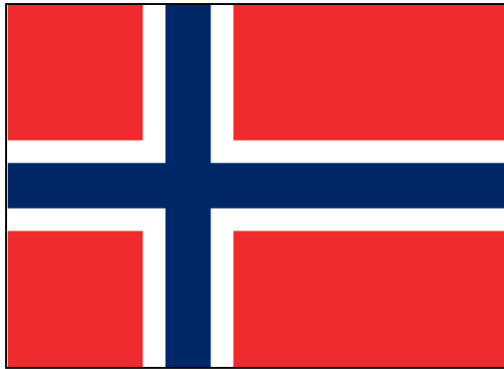
Source : [worldbank.org](http://worldbank.org)



Données pour 2011	Grammes CO2 / km
Génération	153,7
Pertes réseau (6,5%)	10,7
<b>Total</b>	<b>164,4</b>



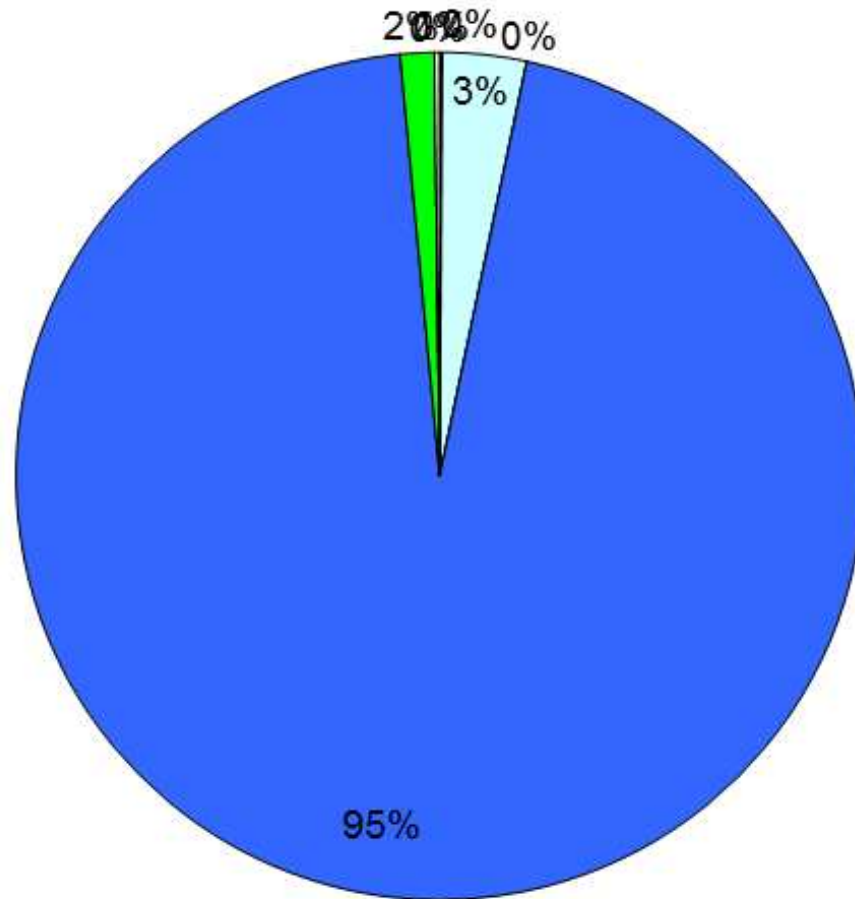
HOW ELECTRIC CARS WORK.



- Charbon
- Gaz naturel
- Pétrole
- Hydroélectricité
- Sources renouvelables
- Nucléaire
- Autre

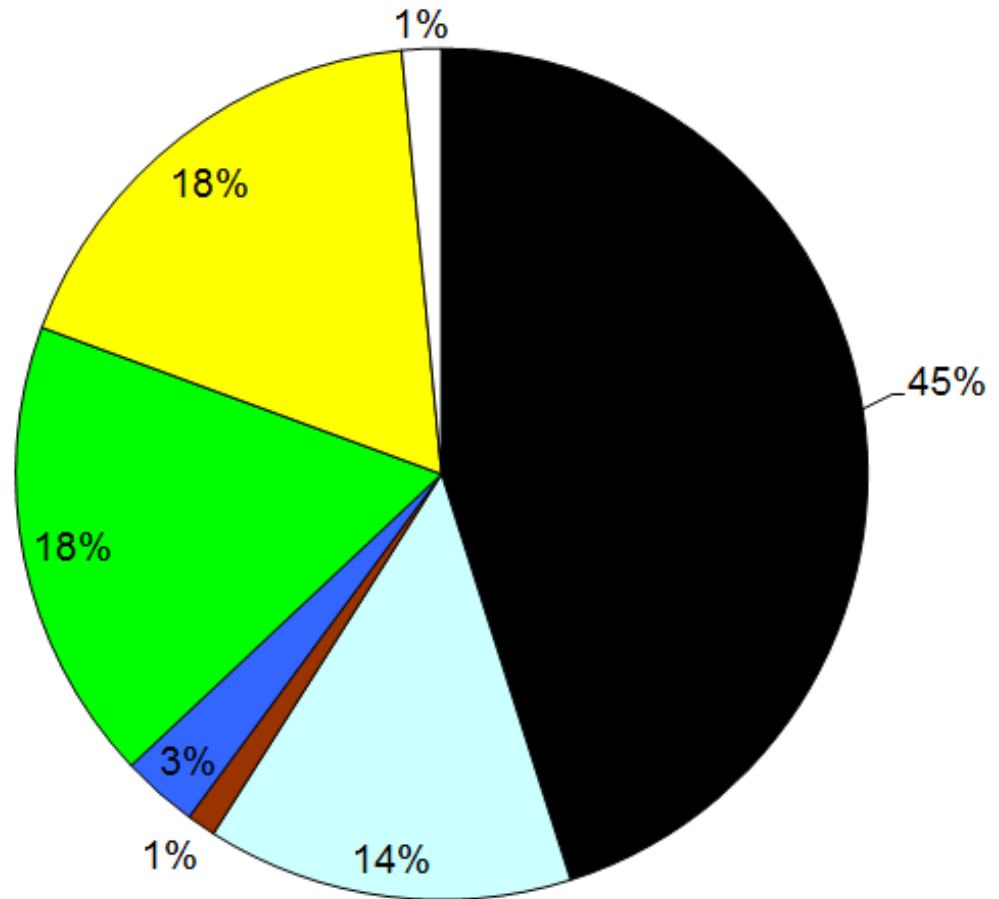
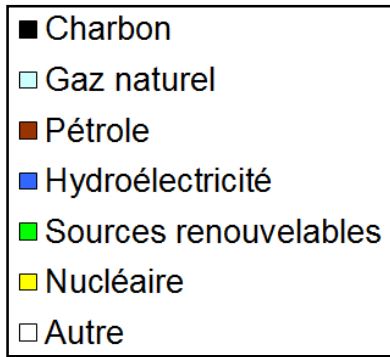
Norvège

Population : 5.063.709



Source : [worldbank.org](http://worldbank.org)

Données pour 2011	Grammes CO2 / km
Génération	2,6
Pertes réseau (8,1%)	0,2
<b>Total</b>	<b>2,8</b>



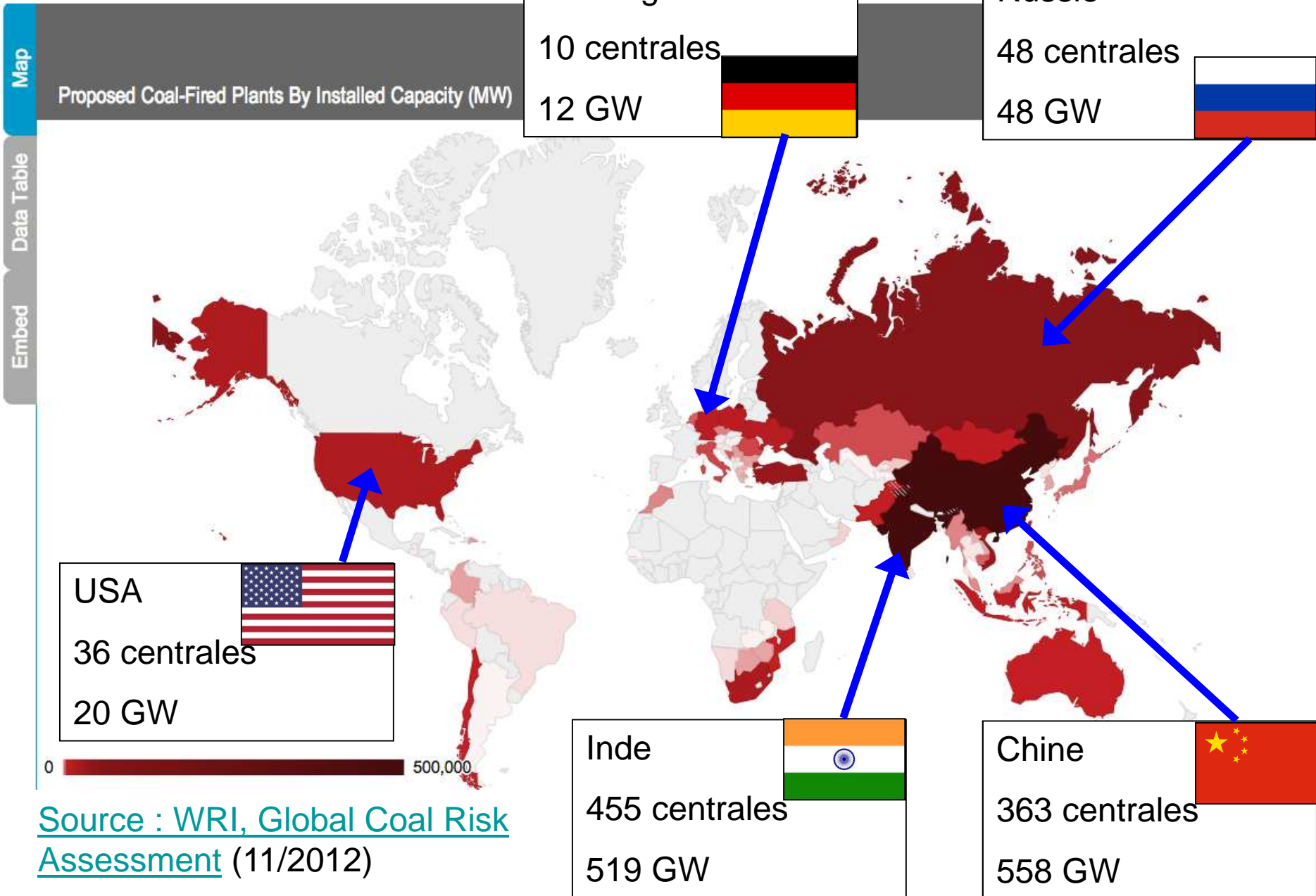
Source : [worldbank.org](http://worldbank.org)

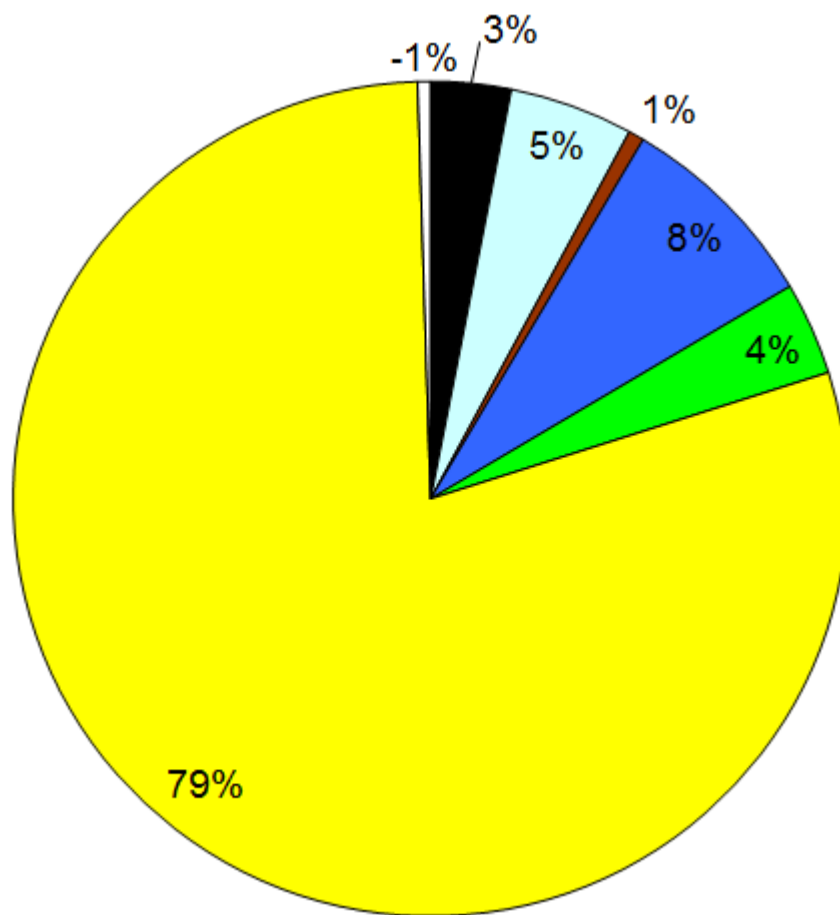
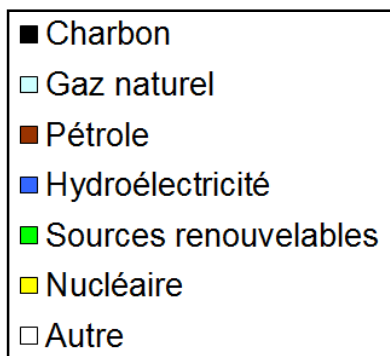
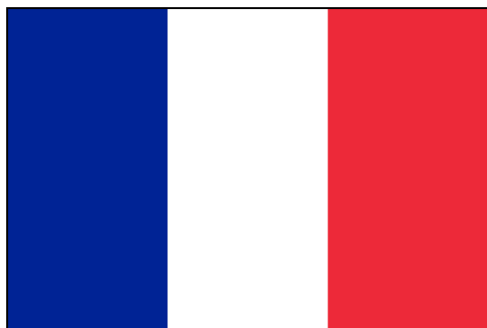
Allemagne

Population : 80.399.300



Données pour 2011	Grammes CO2 / km
Génération	94,0
Pertes réseau (4,3%)	4,2
<b>Total</b>	<b>98,2</b>





Source : [worldbank.org](http://worldbank.org)

France

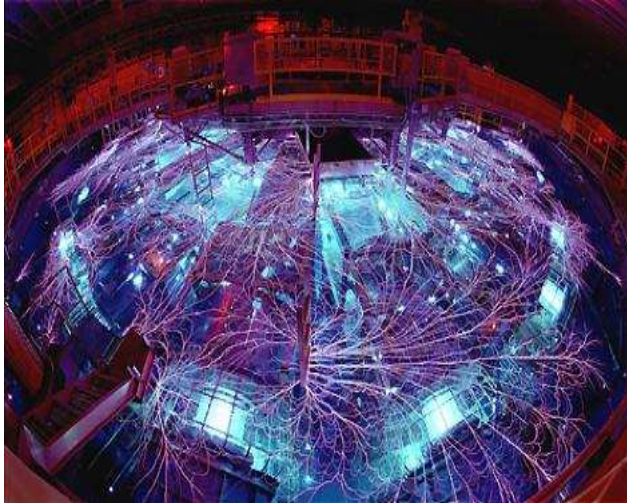
Population 65.350.000



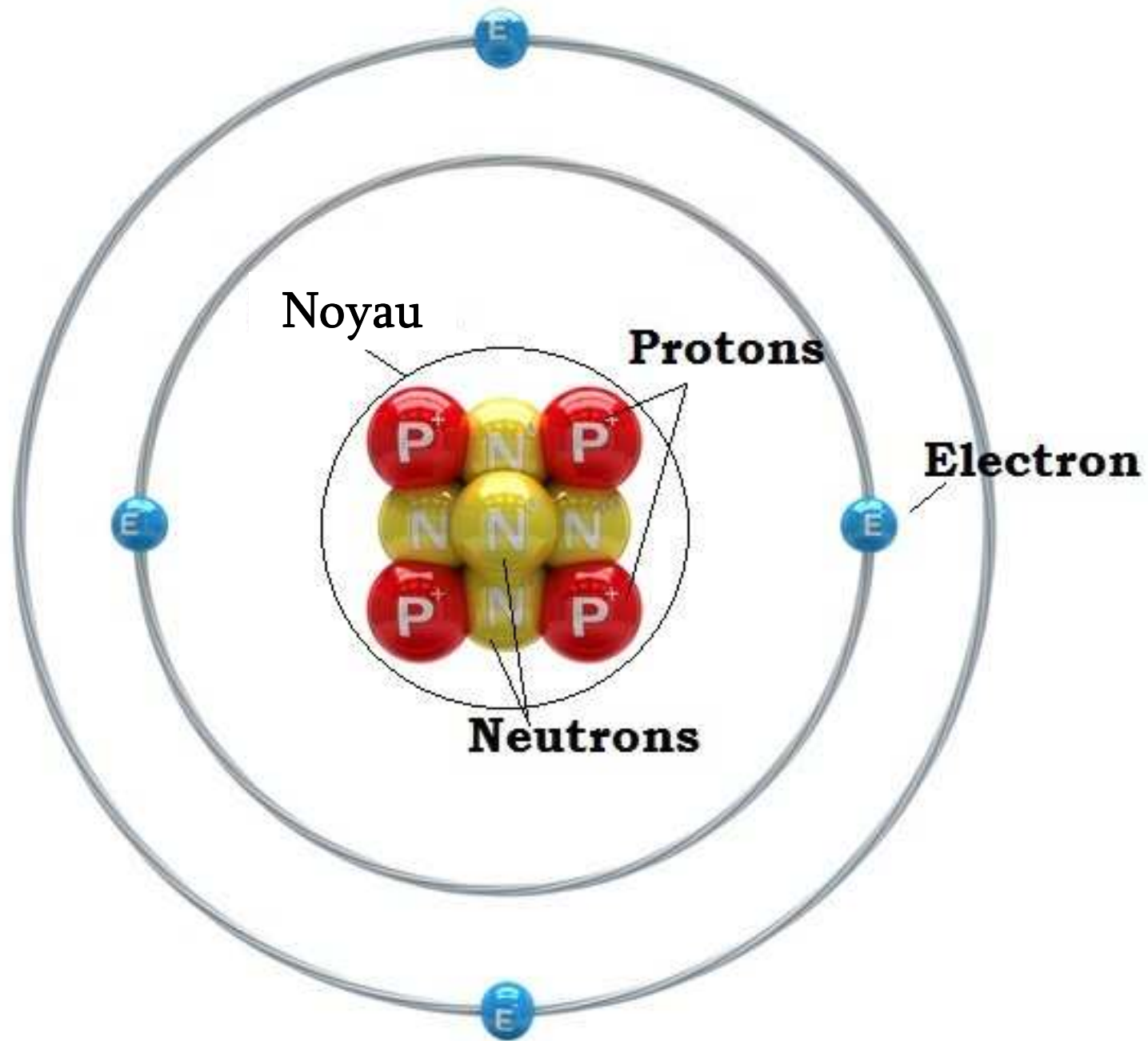
Données pour 2011	Grammes CO2 / km
Génération	12,0
Pertes réseau (5,2%)	0,7
<b>Total</b>	<b>12,7</b>

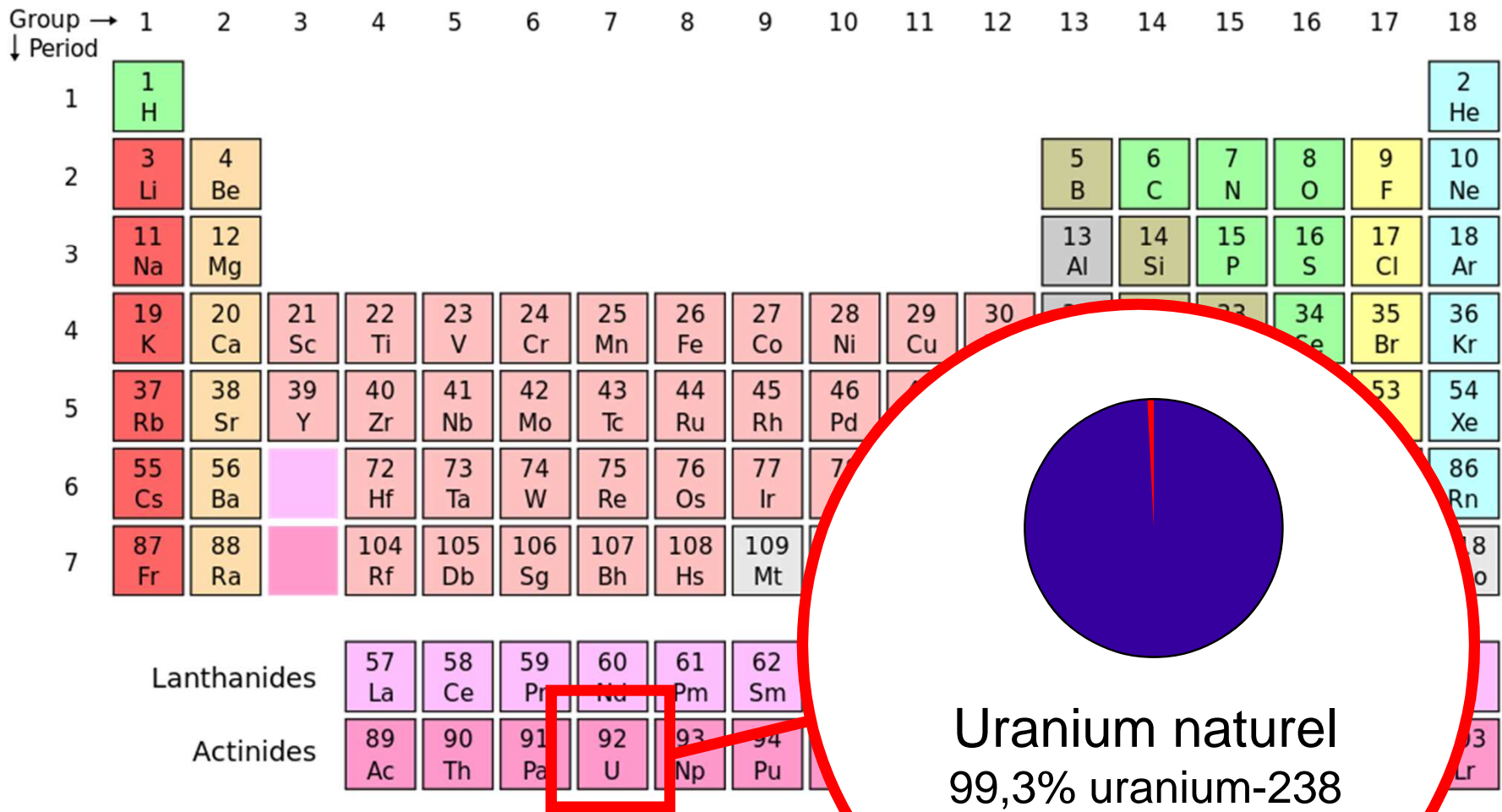


**En France, 3 ZOE sur 4 sont des voitures nucléaires**





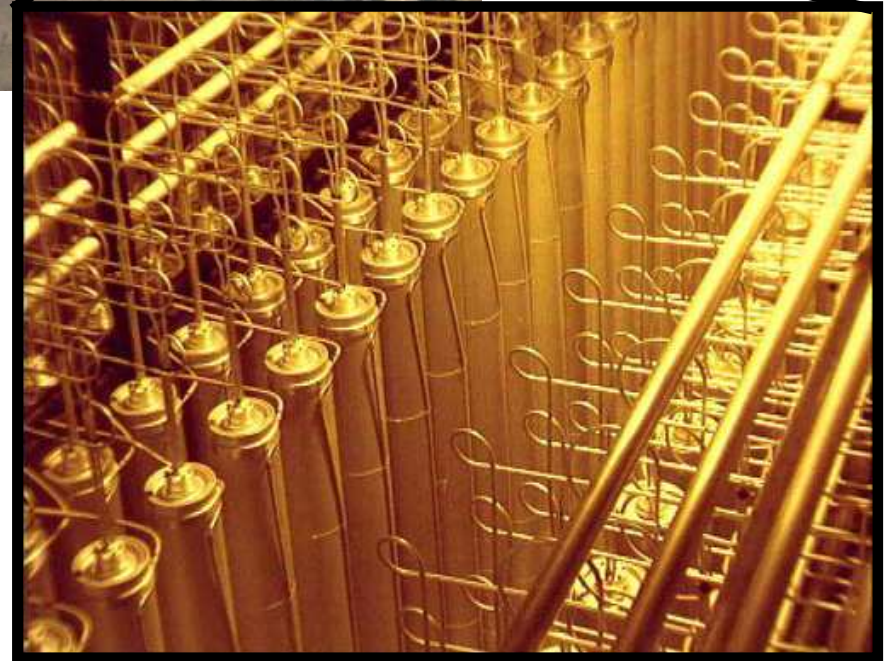




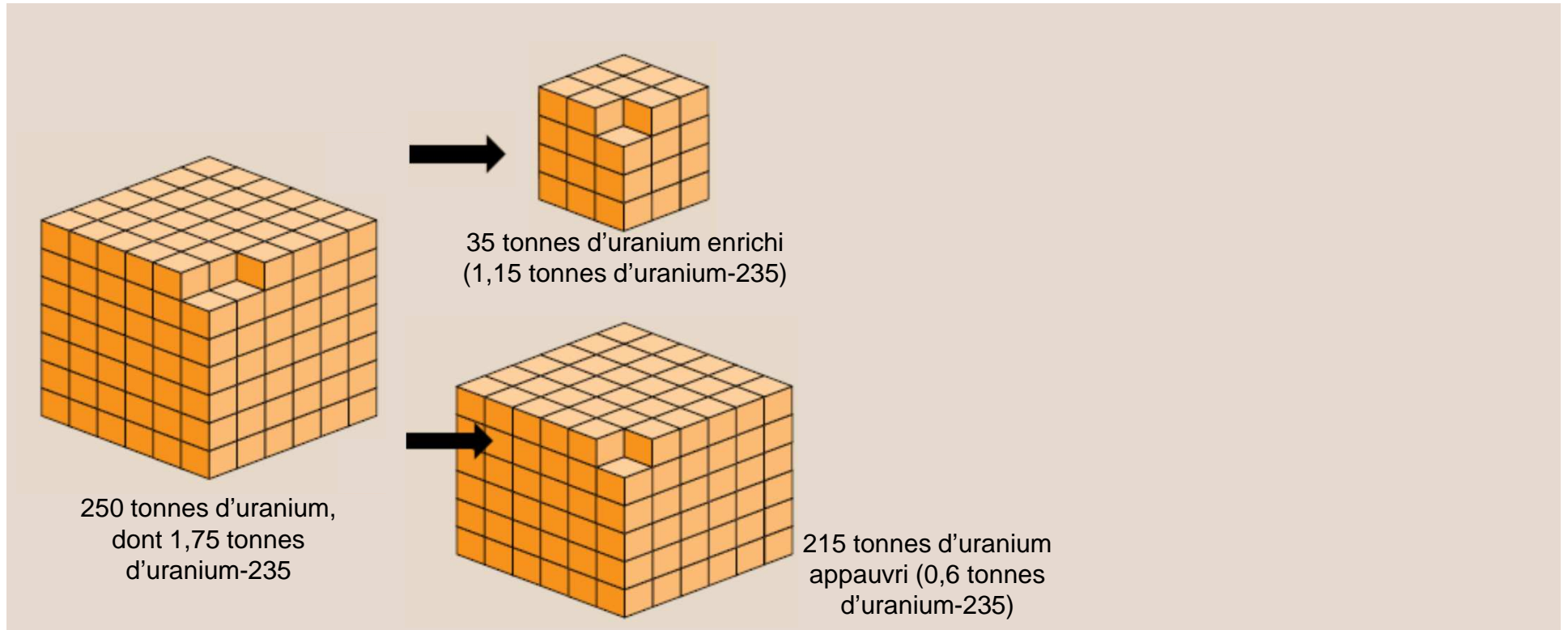




Usine  
d'enrichissement



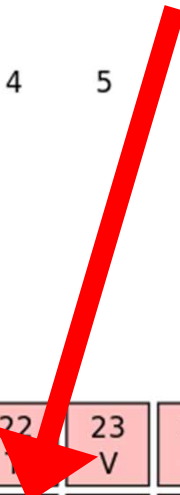
Pour produire 1 GigaWatt-Année d'électricité :





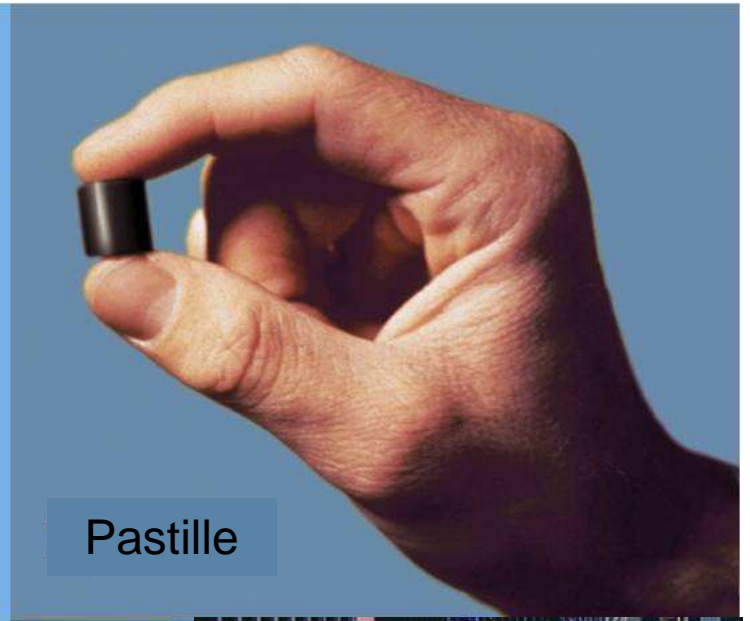
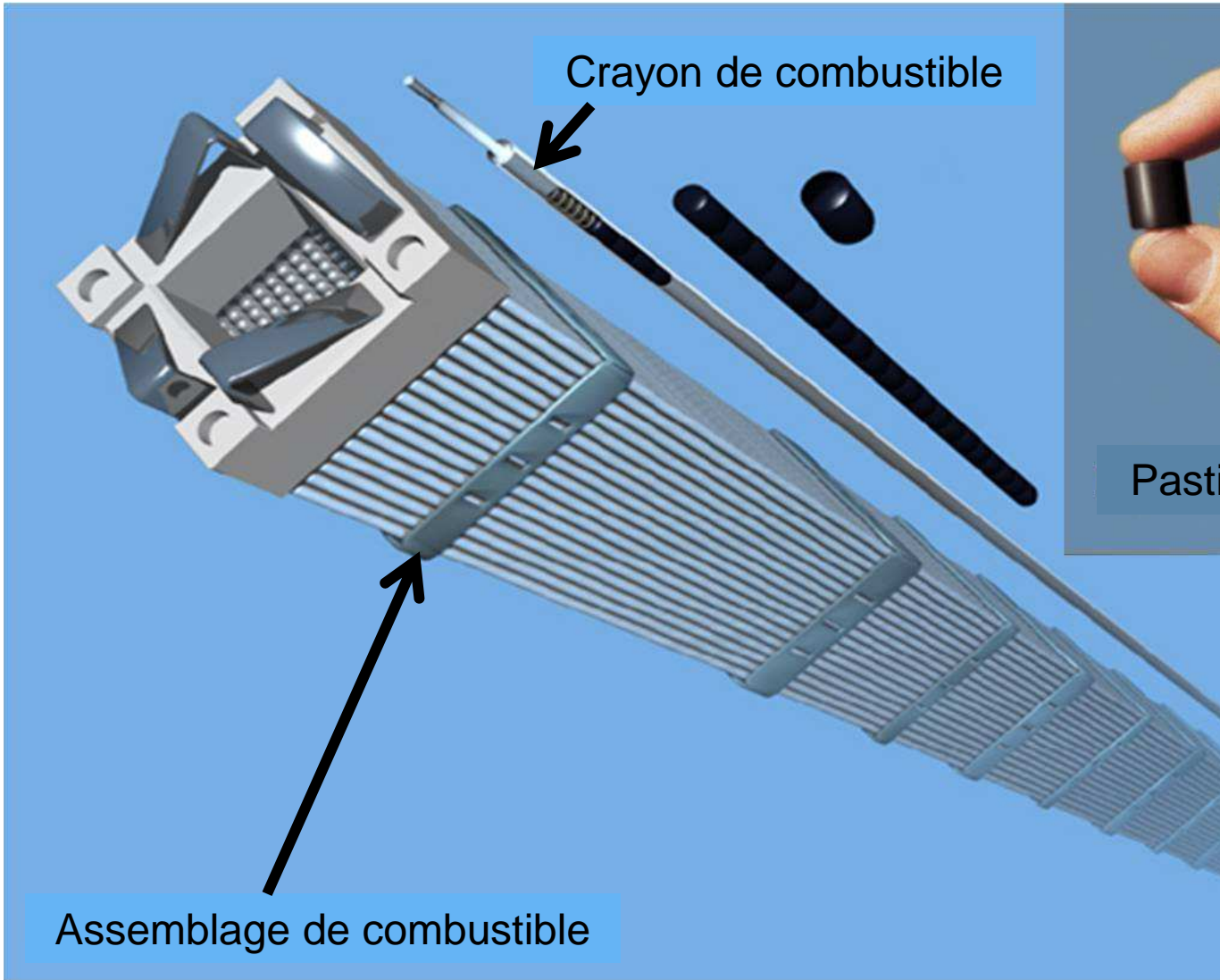


# Zirconium



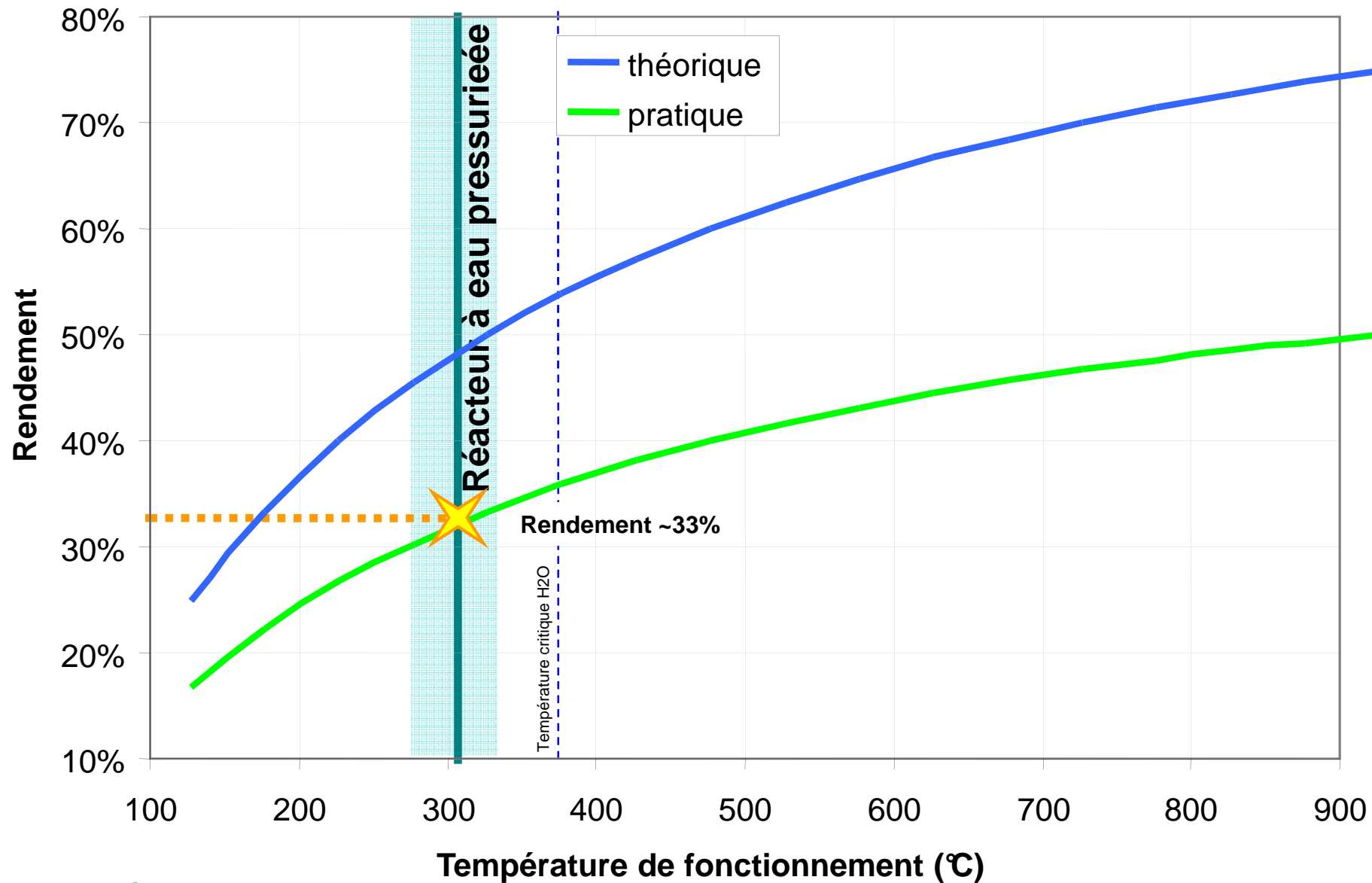
Group → ↓ Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo
Lanthanides				57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides				89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr



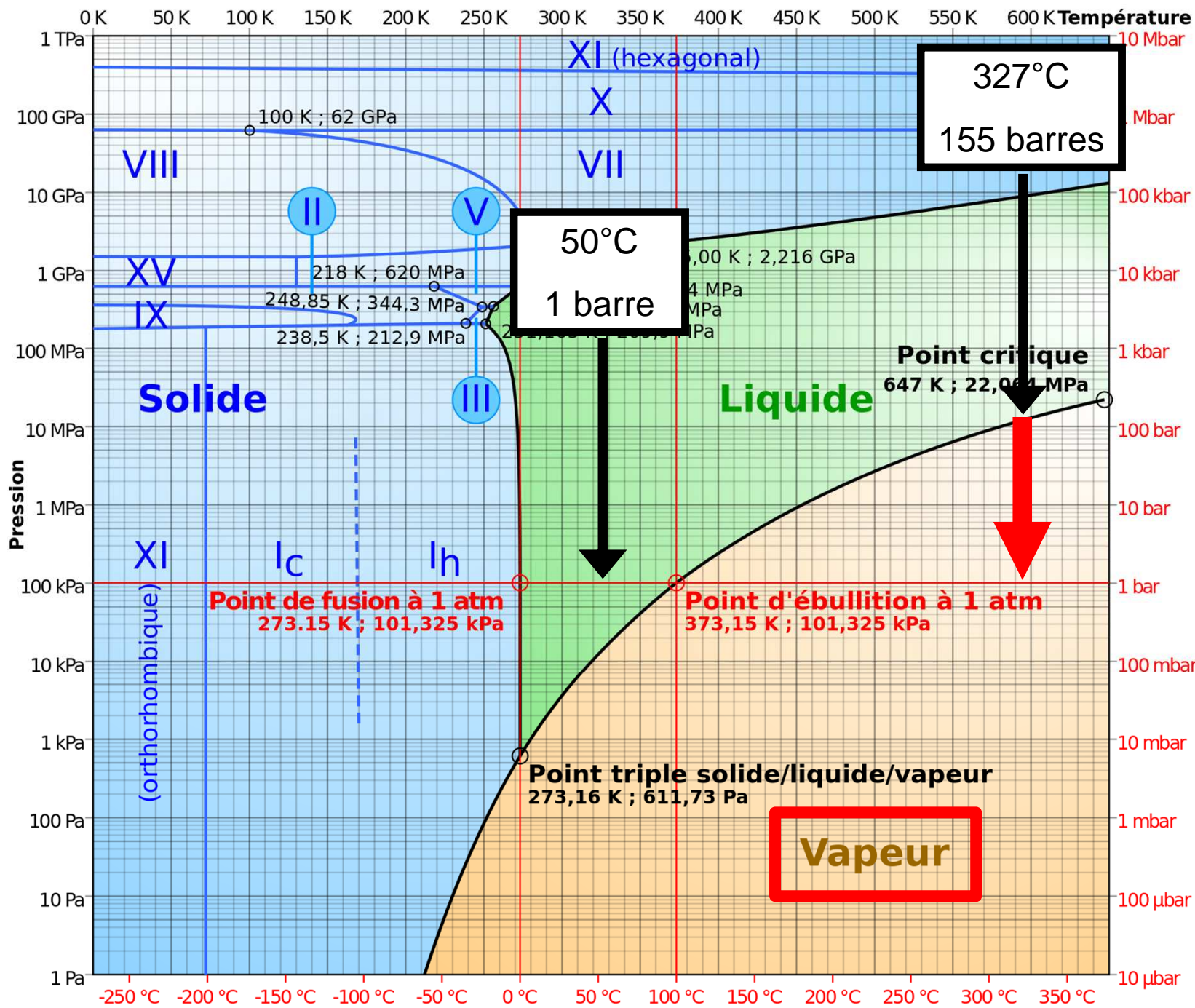


(video)

# Rendement dans la production d'électricité



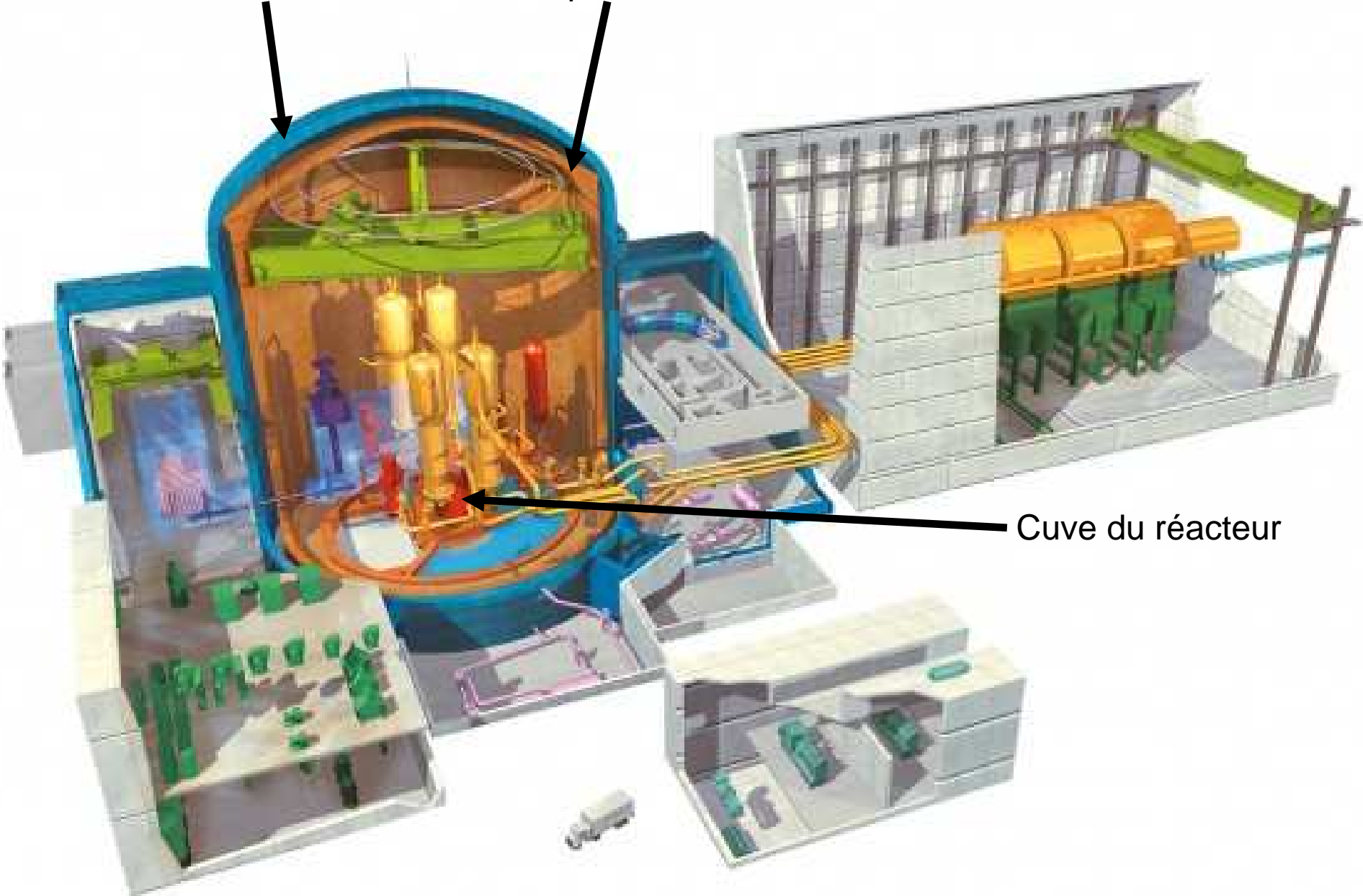
Source : [K Sorensen, Flibe Energy](#)



Source : [Wikimedia Commons](https://commons.wikimedia.org/wiki/File:Diagramme_de_phase_de_l'eau_2010.png)



2 Enceintes de confinement : épaisseur 130cm



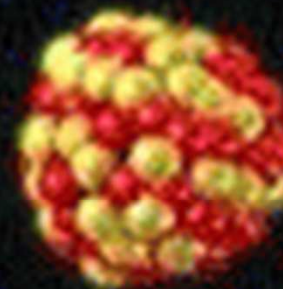
Cuve du réacteur



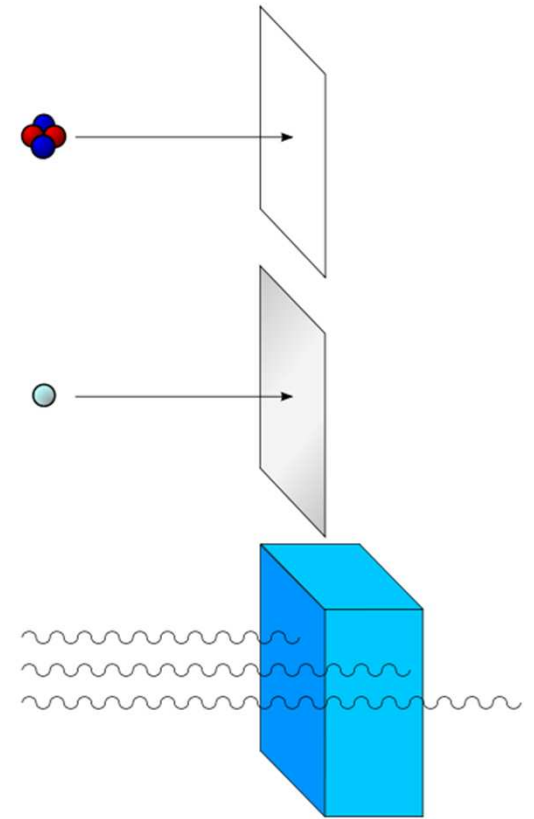
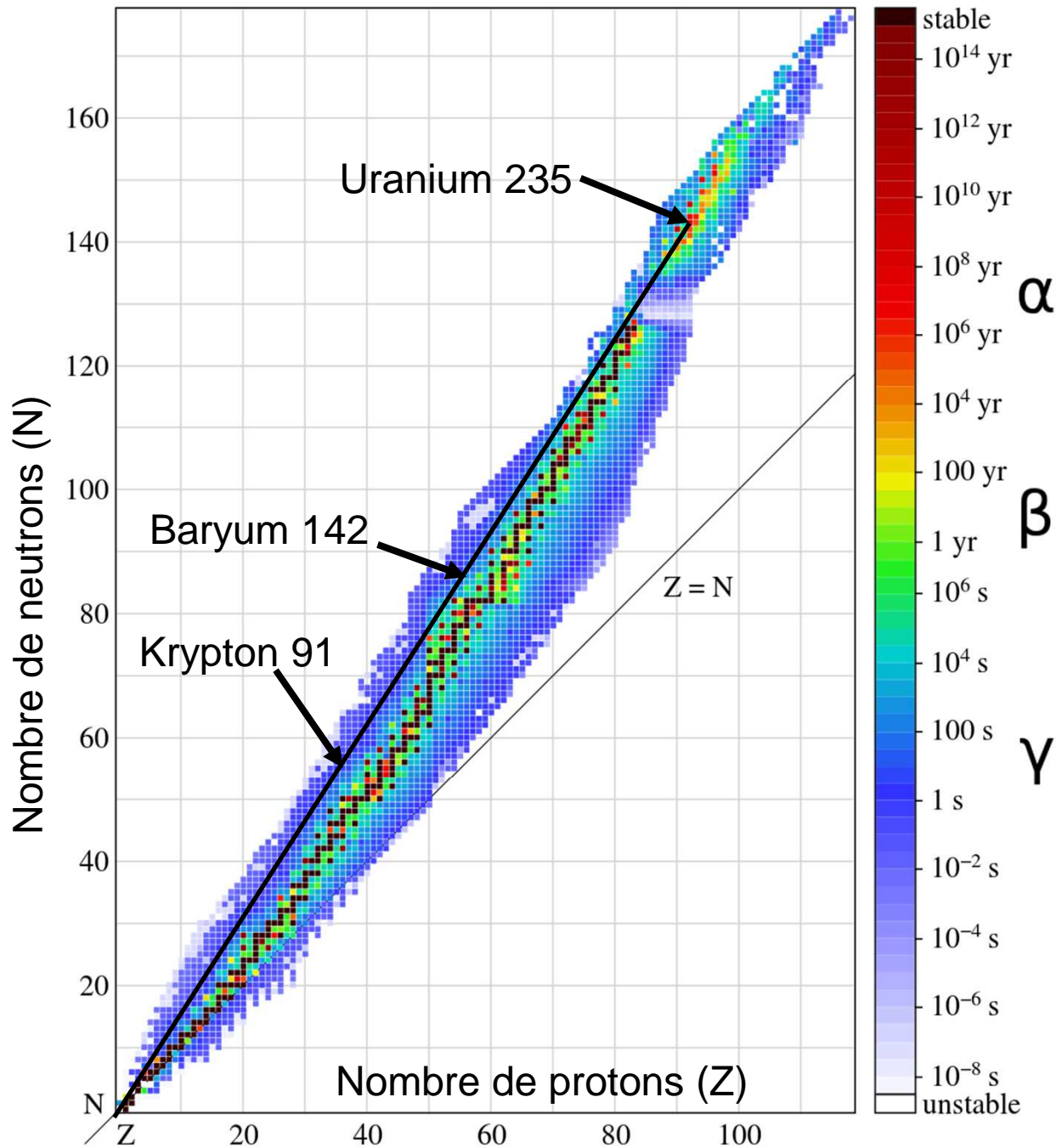
accelerated  
neutron



uranium

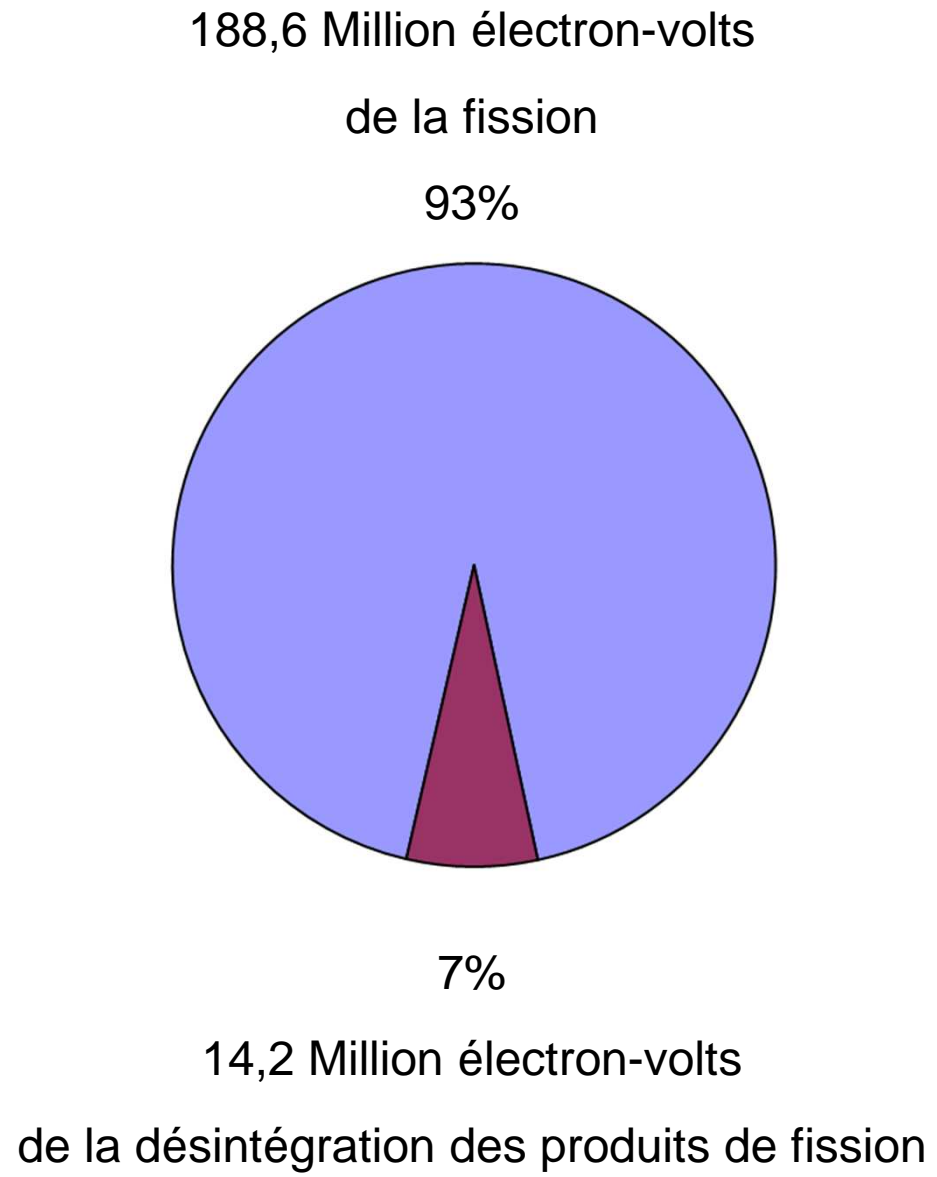




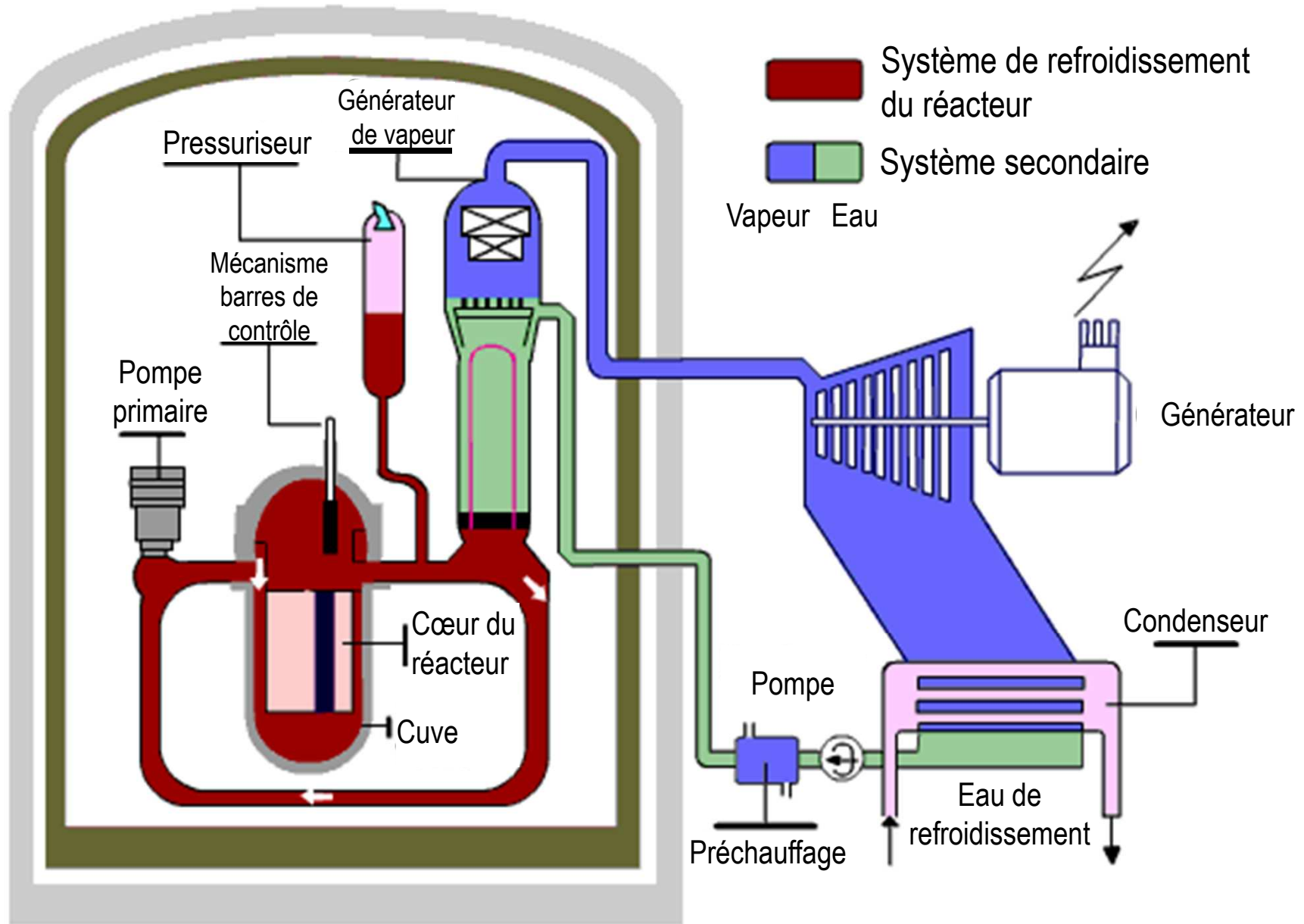


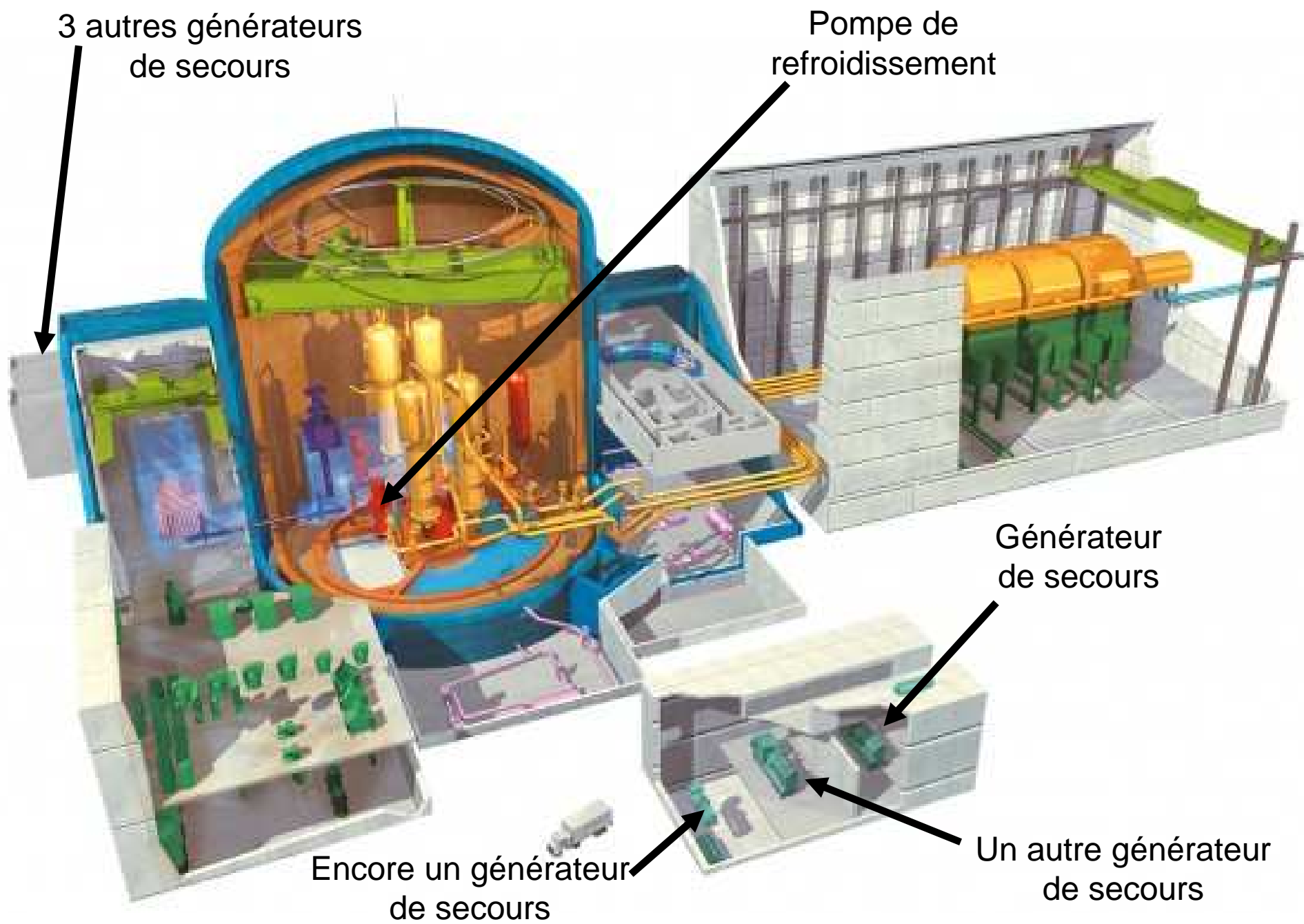
Source : [Wikipedia](https://fr.wikipedia.org/wiki/Mod%C3%A8le:RadioactiveDecay)

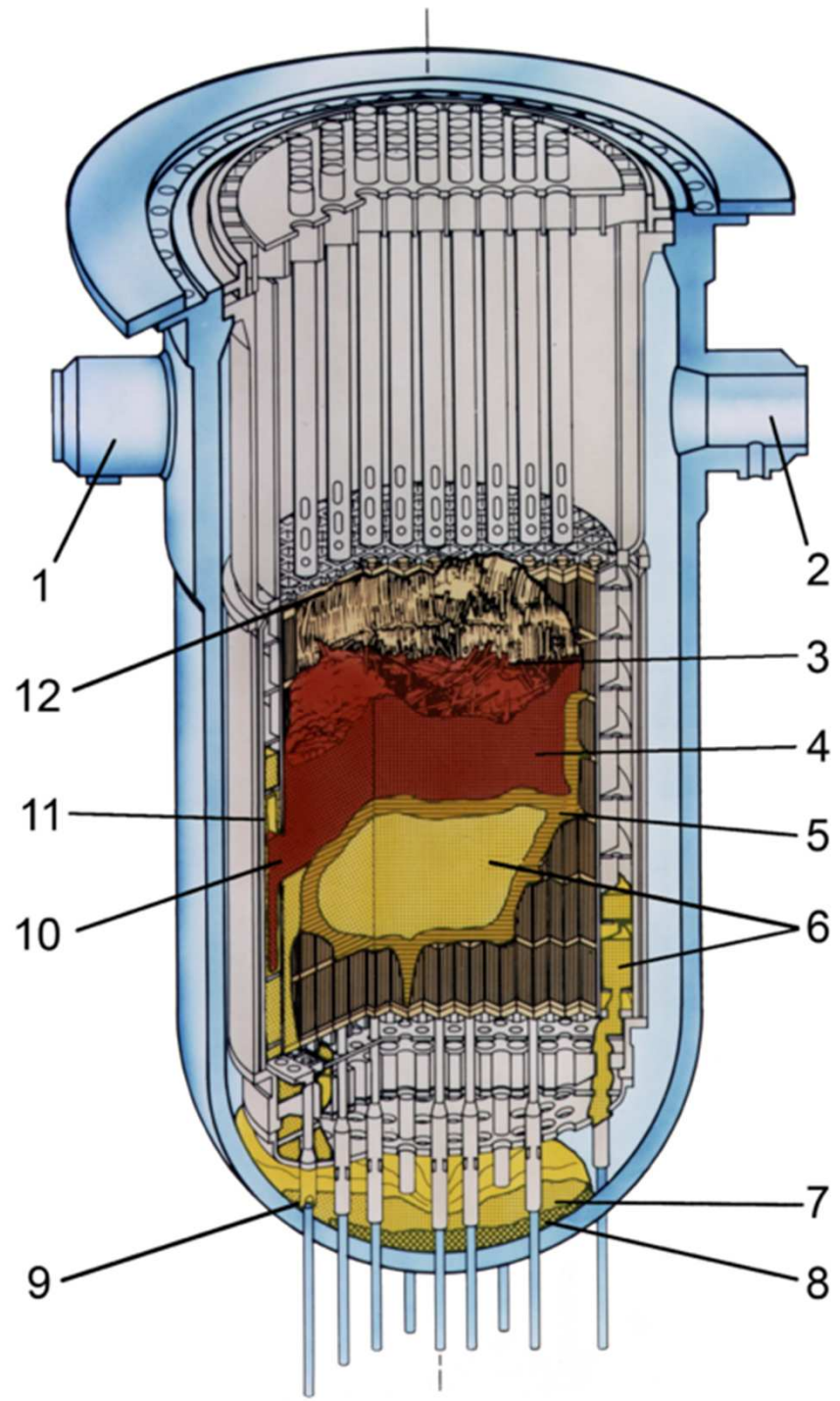
Energie de la fission d'un  
atome d'Uranium 235 :  
202,8 Million électron-volts



Source : [wikipedia.fr](http://wikipedia.fr)







Three Mile Island



Fukushima



Tchernobyl



**Transuraniens**

Group →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
↓ Period																		
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo
Lanthanides				57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides				89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

**Uranium-235**  
(0.7% de tout U)  
**Fissile**

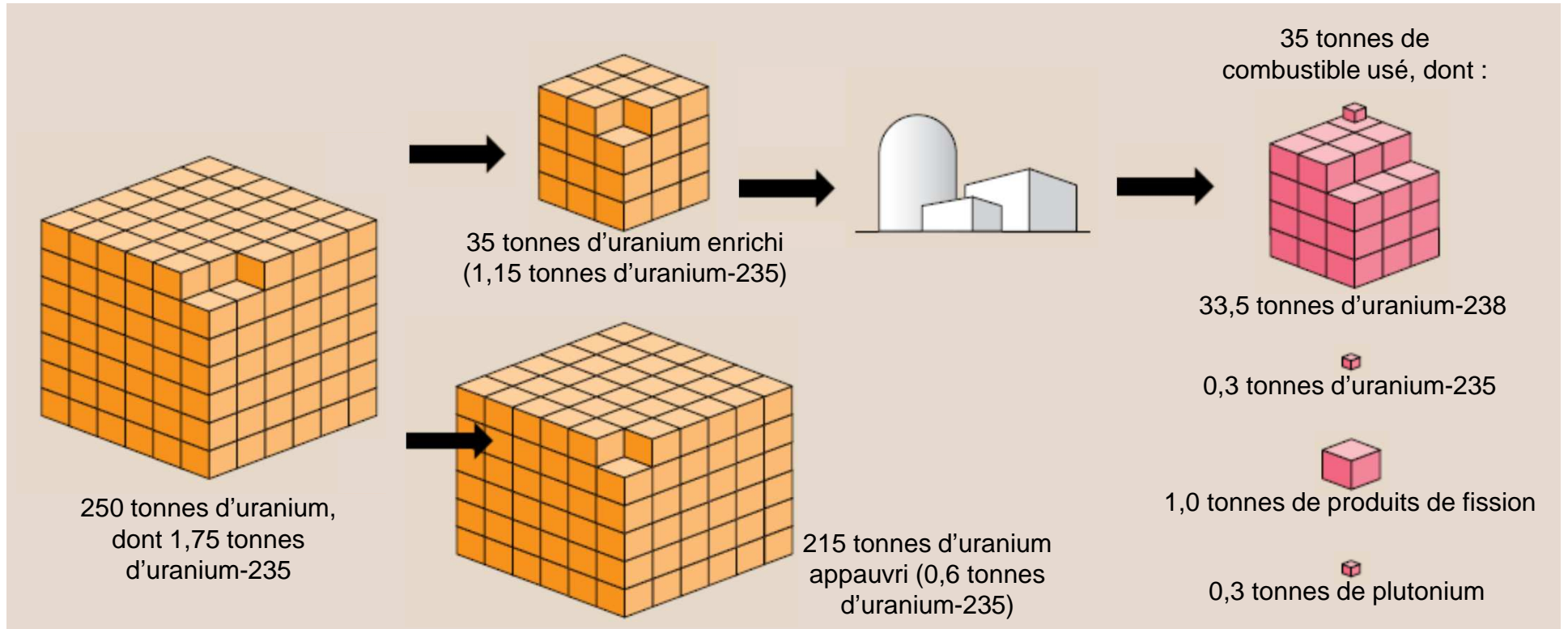
**Uranium-238**  
(99.3% de tout U)  
**Fertile**

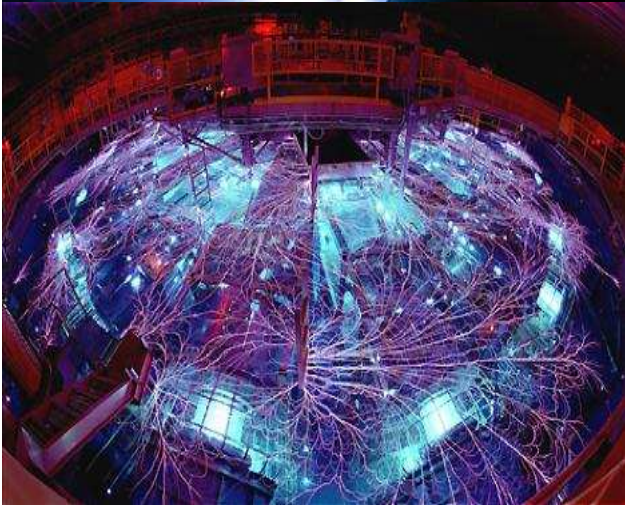
**Plutonium-239**  
**Fissile**





## Pour produire 1 GigaWatt-Année d'électricité :





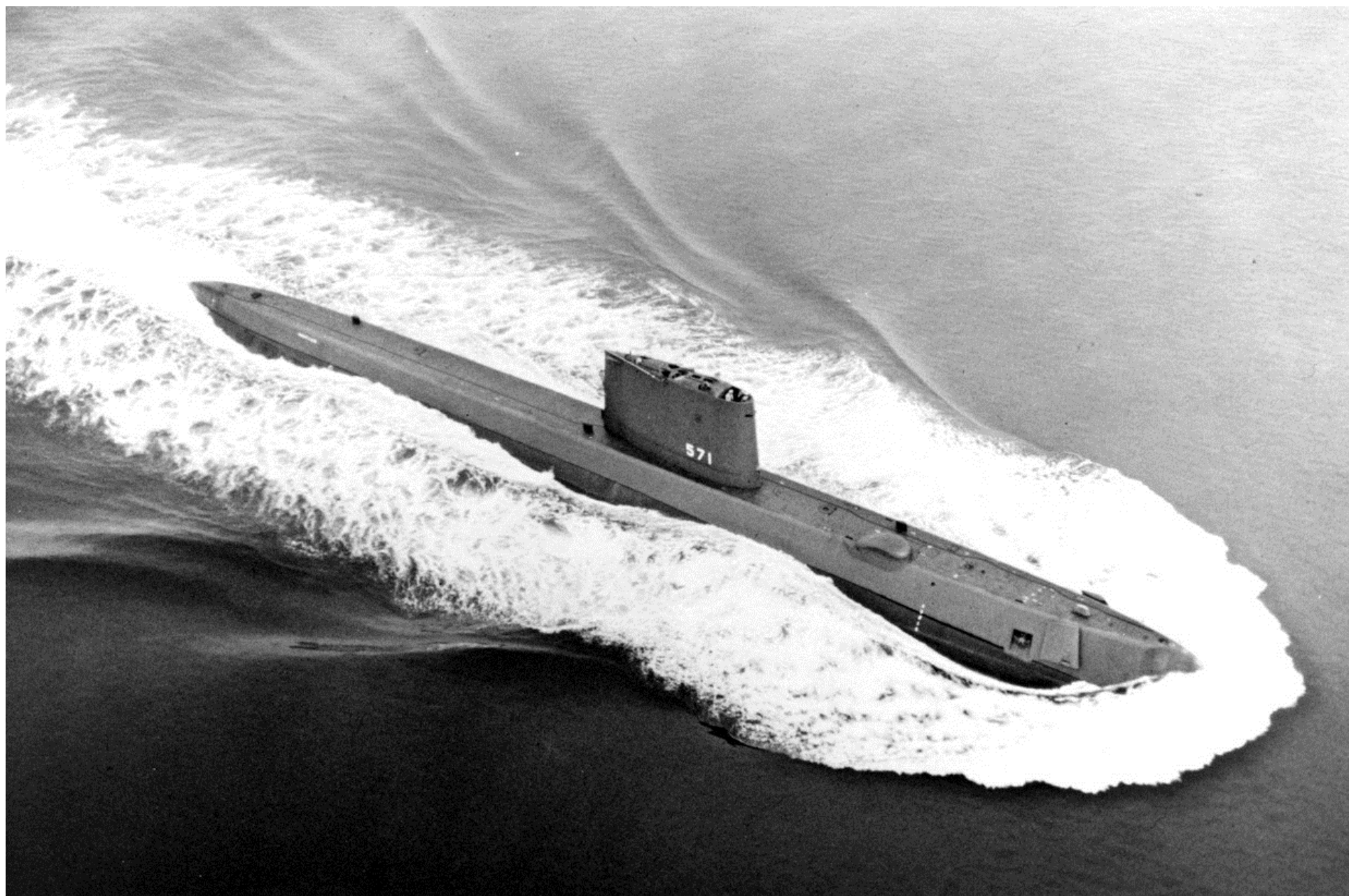
**FIABLE** 😊

**BON MARCHÉ** 😊

**SÛRE** 😞

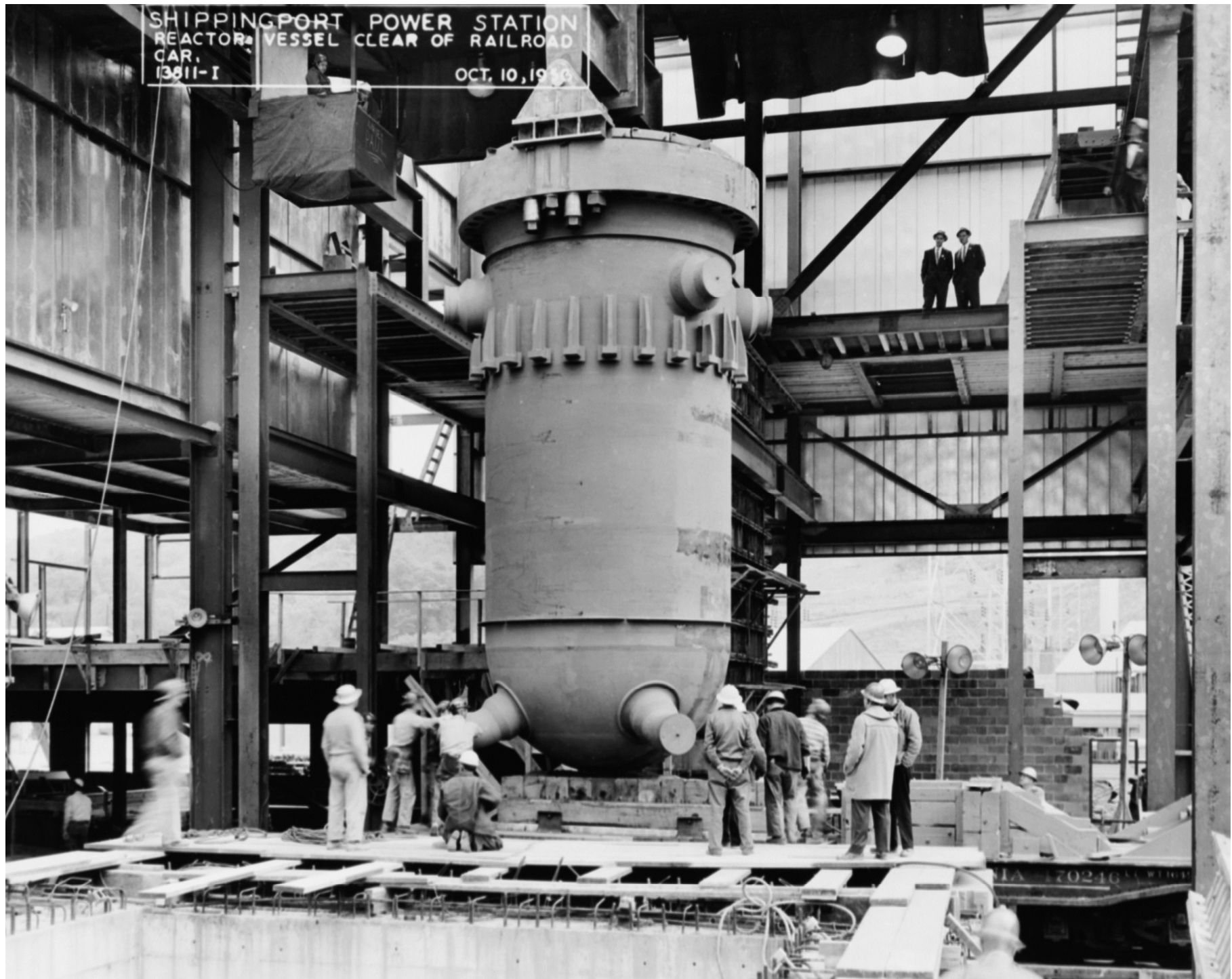
**DURABLE** 😞

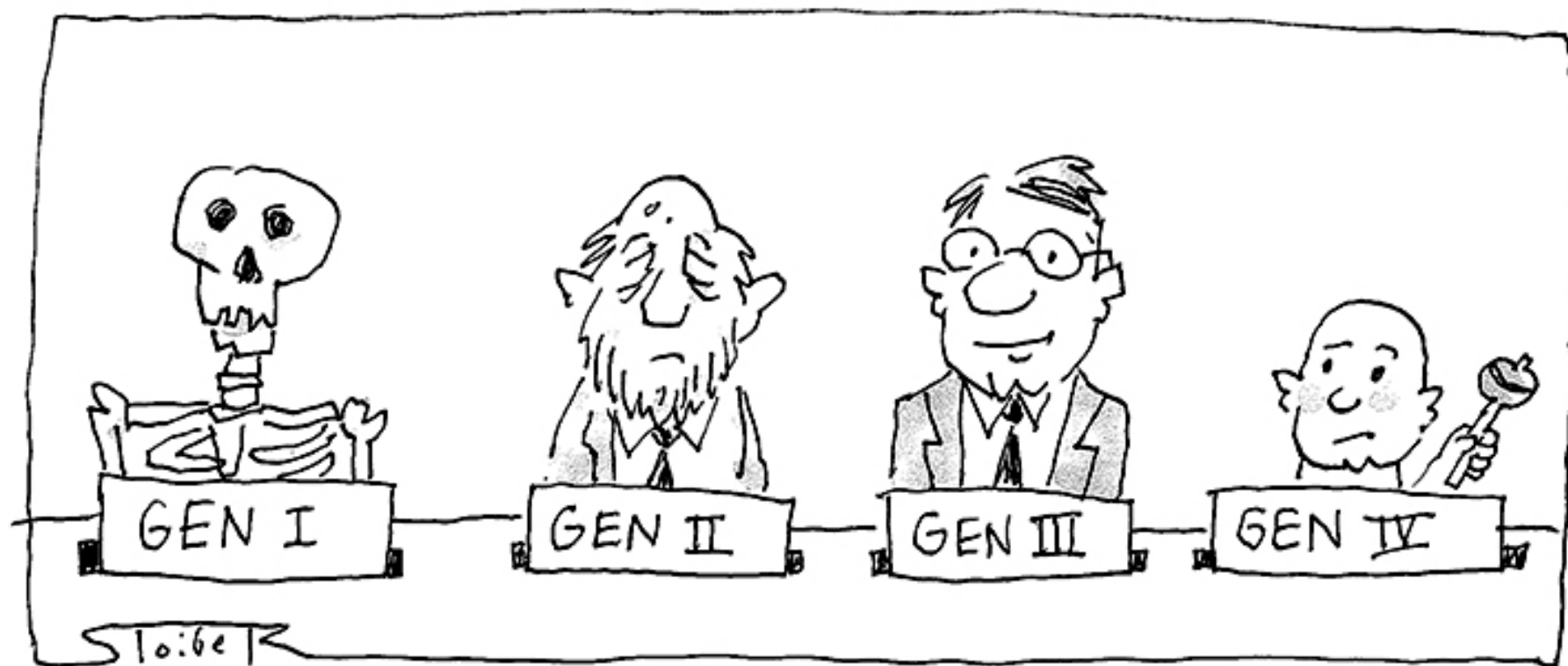
**PROPRE** 😞



SHIPPINGPORT POWER STATION  
REACTOR VESSEL CLEAR OF RAILROAD  
CAR,  
13511-1

OCT. 10, 1956





GEN I

GEN II

GEN III

GEN IV

Stoiber

**FISSION**

**LIQUIDE**

# Quel Liquide ?




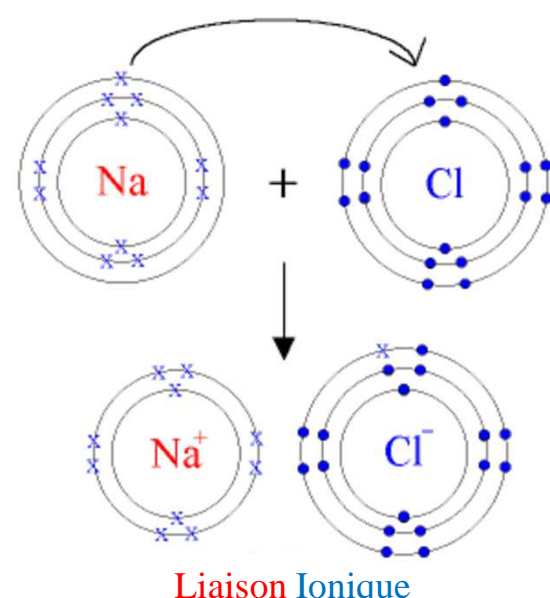
- Température de fusion basse
- Température d'ébullition élevée
- Bonnes propriétés thermiques
- Bonnes propriétés hydrauliques
- Bonne stabilité sous rayonnement
- Bonne solubilité des matériaux fissiles et fertiles
- Eviter la production d'isotopes radioactifs
- Permettre le retraitement du combustible



## Sels Fondus

Group → 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18  
 ↓ Period

1	1 H																2 He
2	3 Li	4 Be															
3	11 Na	12 Mg															
4	19 K	20 Ca															
5	37 Rb	38 Sr															
6	55 Cs	56 Ba															
7	87 Fr	88 Ra															

5	6	7	8	9	10
13	14	15	16	17	18
31	32	33	34	35	36
49	50	51	52	53	54
81	82	83	84	85	86
113	114	115	116	117	118
Uut	Fl	Uup	Lv	Uus	Uuo

Lanthanides	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

**LiF : Fluorure de Lithium**

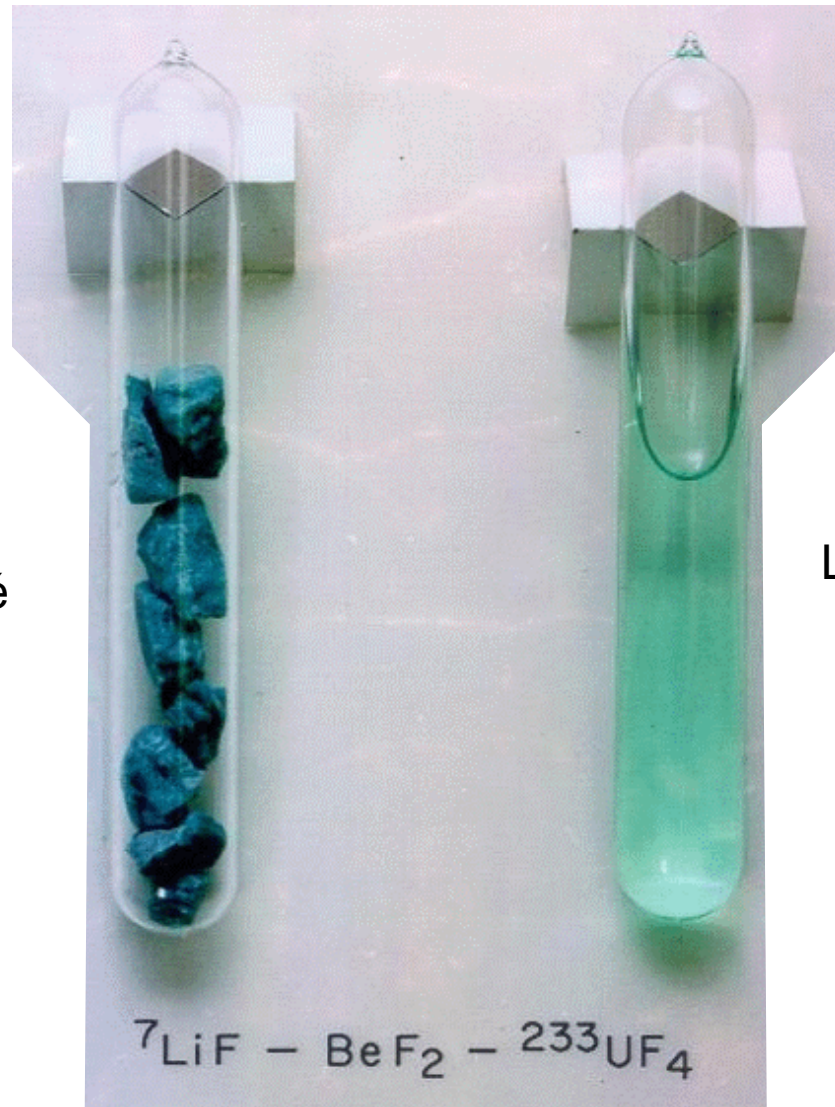
**BeF : Fluorure de Béryllium**

**Mélange de Fluorures de Lithium & Béryllium : FLiBe**

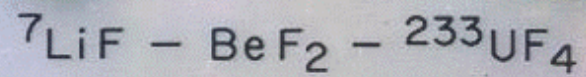


# Combustibles nucléaires liquides

Solide  
Cristallisé

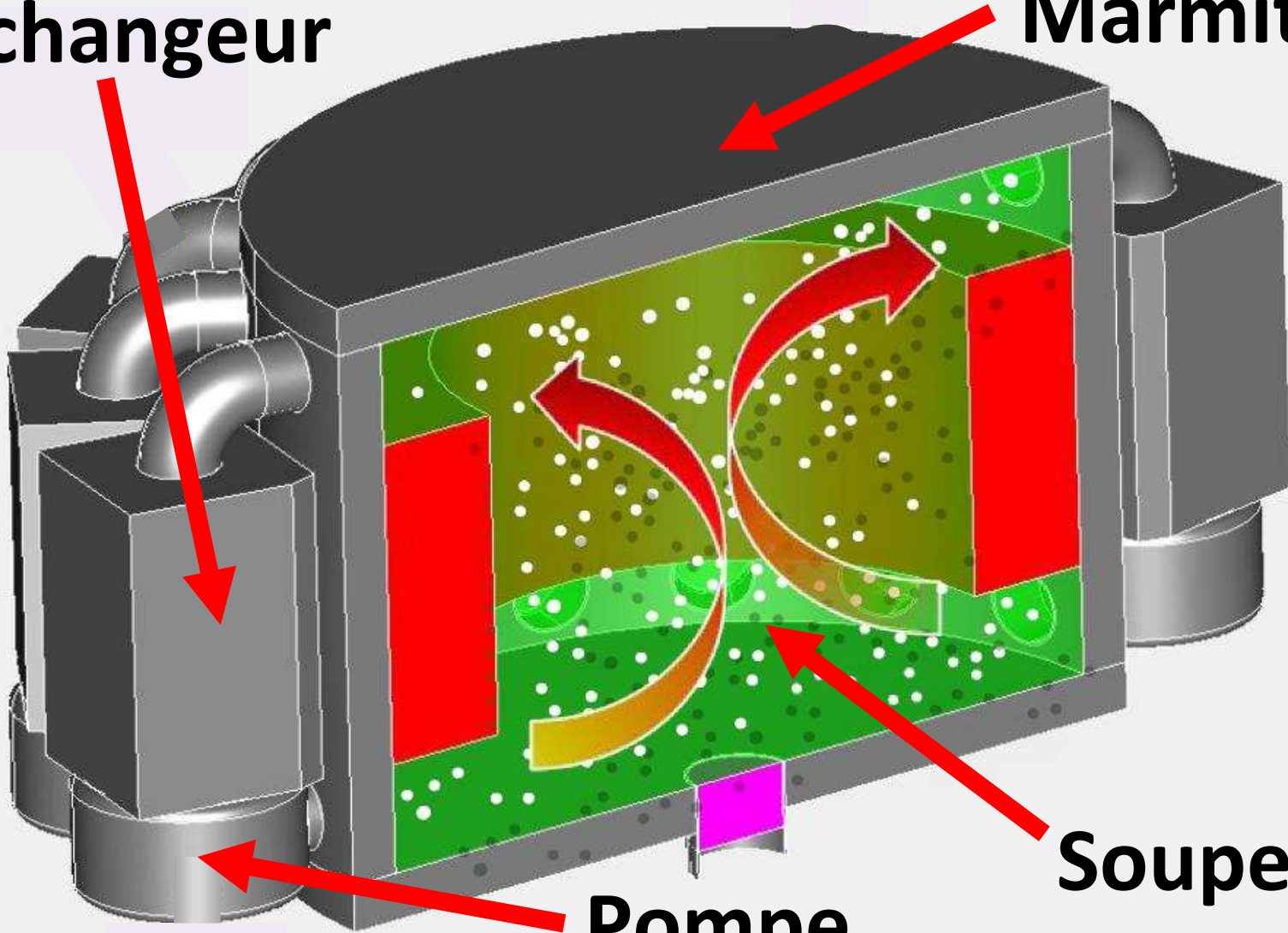


Liquide



**Echangeur**

**Marmite**



**Pompe**

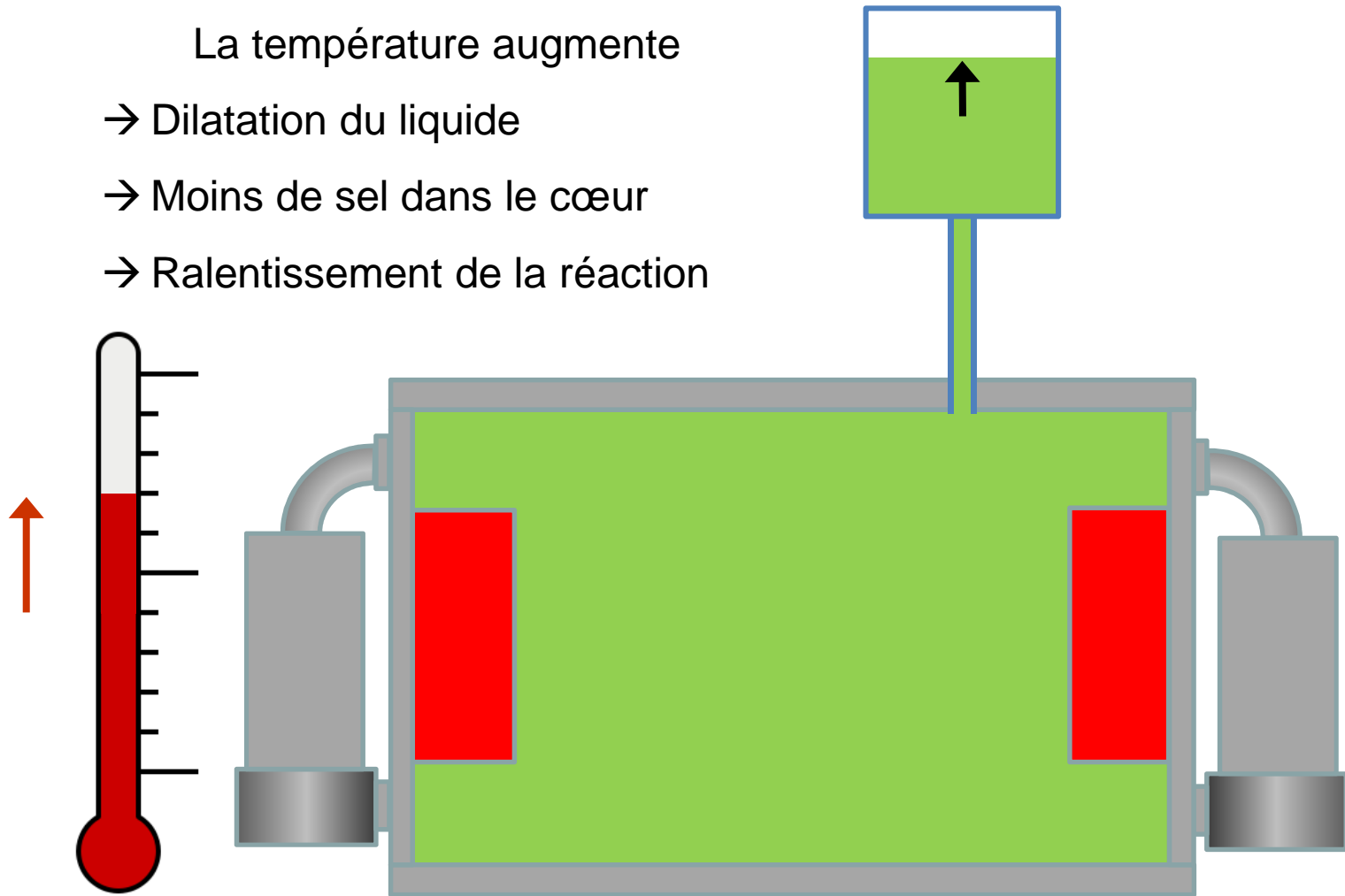
**Soupe**

La température augmente

→ Dilatation du liquide

→ Moins de sel dans le cœur

→ Ralentissement de la réaction

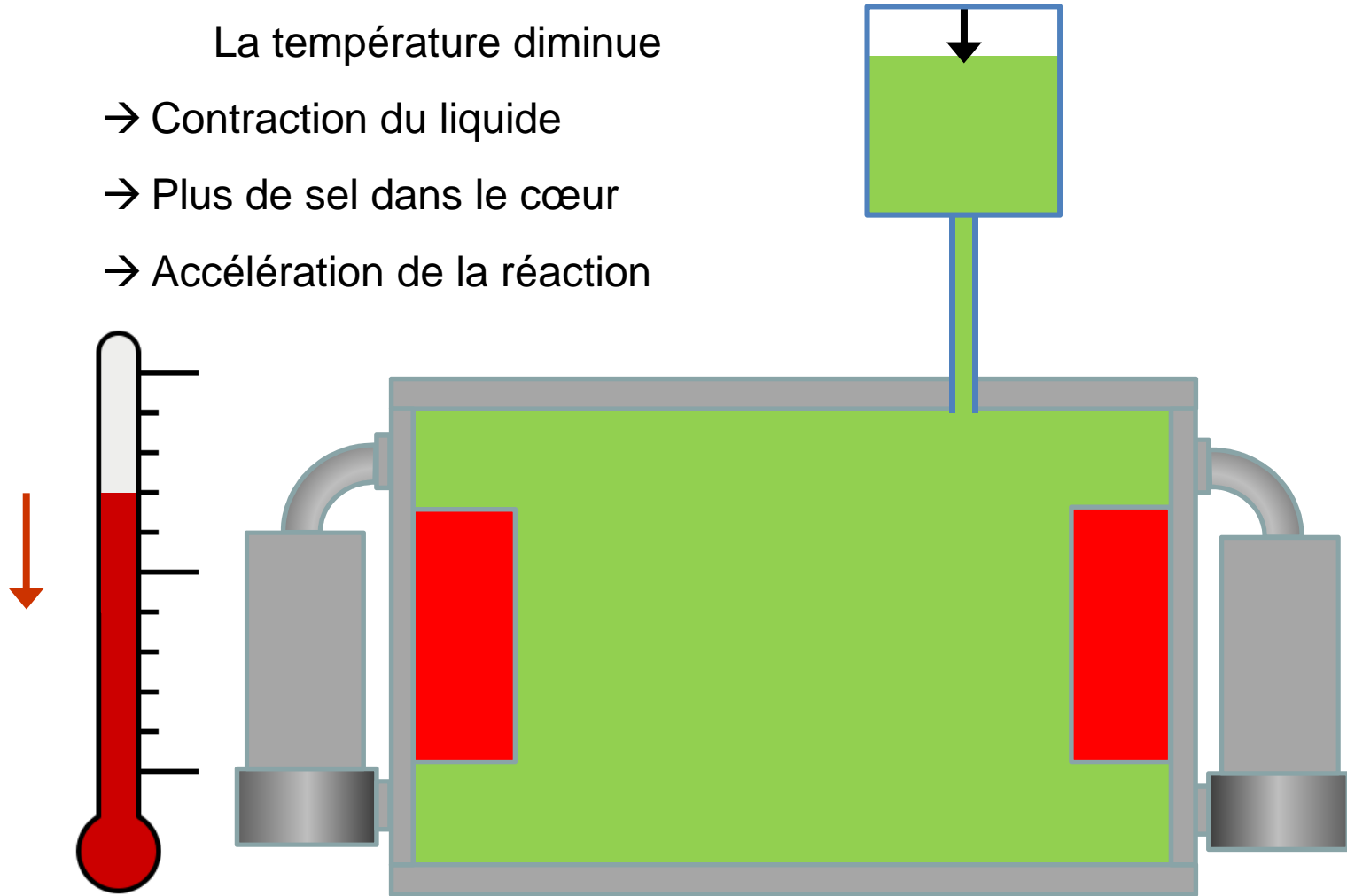


La température diminue

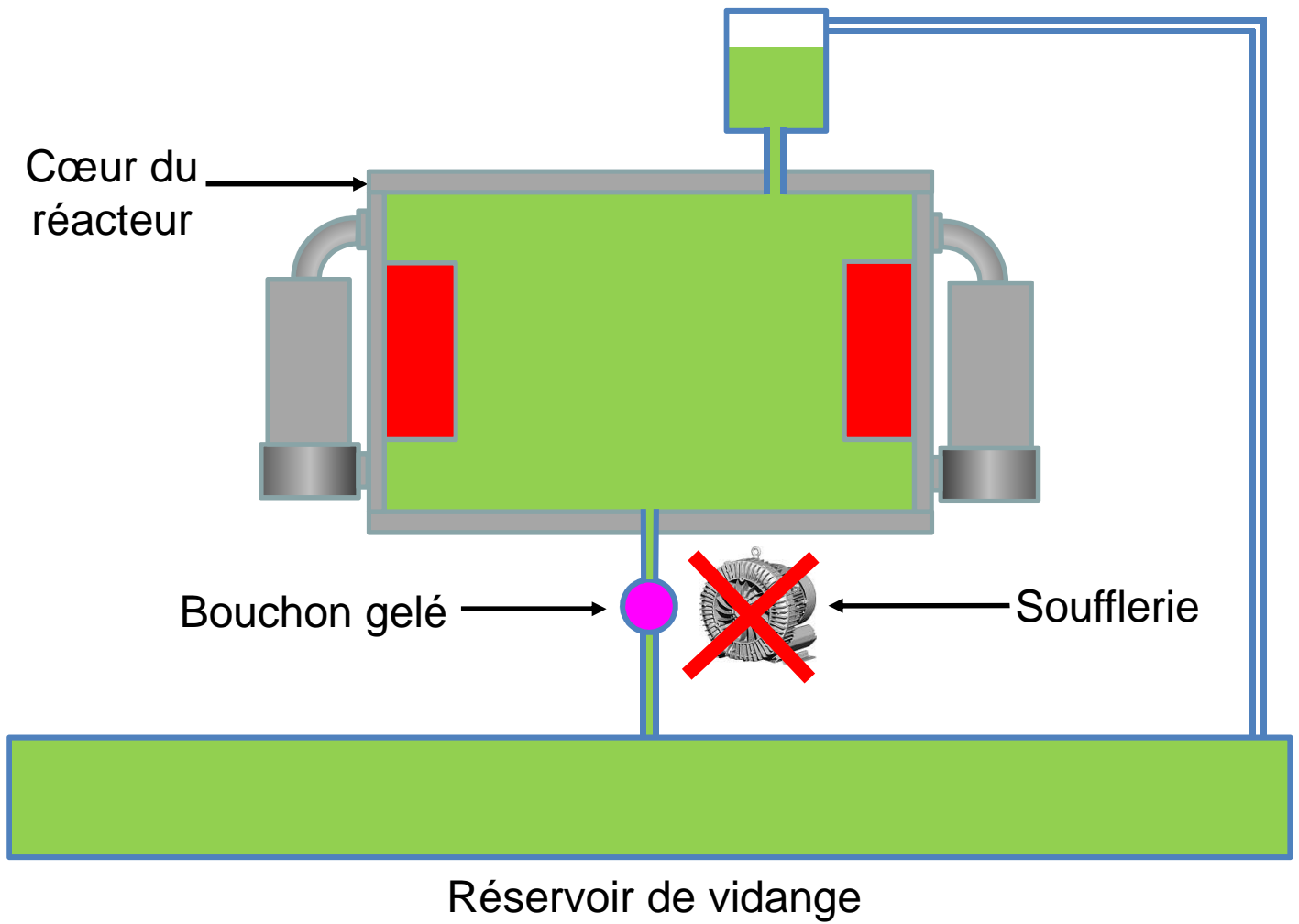
→ Contraction du liquide

→ Plus de sel dans le cœur

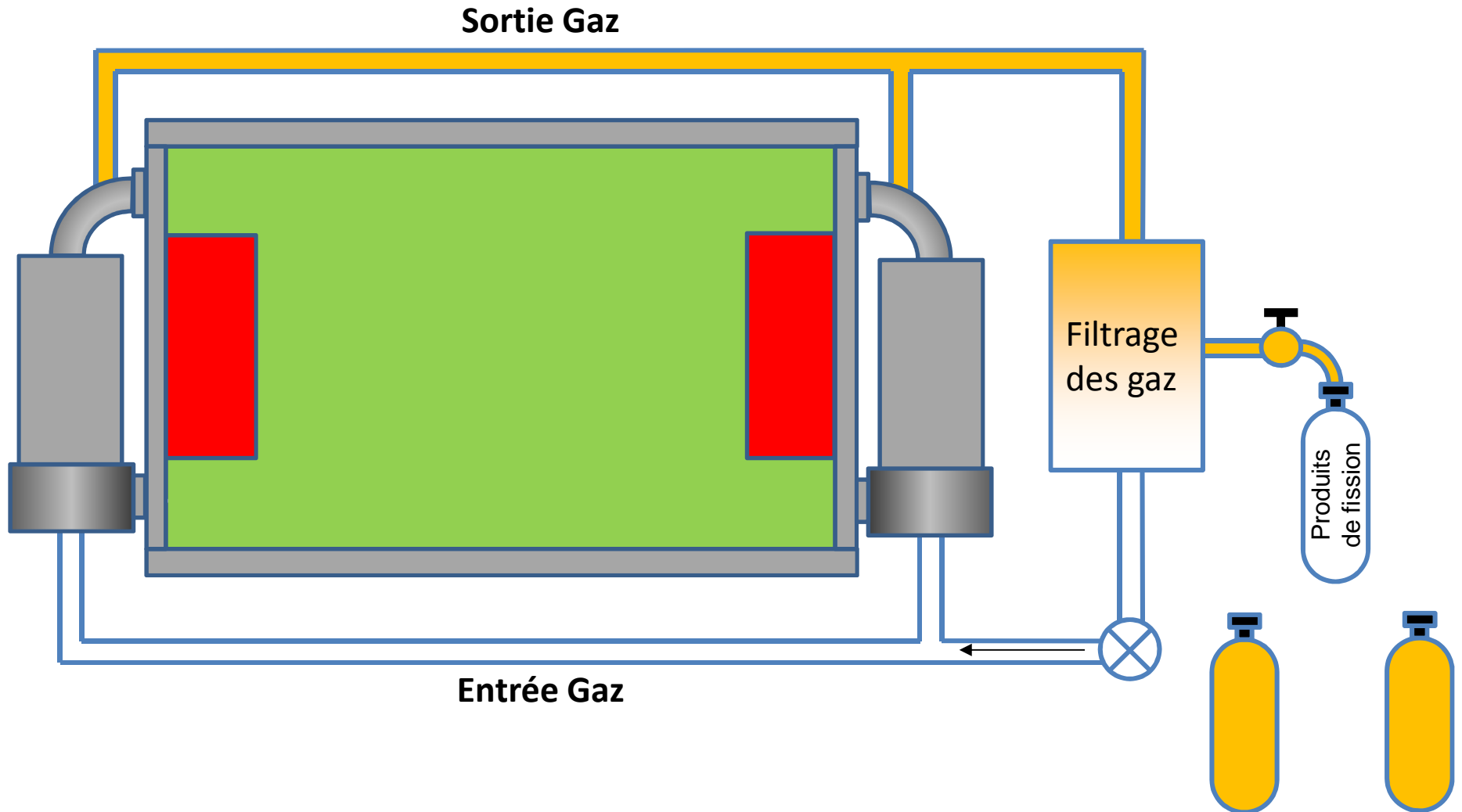
→ Accélération de la réaction



# Enceinte de Confinement

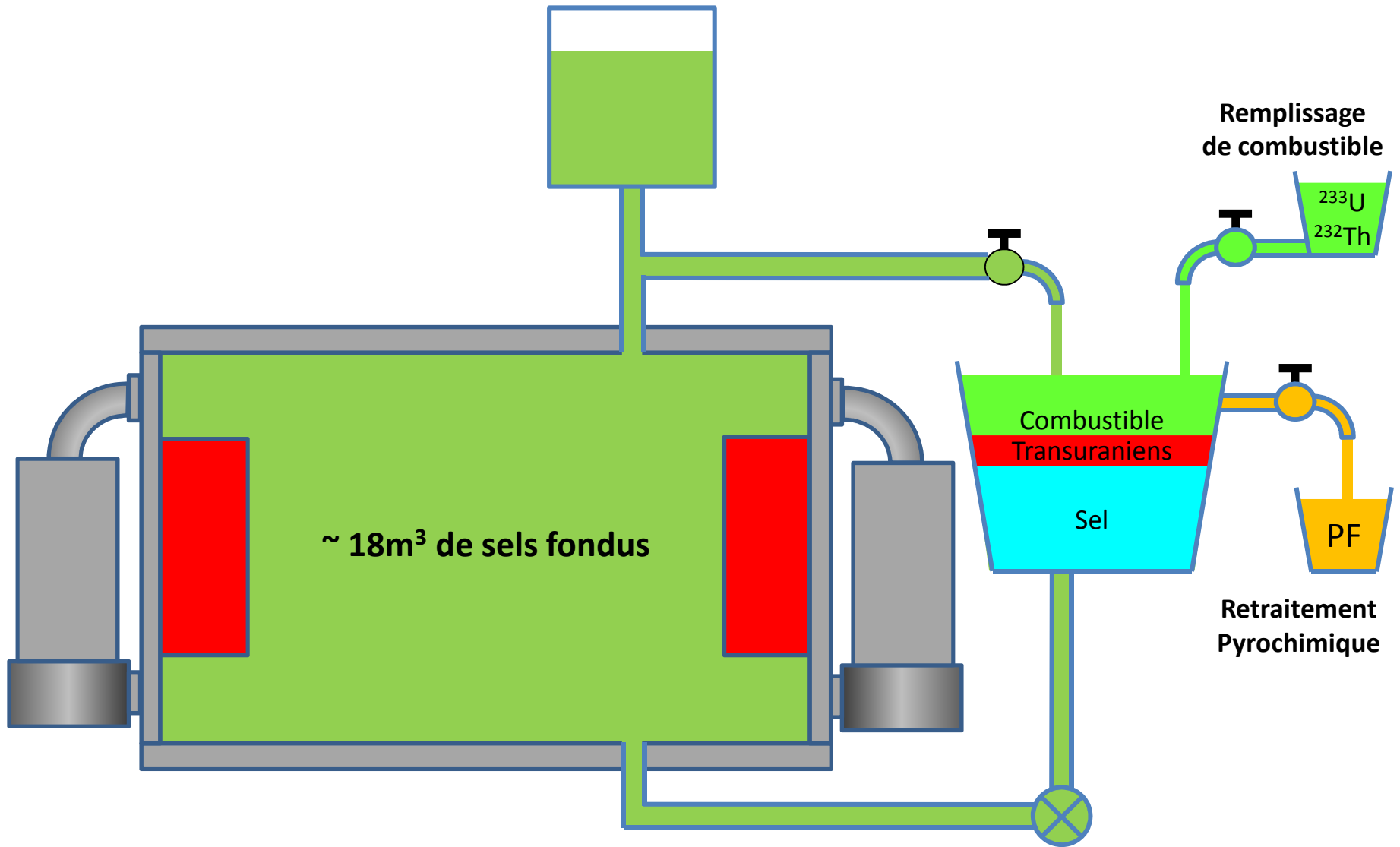


# Nettoyage des produits de fission gazeux dans un réacteur MSFR par bullage de gaz



1 bouteille par jour. 2 litres @ 100 barres

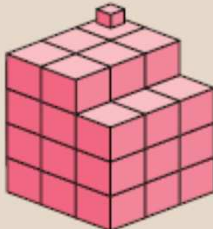
## Traitement du sel combustible d'un réacteur à sels fondus MSFR



Group →	1	2	3	4	5	6	7	8	9	10	11	12	13	14
↓ Period														
1	1 H													
2	3 Li	4 Be										5 B	6 C	
3	11 Na	12 Mg										13 Al	14 Si	
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn
6	55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb
7	87 Fr	88 Ra		104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl

# Uranium 235

35 tons of spent fuel stored containing:



33.4 tons of uranium-238

0.3 tons of uranium-235

1.0 tons of fission products

0.3 tons of plutonium

Lanthanides	57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinides	89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

**Thorium**

**Plutonium**

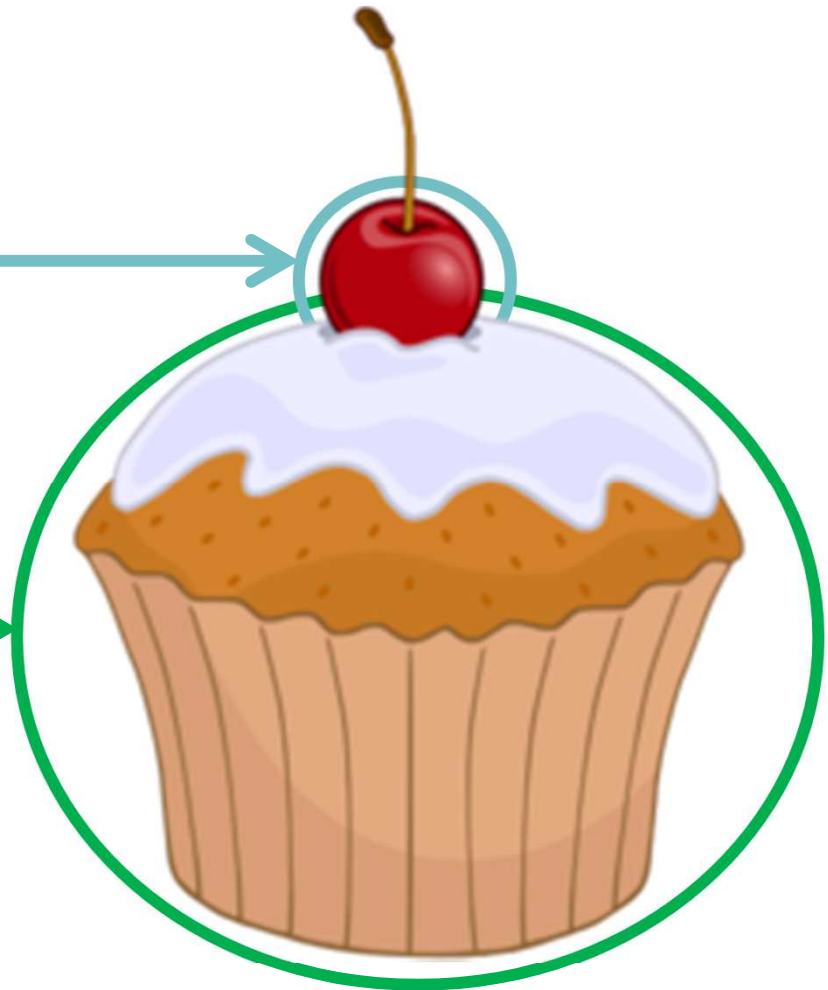


Le Thorium est la cerise sur le gâteau

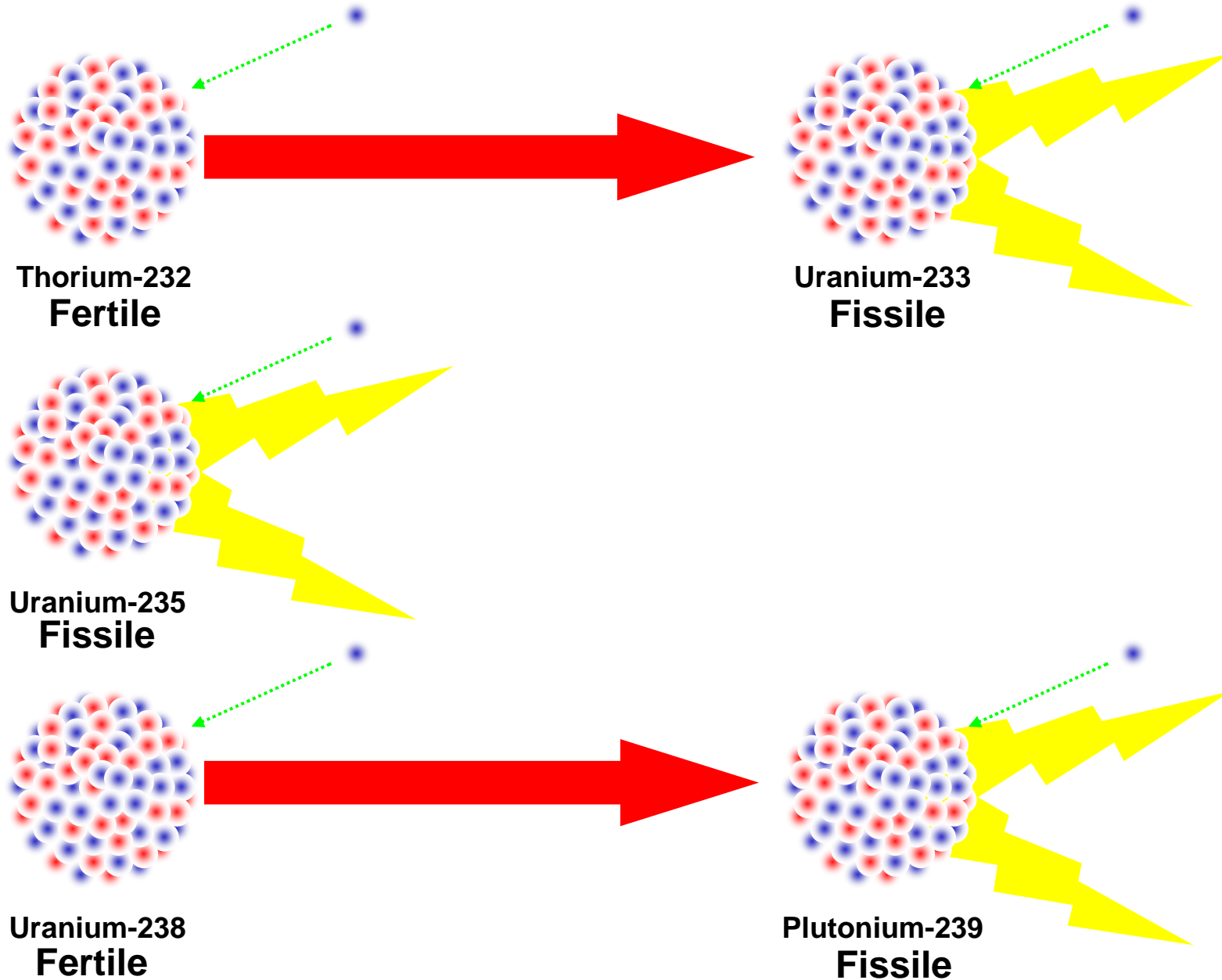
Thorium



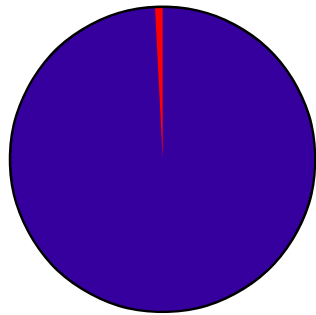
Combustible  
Solide → Liquide



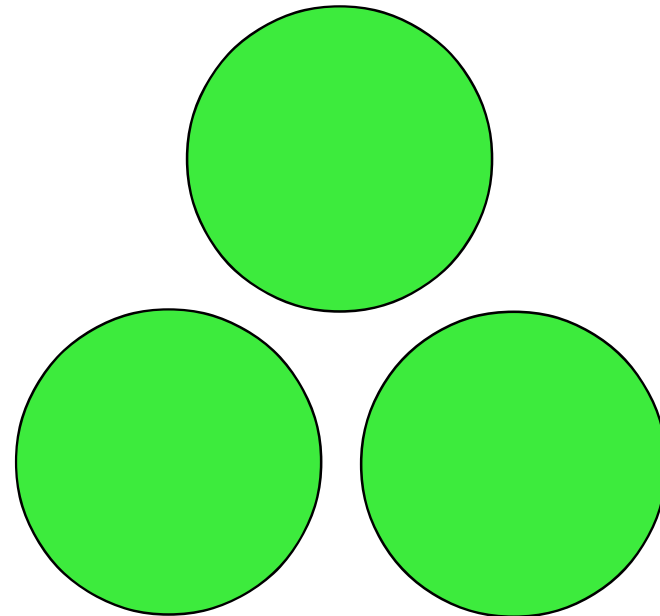
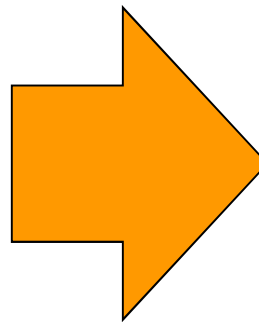
# Trois options de combustible nucléaire



# Le Thorium est plus abondant



Uranium naturel  
99.3% uranium-238  
0.7% uranium-235



Thorium naturel  
100% thorium-232

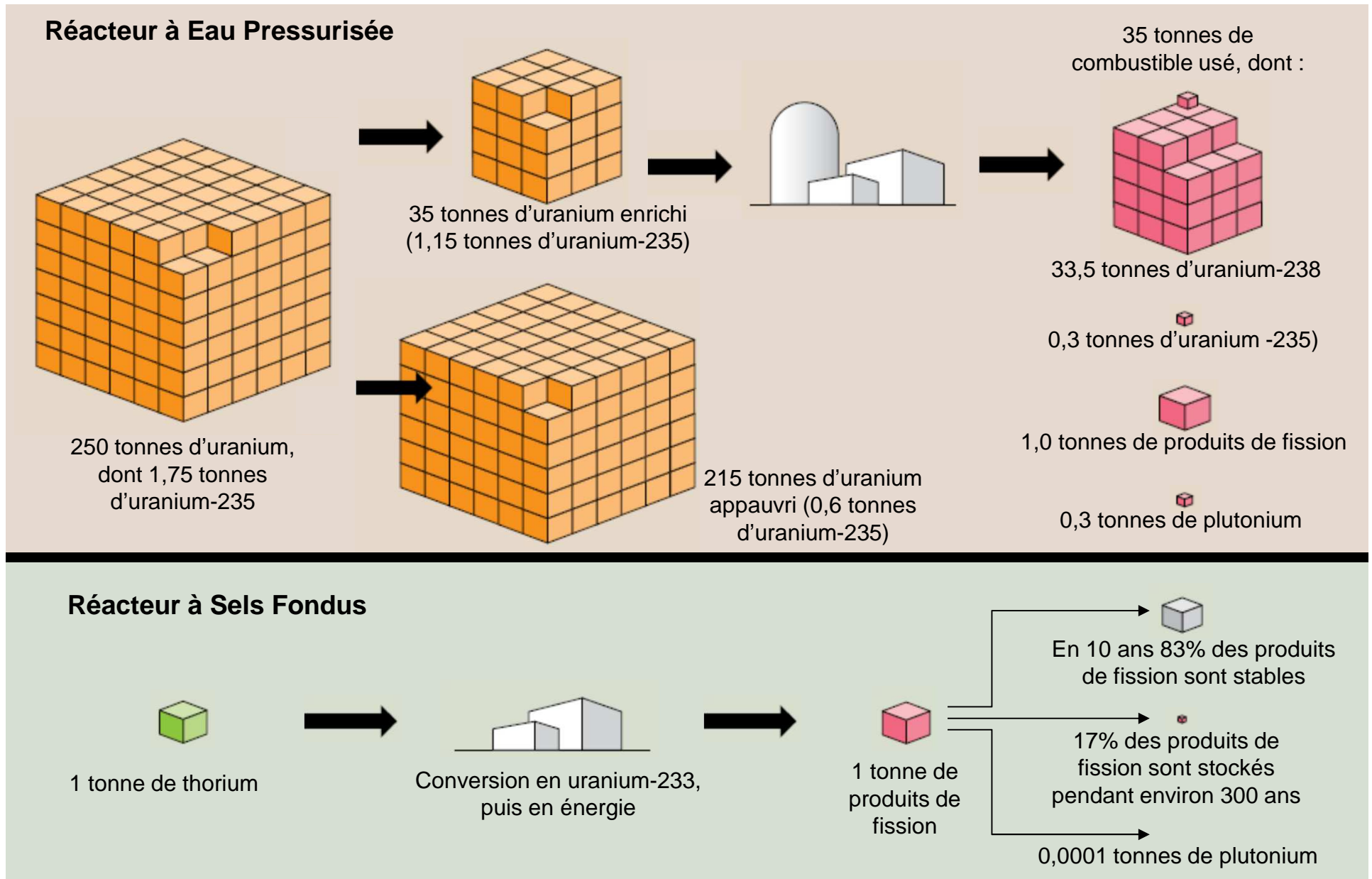
Réacteur à eau pressurisé :

Typiquement 0,5% de la teneur  
en énergie de l'uranium

Combustible liquide :

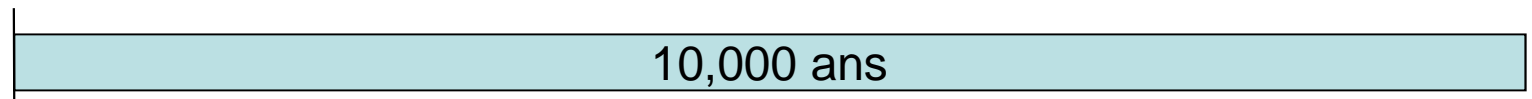
100% de la teneur en  
énergie du thorium

# Pour produire 1 GigaWatt-Année d'électricité :

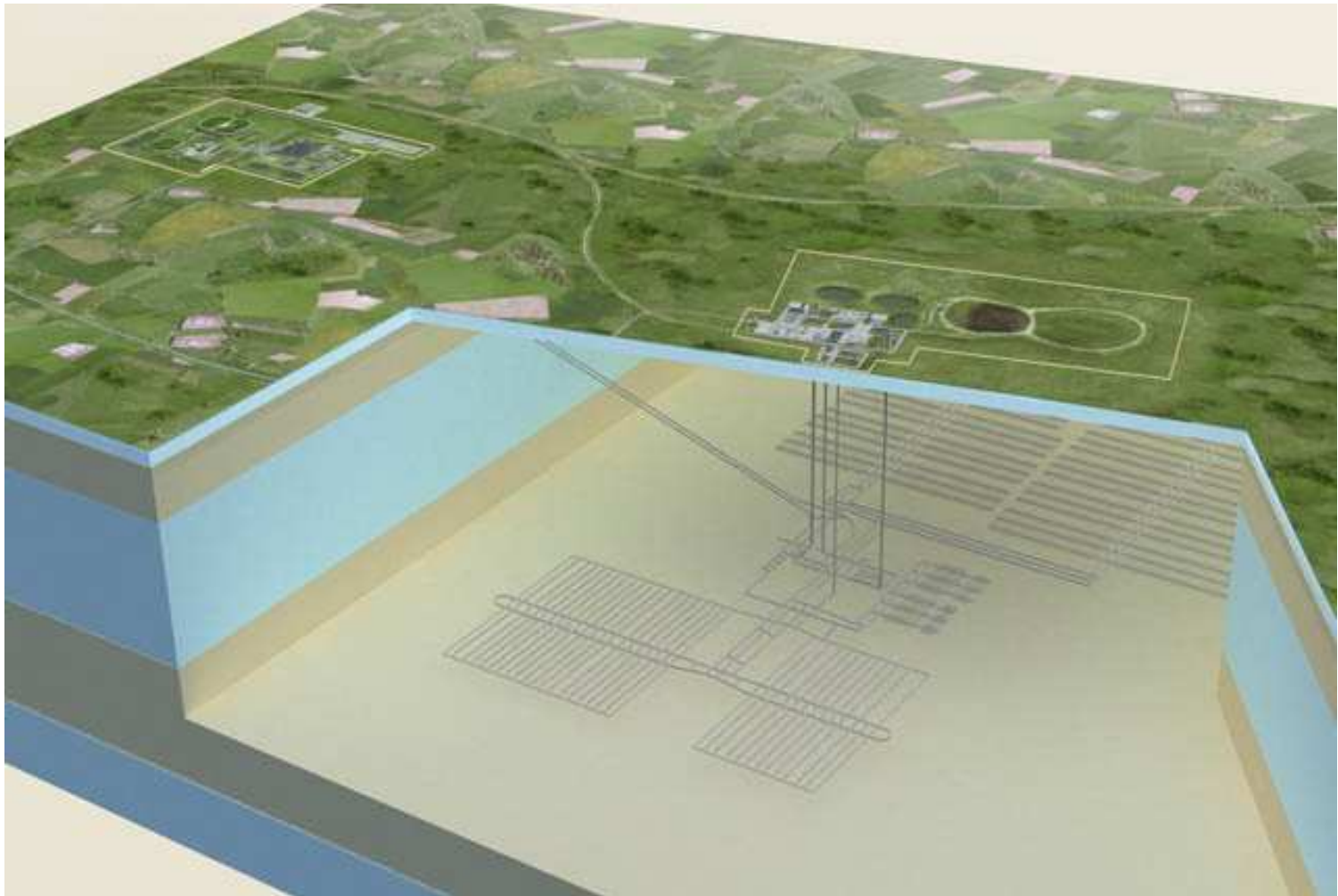


Source : Robert Hargraves et Ralph Moir, American Scientist No. 98, Juillet-Août 2010, p.308

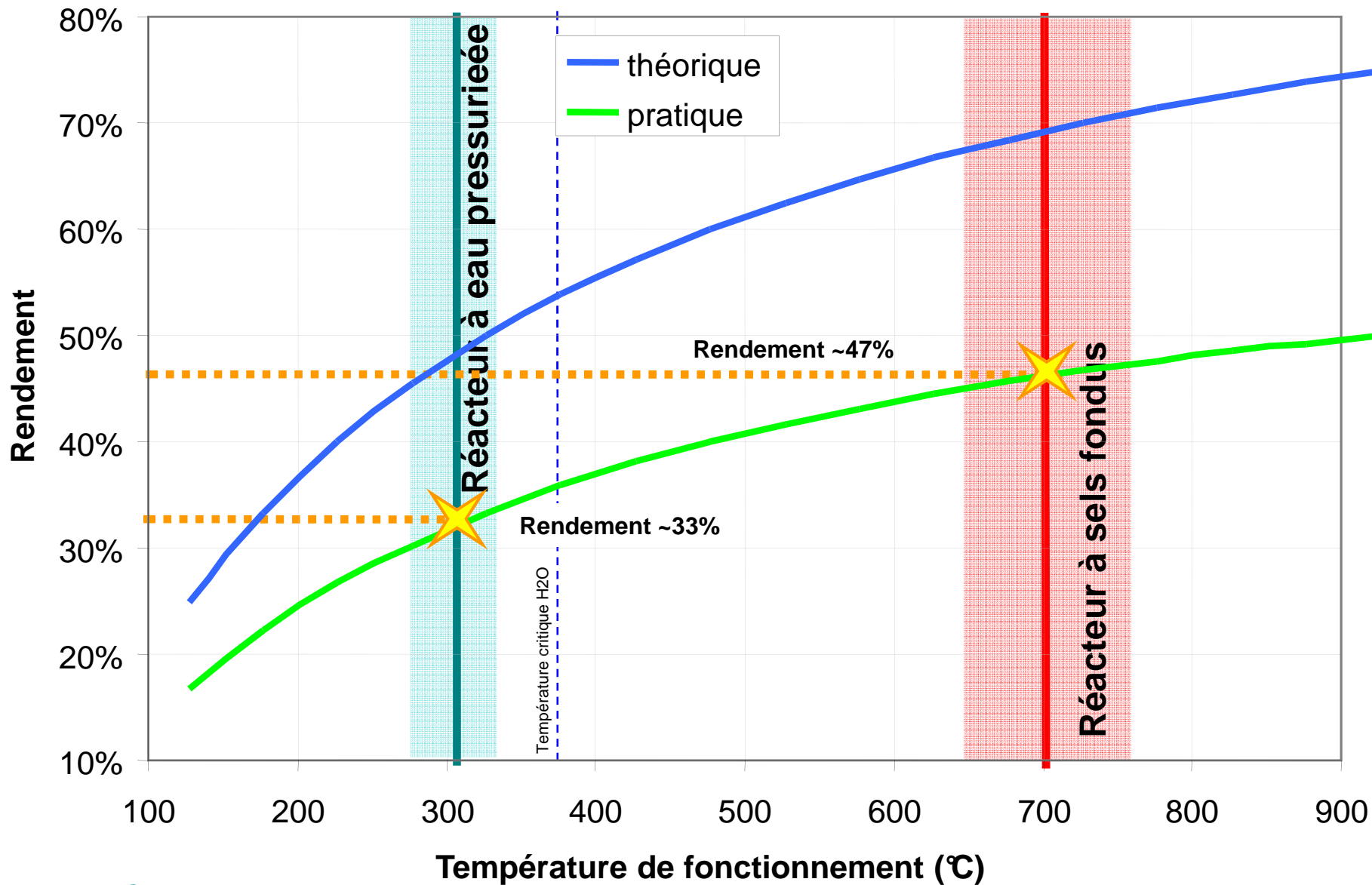
Aujourd'hui



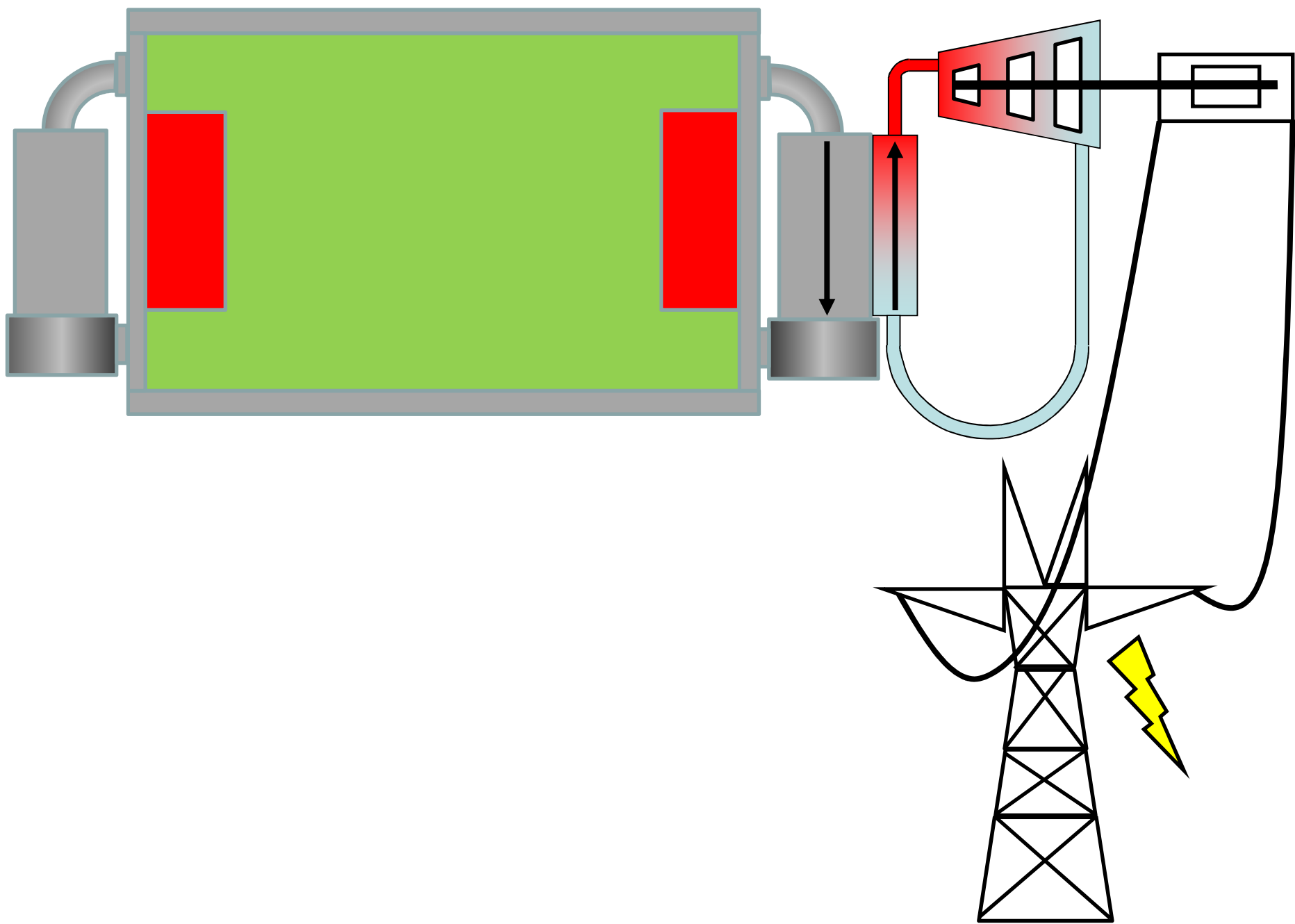
300 ans

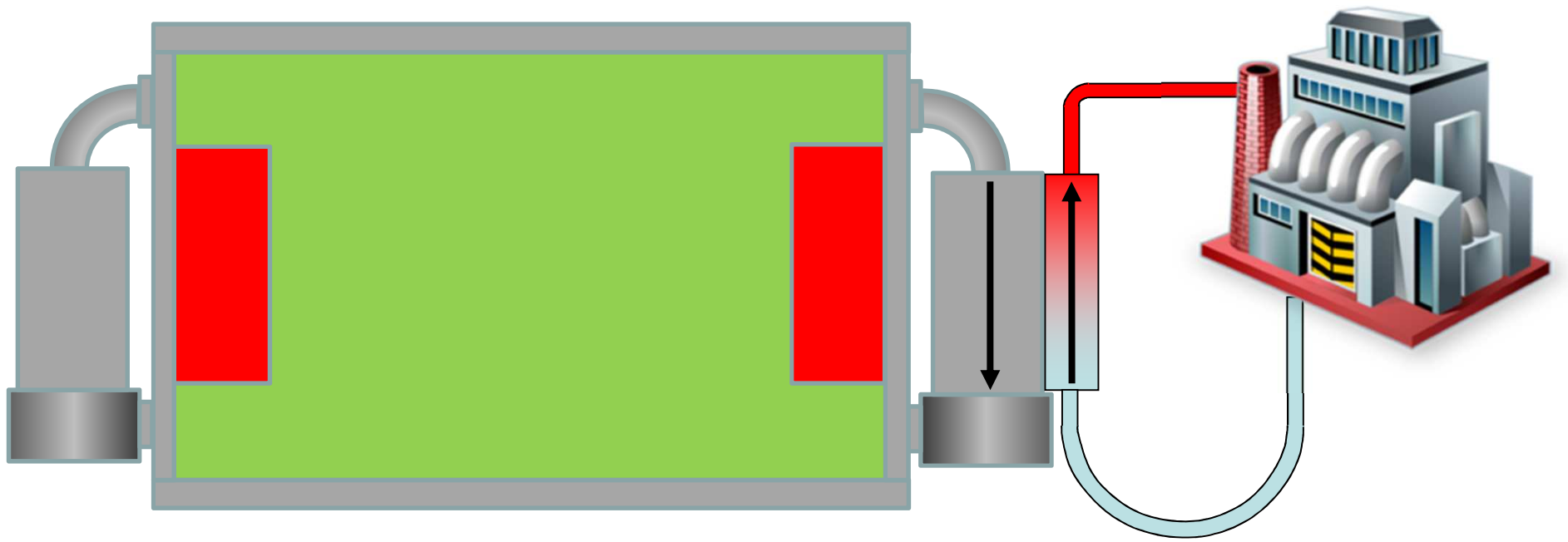


# Rendements dans la production d'électricité



Source : [K Sorensen, Flibe Energy](#)



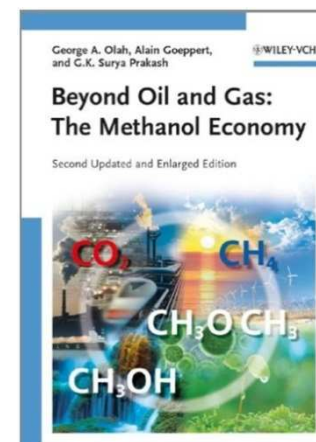
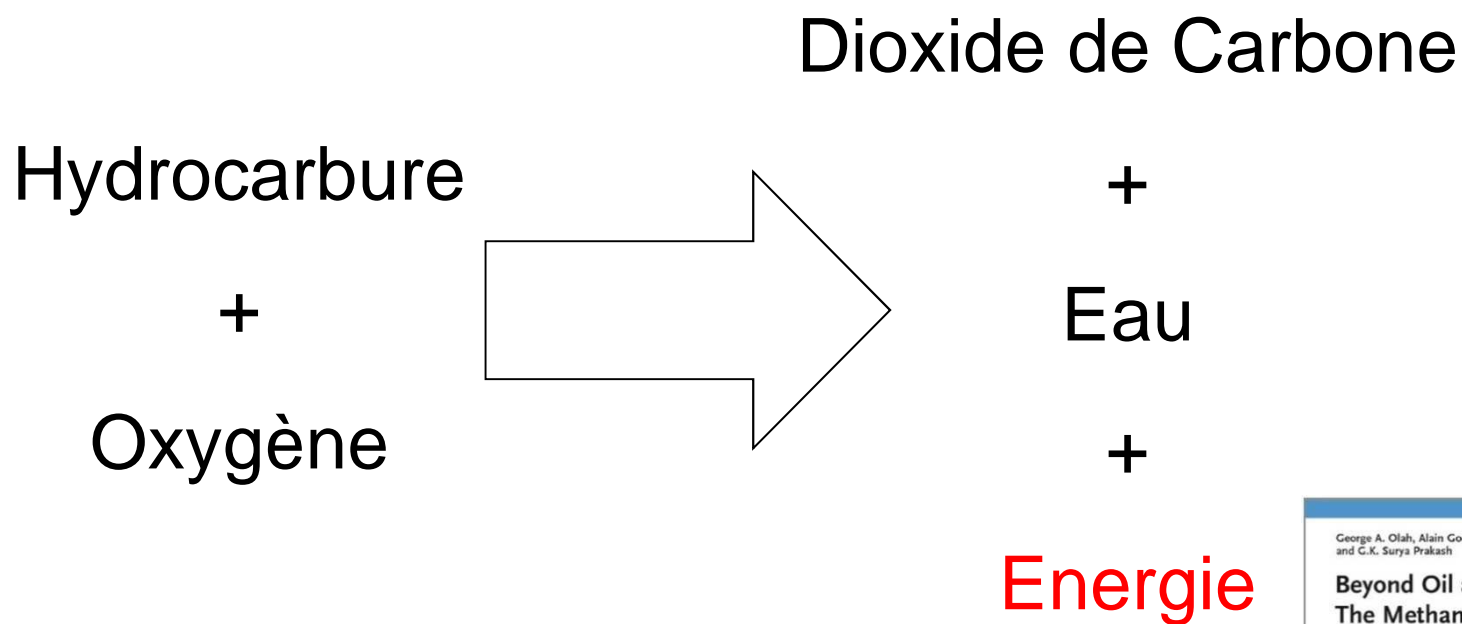


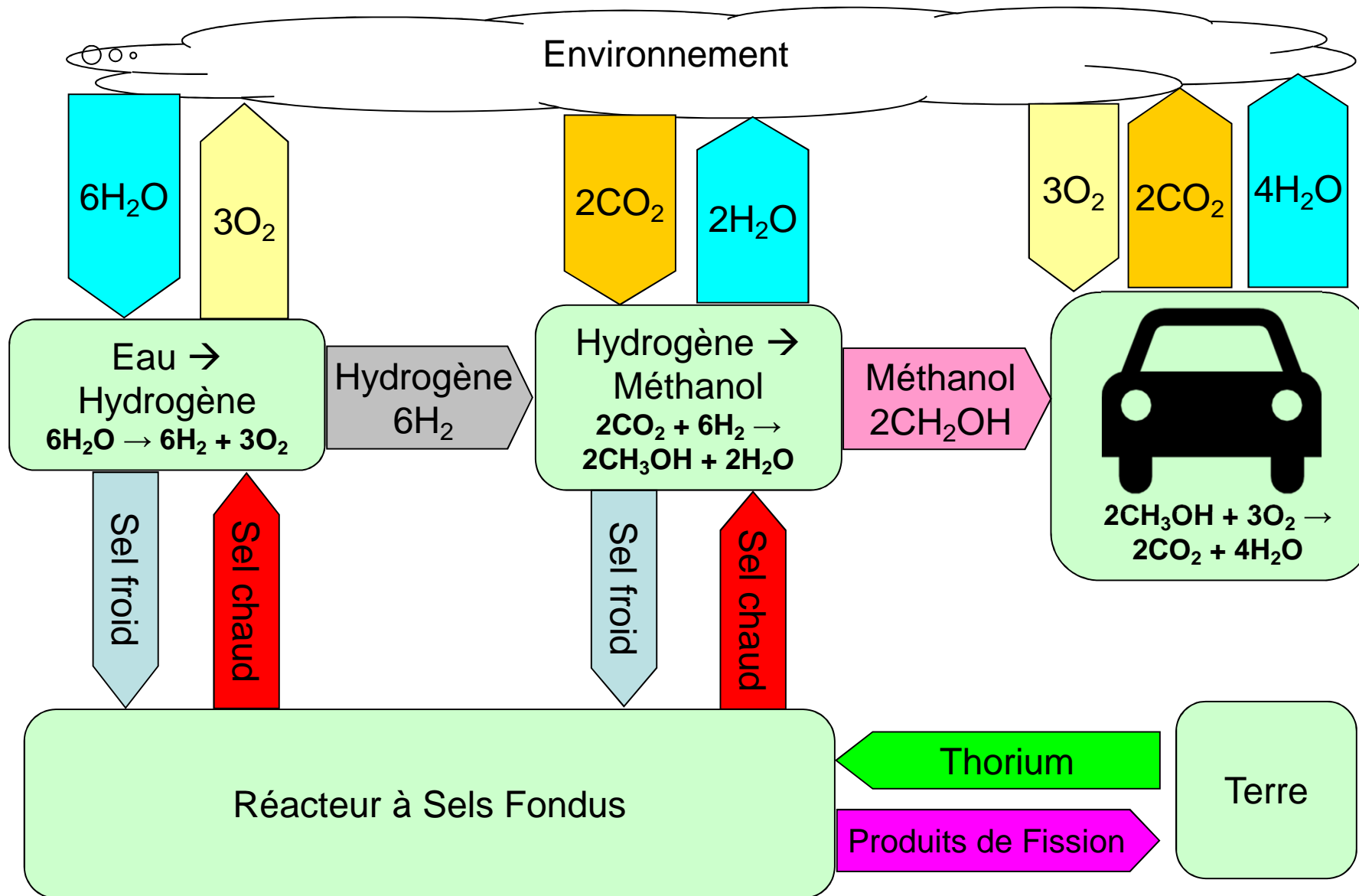






# Carburants de synthèse à partir de la chaleur nucléaire







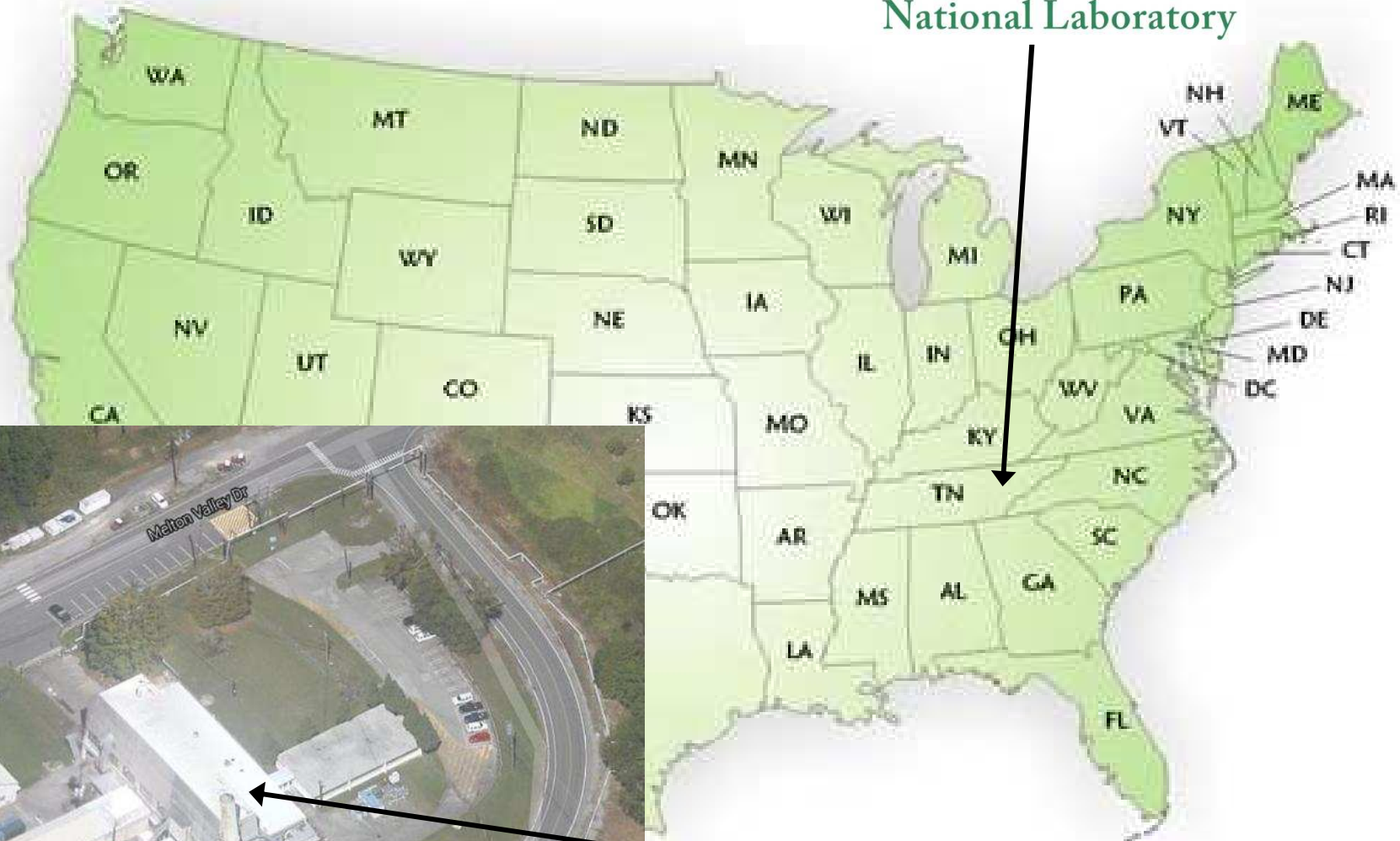


Alvin Weinberg

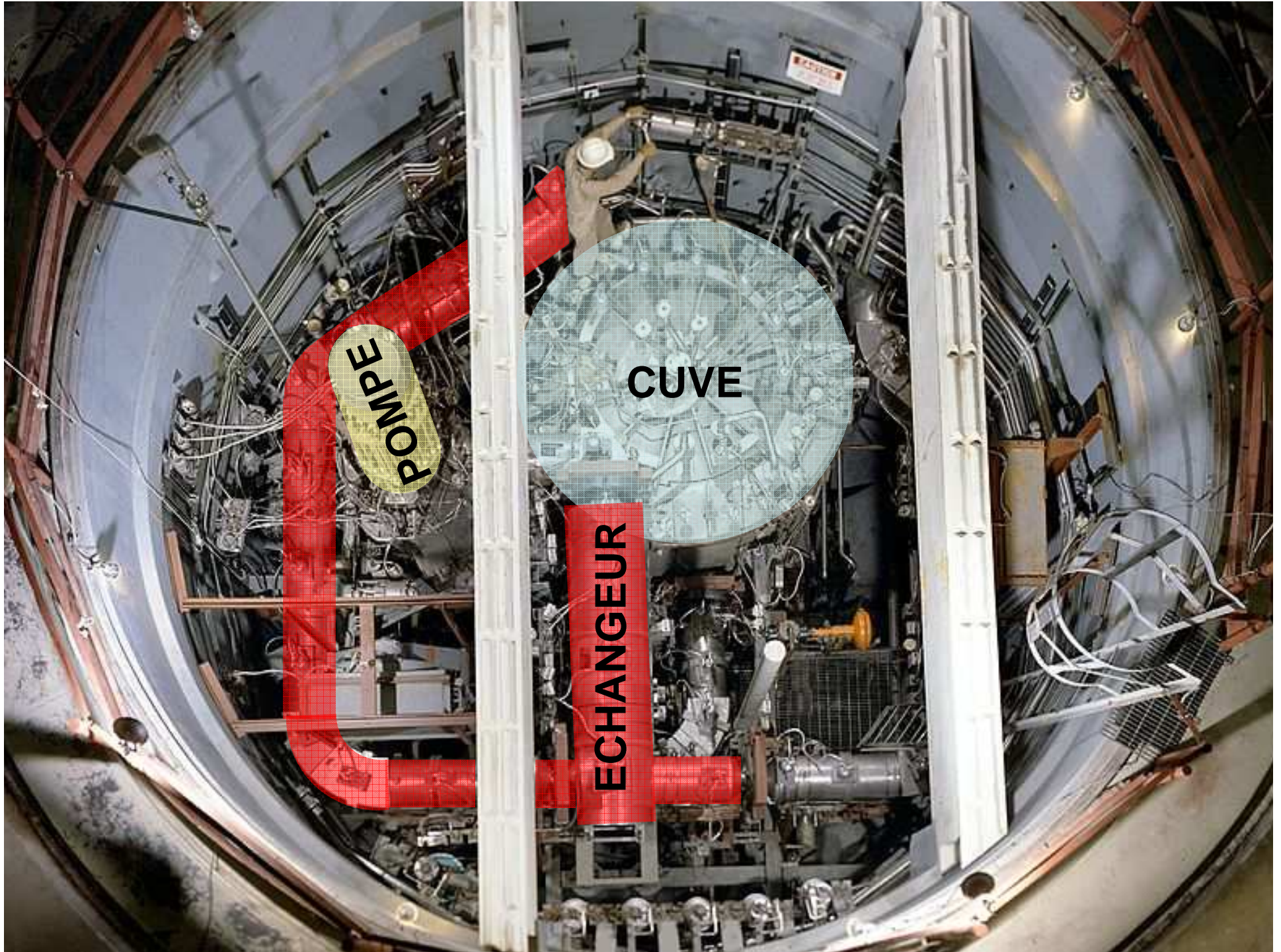


# OAK RIDGE

National Laboratory



Molten Salt Reactor Experiment  
(MSRE)



**POMPE**

**CUVE**

**ECHANGEUR**





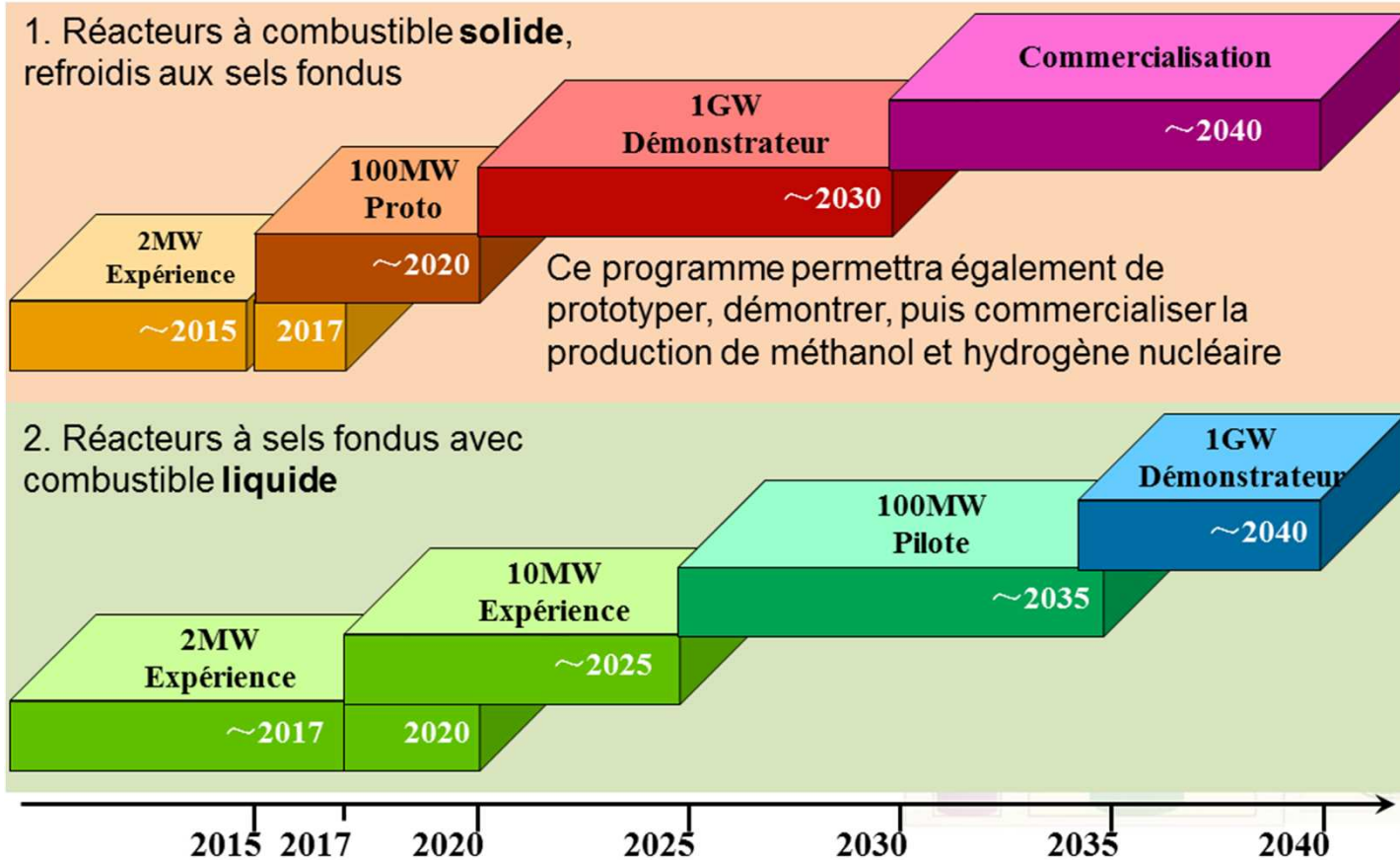




Jiang Mianheng



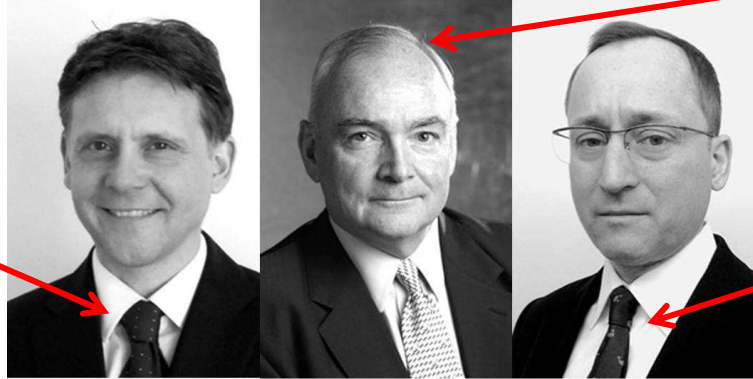
Hongjie Xu





# TERRESTRIAL E N E R G Y

Ex-PDG, Energie  
Atomique du  
Canada limité



Avocat

Banquier

Ingénieur, industrie  
des sables  
bitumineux

David Leblanc  
Physicien, expert  
en réacteurs à  
sels fondus



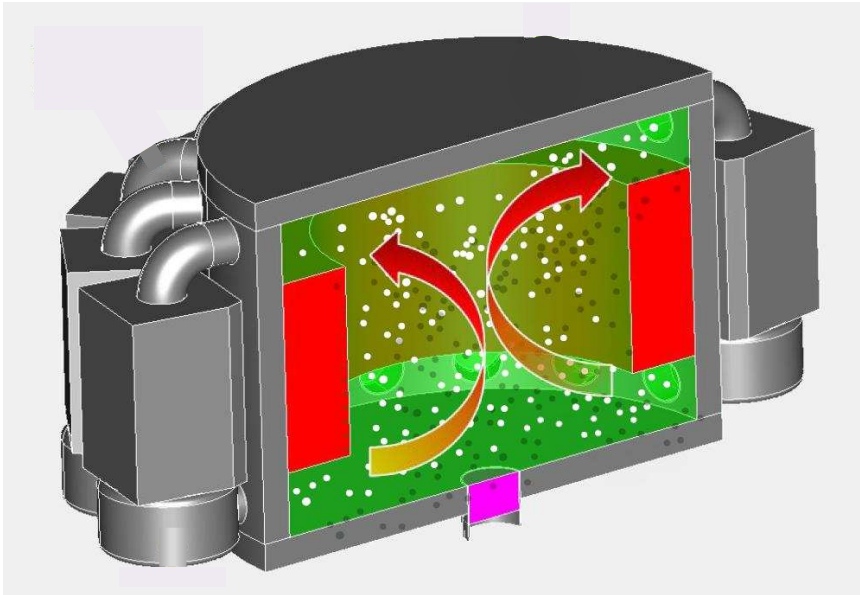
Scientifique,  
exploration  
pétrolière

Financier

Directeur, alliance pour  
l'énergie du thorium  
(association)

Cadre, industrie  
pétrolière





## FISSION LIQUIDE

**FIABLE** 😊

**BON MARCHÉ** 😊

**SÛR** 😊

**DURABLE** 😊

**PROPRE** 😊



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