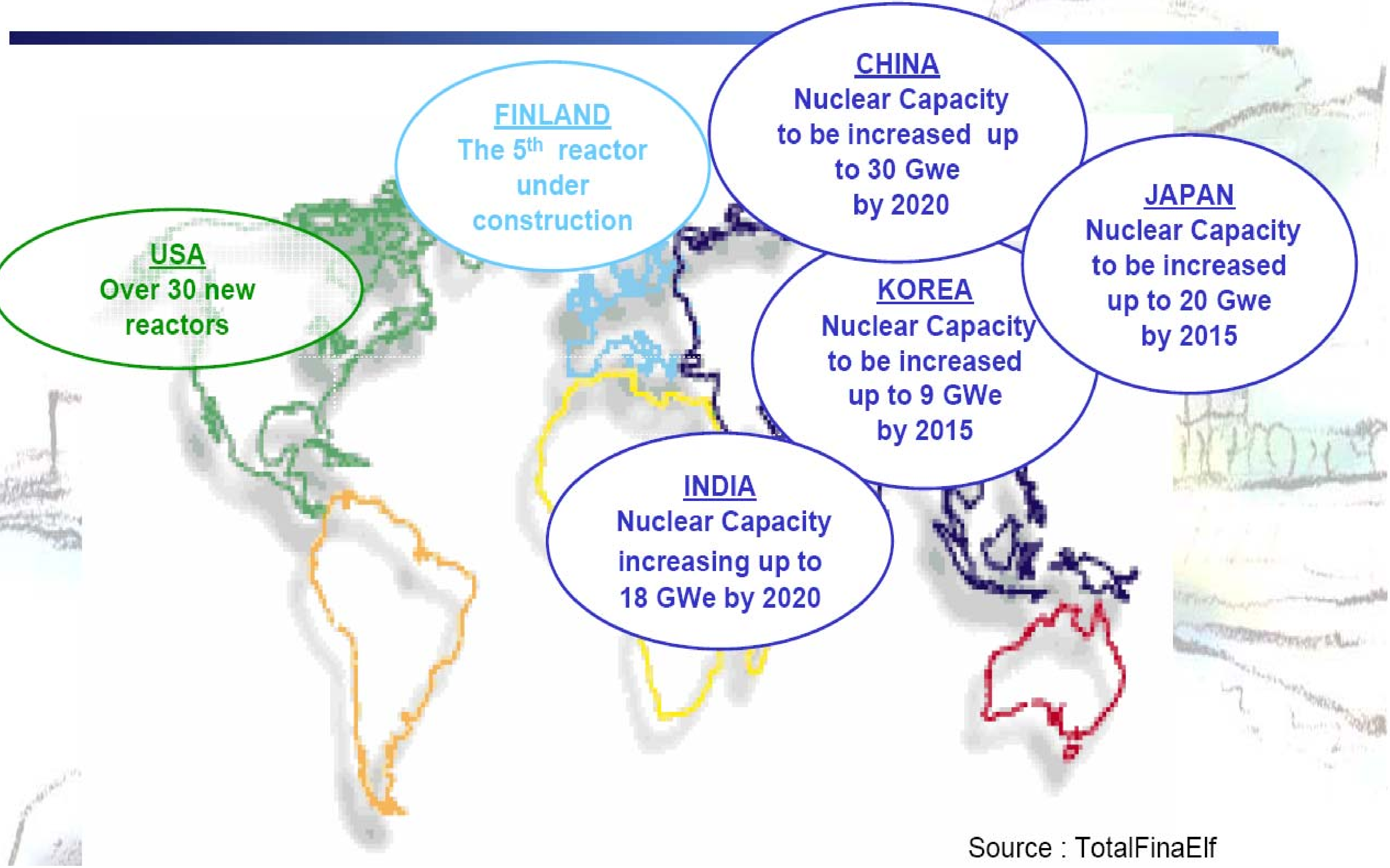
Nuclear Renaissance



Source : TotalFinaElf

Nuclear renaissance

NUCLEAR POLICY

Outlook

May / June 2007 Policy Matters That Affect Your Business

In This Issue...

The restart of the Tennessee Valley Authority's Brown Ferry 1 reactor last month marks a major achievement for the U.S. nuclear energy industry. Although TVA did not build the reactor from scratch, it completed the Brown Ferry 1 project on schedule and within budget expectations. This augurs well for other companies exploring construction of new reactors in the United States. This issue of Nuclear Policy Outlook examines what made TVA's effort successful and what this means for the rest of the industry.

Bringing Back Browns Ferry 1

What Does the Achievement Mean to an Industry Poised for Growth?

A little more than five years ago, a collection of managers, engineers and planners at the Tennessee Valley Authority set out to determine how they were to address the challenge looming before electric utilities all across America: What to do to secure new baseload generating capacity? They weighed the generating options. They assessed available generating sources, fuels, costs and timetables. And they sized up environmental issues. Their decision: Let's go nuclear.

Browns Ferry 1 returned to service in May.

With that decision, they set in motion a massive project to refurbish the Browns Ferry 1 reactor, long abandoned in the minds of many after its shutdown 22 years ago.

No small endeavor. This was not a "new" reactor in the sense that earthmoving equipment carved out the site, with builders pouring thousands of tons of fresh concrete and operators bringing a new reactor on line from scratch.

But the project that ensued at this northern Alabama site involved the laying of some 200 miles of electrical cable and nearly 9 miles of pipe, and the installation of nearly 200 tons of structural steel—all the product of more than 15 million worker hours. The result of this five-year, $1.8 billion construction effort: Browns Ferry 1 restarted in late May, this time as a state-of-the-art, wholly revitalized and modern machine. And it did so on schedule, within the agency's budget expectations.

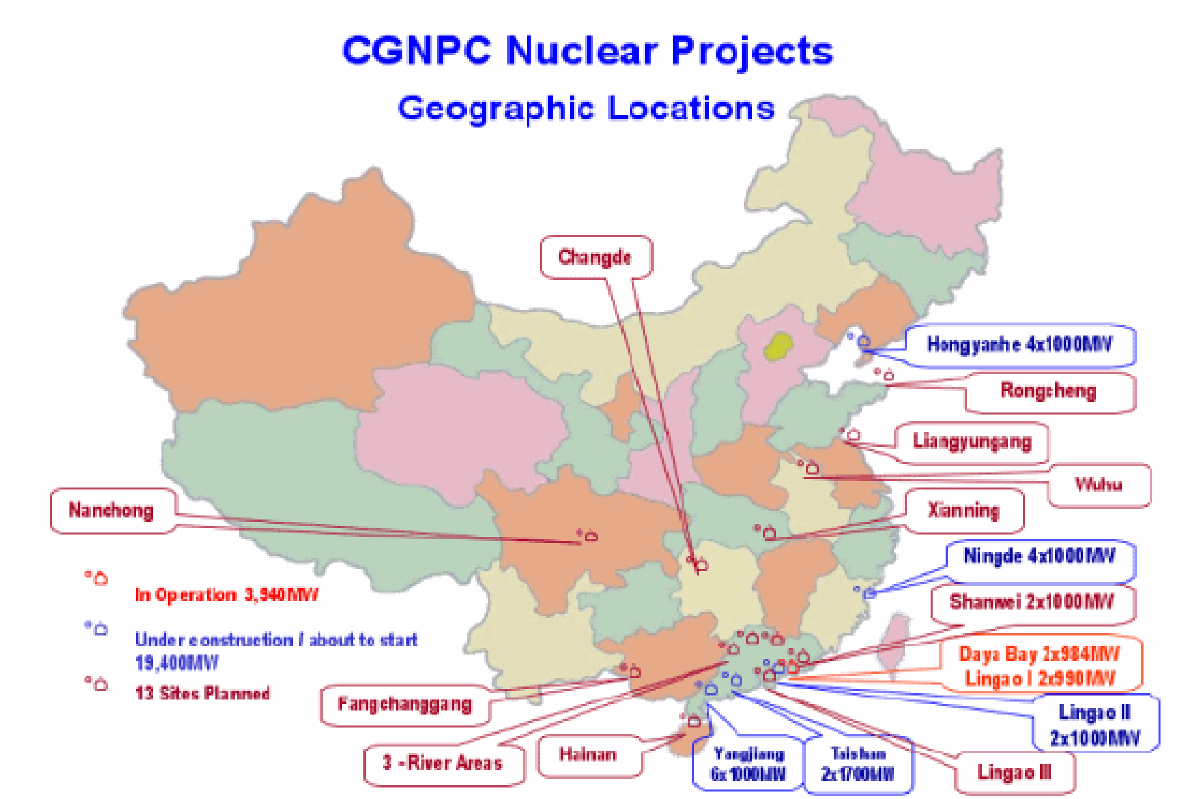
Any assessment of industry events would have to put the Browns Ferry 1 restart high on the list of key milestones. In the 1960s, Browns Ferry became the site of TVA's first nuclear power plant. When the three reactors first began operating in the 1970s, it was the world's largest nuclear power plant. The agency proudly notes that the three-reactor site was the first nuclear plant in the world to produce more than 1 billion watts of electricity.

Now, Browns Ferry is the site of another first—the first U.S. reactor to come on line in this century. The reactor reached full power on June 8. But it is likely that it will not be the last.

Tenessee : a reactor stopped since 22 years has been restarted on June 8th 2007

New Nuclear Reactors in China

On WNA reactor table, those here not under construction are "planned". At 30 April 2009, 12 under construction: 12,100 MWe, 33 planned, 35,320 MWe.



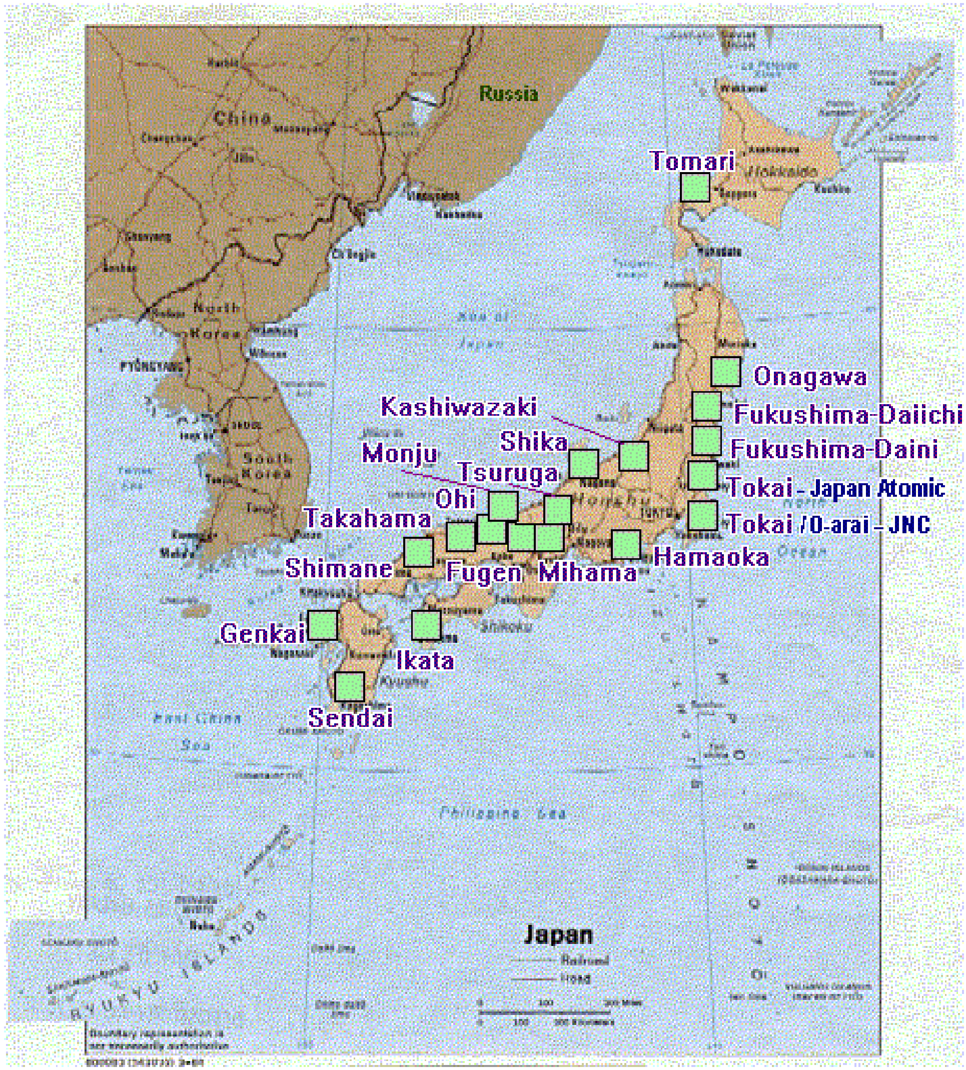
New Nuclear Reactors in China

Nuclear reactors under construction and planned

Plant	Province	MWe gross	Type	Project control	Start const.	Operation
Lingao-2 (units 3 & 4)	Guangdong	2x1080	CPR-1000	CGNPC	**12/05, 5/06**	12/10, 8/11
Qinshan 4 (units 6 & 7)	Zhejiang	2x650	CNP-600	CNNC	**4/06, 1/07**	2011, 2012
Hongyanhe 1 (units 1-4)	Liaoning	4x1080	CPR-1000	CGNPC	**8/07, 4/08,** 3/09, 7/10	10/12, 2014
Ningde 1 (units 1-2)	Fujian	2x1080	CPR-1000	CGNPC	**2/08,** 11/08,	12/12-2013
Yangjiang 1 (units 1-2)	Guangdong	2x1080	CPR-1000	CGNPC	**12/08**, 15/6/09	8/13, 2015
Fuqing 1 (units 1-2)	Fujian	2 x 1080	CPR-1000	CNNC	**11/08,** 2009	10/13, 8/14
Fangjiashan (Qinshan 5)	Zhejiang	2 x 1080	CNP-1000?	CNNC	**12/08,** 6/09	12/13, 10/14
Sanmen 1 (units 1 & 2)	Zhejiang	2x1100	AP1000	CNNC	**3/09,** 2010	10/13, 2014
Haiyang (units 1 & 2)	Shandong	2x1100	AP1000	CPI	9/2009, ?	2014-15
Taishan 1 (units 1 & 2)	Guangdong	2x1700	EPR	CGNPC	8/8/09, 1/7/10	12/13, 11/14
Shidaowan	Shandong	200	HTR-PM	China Huaneng	9/09	2013 or 2014
Fangchengang	Guangxi	2x1080	CPR-1000	CGNPC	12/09, ?	2014, ?
Yangjiang 2 (units 3 & 4)	Guangdong	2x1080	CPR-1000	CGNPC	9/09, 7/10	2015, 15
Ningde 2 (units 3 & 4)	Fujian	2x1080	CPR-1000	CGNPC	7/09. 3/10	2014, 15
Fuqing 2 (units 4-6)	Fujian	4x1080	CPR-1000	CNNC	2010?	
Tianwan 2 (units 3 & 4)	Jiangsu	2x1060	AES-91	CNNC	2009?	
Hongshiding 1(Rushan)	Shandong	2x1080	CPR-1000	CNEC/CNNC	2009	2015
Changjiang 1	Hainan	2x650	CNP-600	CNNC	2/2009	2014, 2015
Dafan 1, Xianning	Hubei	2x1080	CPR-1000	CGNPC	2009, 2010	
Xiaomoshan 1	Hunan	2x1100	AP1000	CPI	2010	
Pengze 1	Jiangxi	2x1100	AP1000	CPI	2010	2015
Haiyang 2 (units 3 & 4)	Shandong	2x1100	AP1000	CPI	2010?	
Wuhu	Anhui	2x1080	CPR-1000	CGNPC	late 2011	2015
total 49	51,740 MWe					

Main numbers = phase, Bold = construction started

Nuclear Reactors in Japan



Nuclear Reactors in India

Individual plants within the country as shown on the above map:

Individual units at the plant site: **Kaiga**			
Kaiga 1	PHWR	India	Under construction
Kaiga 2	PHWR	India	Under construction

Individual units at the plant site: **Kakrapar**			
Kakrapar 1	PHWR	India	Operable
Kakrapar 2	PHWR	India	Operable

Individual units at the plant site: **Madras**			
Madras 1	PHWR	India	Operable
Madras 2	PHWR	India	Operable

Individual units at the plant site: **Narora**			
Narora 1	PHWR	India	Operable
Narora 2	PHWR	India	Operable

Individual units at the plant site: **Rajasthan**			
Rajasthan 1	PHWR	India	Operable
Rajasthan 2	PHWR	India	Operable
Rajasthan 3	PHWR	India	Under construction
Rajasthan 4	PHWR	India	Under construction

Individual units at the plant site: **Tarapur**			
Tarapur 1	BWR	India	Operable
Tarapur 2	BWR	India	Operable
Tarapur 3	PHWR	India	Under construction
Tarapur 4	PHWR	India	Under construction

Fast Breeders

India has started the construction of a fast breeder in Kalpakkam, which should operate in 2010

France has closed its two fast breeders Superphenix (in 1998) and Phenix (2009)


Monju (Japan)

The International Forum **Gen IV** has defined six projects to be studied in detail, among which four fast breeders.
The U/Pu cycle can provide CO_2 free energy for centuries.

2003 Wind Energy Resources in California Statistics

Resource Site	Capacity (MW)	Generation (GWh)	Number of Turbines
Altamont	562	1,071	4,788
Solano	165	102	700
Pacheco Pass	16	25	167
Tehachapi Ranges	710	1,482	3,444
SanGorgonio Pass	359	893	2,556
State Total	1,812	3,573	11,655

1 Réacteur nucléaire	1,000	7,800	

With 11655 windmills, one gets a maximum **power** (in Watts) equal to that of 2 nuclear reactors, but only one half of the **energy** (in Watts.hour) produced by these 2 reactors.

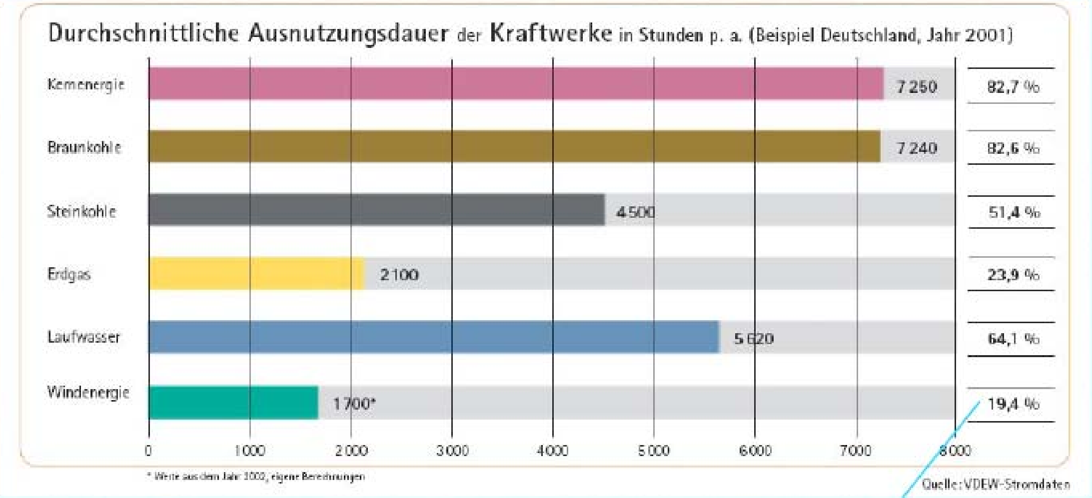
ÉCOLE POLYTECHNIQUE MONTRÉAL

Les éoliennes dans le monde

Rang	Pays (fin 2004)	MW
01	Allemagne	18 428
02	Espagne	10 027
03	États-Unis	9 149
04	Inde	4 430
05	Danemark	3 128
06	Italie	1 717
07	Royaume-Uni	1 353
08	Chine	1 260
09	Pays-Bas	1 219
10	Japon	1 040
11	Portugal	1 022
12	France	1000
13	Autriche	819
14	Canada	683
15	Grèce	573
16	Australie	572
17	Suède	510
18	Irlande	496
19	Norvège	270
20	Nouvelle-Zélande	168
	Total mondial	**58 982**

Source : *World Wind Energy Association (2004)*

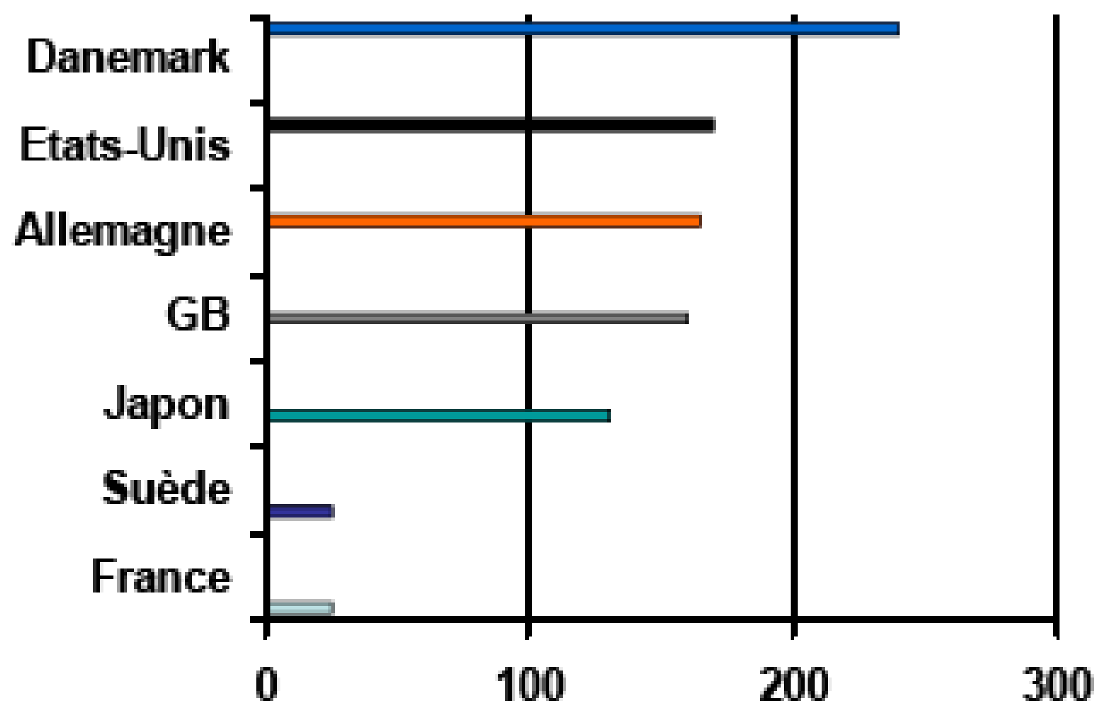
- Il n'est pas facile de connaître l'énergie produite avec cette puissance installée. Par exemple, en Allemagne, on rapporte:



un facteur d'utilisation de seulement 19.4%

CO_2 production/habitant

Le choix des énergies : rejets de CO_2 par kWh dans le monde (gC/kWh)



2004

Source : Jancovici, 2004

Jancovici

Predictions of the Deutsche Energie Agentur GmbH

Scénarios envisagés	Sortie du nucléaire			Extension de la durée de vie des centrales		
	2010	2015	2020	2010	2015	2020
1) Programme gouvernemental (diminution de la consommation)	**-2261**	**2837**	**11664**	-4793	-4917	-4827
2) Consommation électrique constante	-1434	5318	15799	-3966	-2436	-692
3) Augmentation de la consommation électrique	385	9039	21009	-2147	1285	4518

Synthèse des résultats de l'étude de la DENA :
estimation de la différence [demande maximale – offre disponible] électrique (en MW) dans les différents scénarios envisagés

www.bulletins-electroniques.com/actualites/53697.htm

Crédits : Arnaud Bertrand

FM

Le constat de la DENA

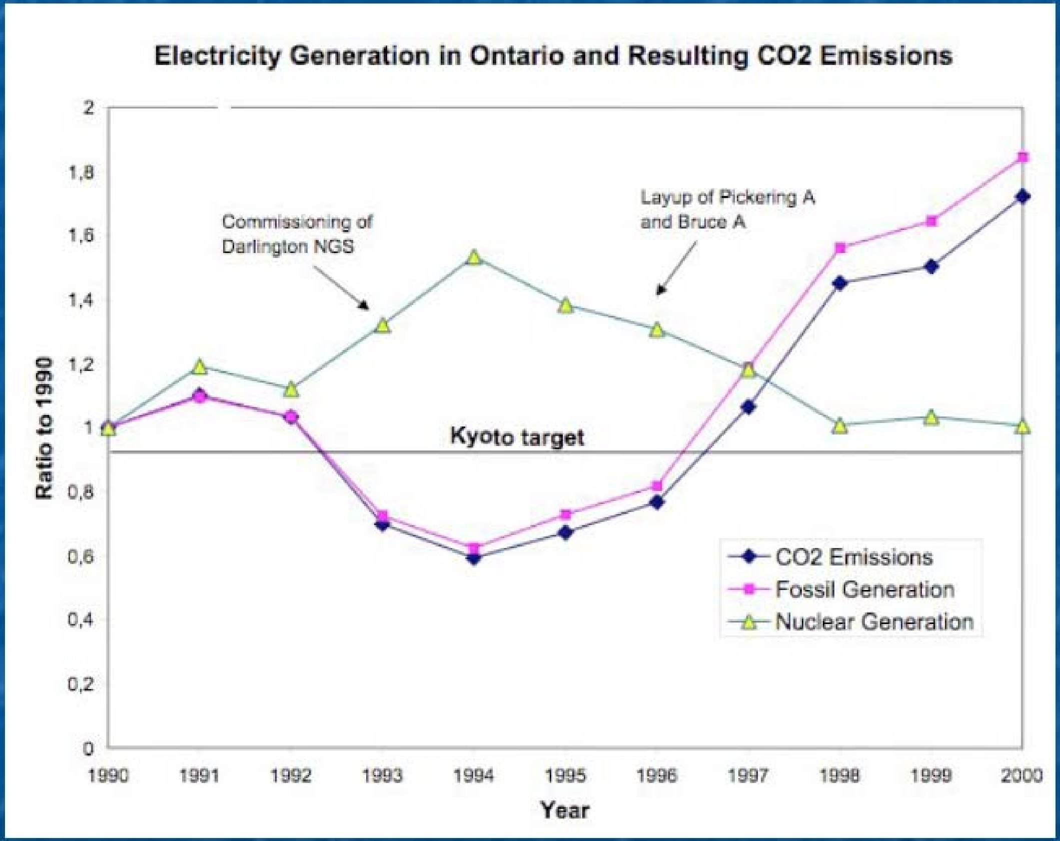
One particular challenge is presented by the integration of around 60,000 megawatts of electricity from wind and sun by the year 2020, as these sources are subject to very strong natural fluctuations. Wind turbines and photovoltaic power plants can therefore only replace a small portion of the power provided from conventional sources. It is therefore of the utmost importance that new and highly efficient conventional power stations are built which can provide the required balancing and reserve power. In addition, the electricity grid must be adapted to the new specifications and extended, as has been explained in the dena Grid Study.

Yet Germany is going in quite the opposite direction at the moment. When the erection of an efficient coal power station is prevented, as happened recently in Ensdorf, Saarland, the fact is celebrated as a great political success for the climate. At the same time there is very strong opposition to the construction of grid cables in Thuringia, Bavaria and Lower Saxony. This will seriously hamper the extension of renewable energies in the future.

The consequences of this trend are clear: old, inefficient coal power stations will continue to operate, emitting a disproportionately higher amount of CO_2 than that emitted by modern plants. At the same time the price for CO_2 certificates will rise because of the need to compensate for the cost advantage of coal and lignite over natural gas. Complaints about rising electricity prices will be superfluous, as increases are the natural.

Kyoto en Ontario

- Entre 1995 et 1998, fermeture provisoire de 7 centrales nucléai-res (Pickering A et Bruce A)
- Démarrage de centrales au charbon pour compenser
- Impact direct sur les émissions totales en Ontario, mettant en cause les objectifs de Kyoto



La pollution des centrales au charbon

- ~1900 décès prématurés et 9800 hospitalisations dus à la pollution de l'air (OMA, Ontario, 2000)
- polluants des centrales au charbon et % du total de l'Ontario (2000):
  - + SO_2, 23.7%
  - + NOx, 14.7%
  - + Mercure, 22.6%
  - + cendres, poussières, ?
- ~ 50% de la pollution de l'air en Ontario provient des centrales au charbon du midwest américain
- CO_2 n'est pas un polluant (36 TWh $\Rightarrow$ 36 Mt CO_2 /an)

USA: retraitement et transmutation

La Hague

Once through

Super Phenix

If we keep our policy and we don't recycle in the United States, we will have to build nine Yucca Mountains over the course of the century, if we just keep Yucca Mountain at 20 percent of our -- if we just keep nuclear power at 20 percent of our electricity generation. If we recycle and can burn down those wastes in a way that we are proposing, we will be able to use -- that one Yucca Mountain will be able to last for the entirety of the century.

The first element is to expand dramatically the use of nuclear power here in the United States. We think -- today, we have 100 nuclear reactors; many of those are going to start phasing out in the coming decades. We think we really need to be, from a public policy standpoint we're shooting for 300 reactors in 2050; that's a significant increase. That's what we think would be appropriate to meet our energy needs as well as to manage our greenhouse gas emissions and that's going to require significant advances in technology.

Génération IV

- **Des systèmes déployables à l'horizon 2040**
- **Des atouts pour de nouvelles applications**
  Hydrogène, eau potable, chaleur
- **Une R&D internationalisée**

Les systèmes Generation IV sélectionnés

Concepts GEN IV	Acronyme	Spectre	Cycle comb.
Sodium Cooled Fast Reactor	SFR	Rapide U/Pu	Fermé
Lead Alloy-Cooled Reactor	LFR	Rapide U/Pu	Fermé
Gas-Cooled Fast Reactor	GFR	Rapide U/Pu	Fermé
Very High Temperature Reactor	VHTR	Thermique	Ouvert
Supercritical Water Cooled Reactor	SCWR	Th.&Rap.	Ouvert/Fermé
Molten Salt Reactor	MSR	Thermique	Fermé

Principe de la transmutation

On place certains déchets (après séparation) dans un flux de neutrons intense

$^{129}I + n_{thermique} \rightarrow {}^{130}I + \gamma$

1,6 10^7 ans — 12 heures

$^{241}Am + n_{rapide} \rightarrow {}^{137}Xe + {}^{102}Mo + 2n$

432 ans — 4 min — 11 min

$\downarrow$ $\rightarrow {}^{136}Xe + {}^{102}Mo + 3n$

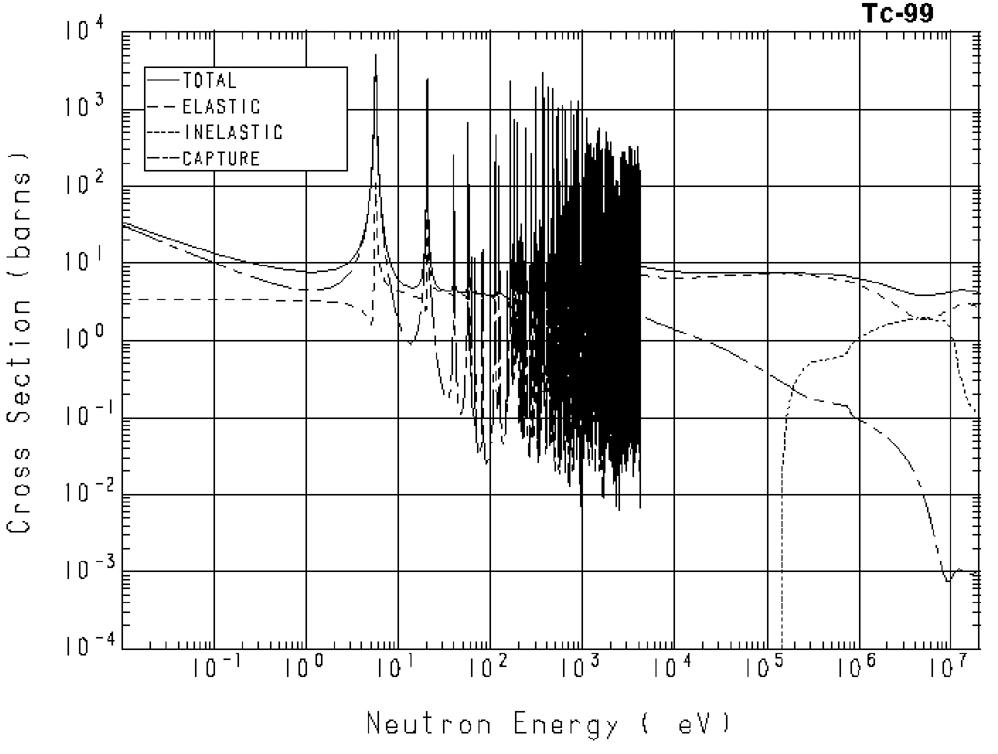
stable — 11 min

$^{237}Np \rightarrow \ldots \rightarrow \ldots$

2 10^6 ans

Transmutation de fragments de fission

^{99}Tc+n ➔ γ + ^{100}Tc (β$^-$ 15.8s) ➔ ^{100}Ru

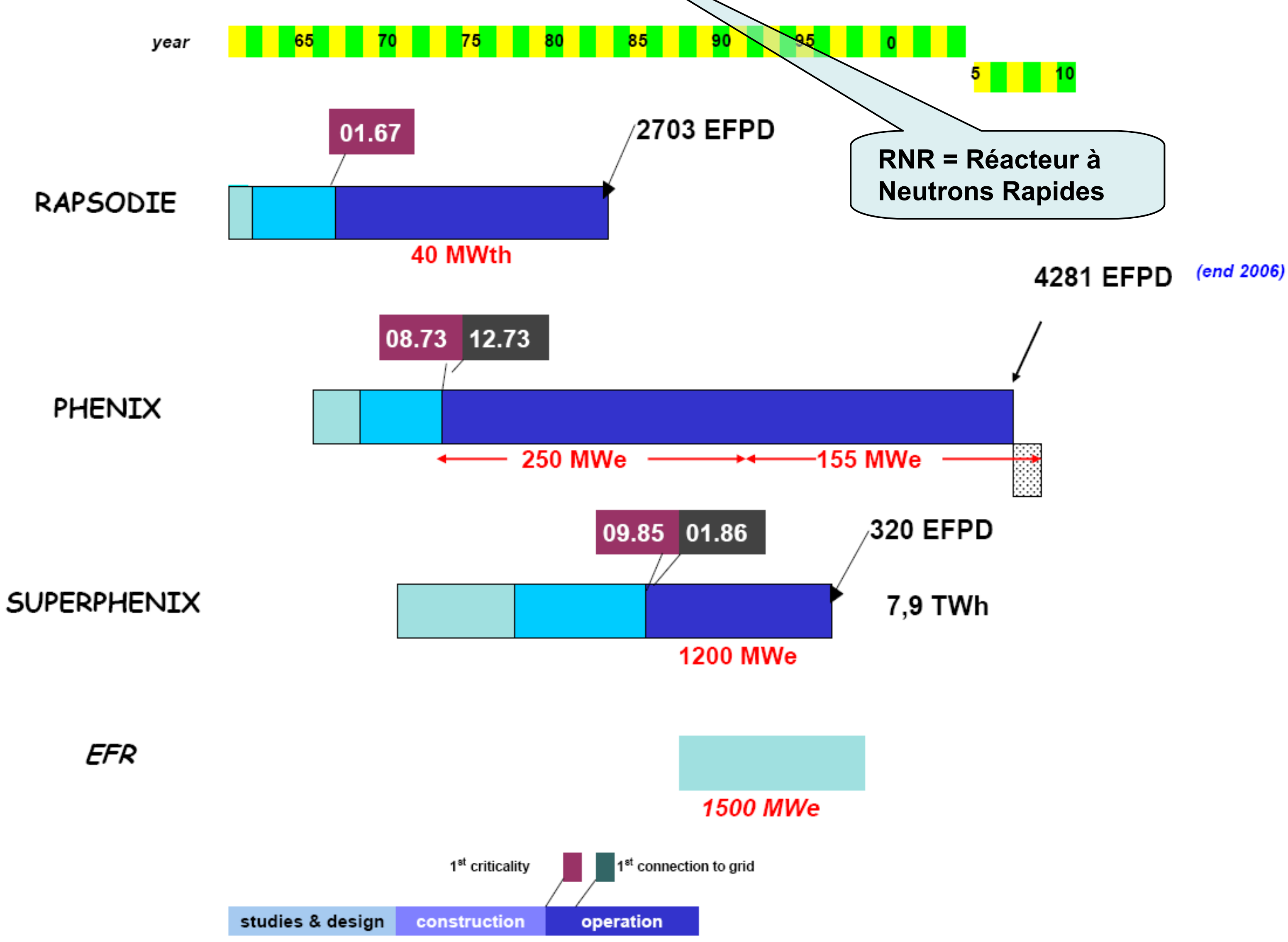


^{99}Tc (2.1 10^5 y)

🡻

^{100}Ru (stable)

L'expérience RNR Na en France



Plans for New Nuclear Reactors

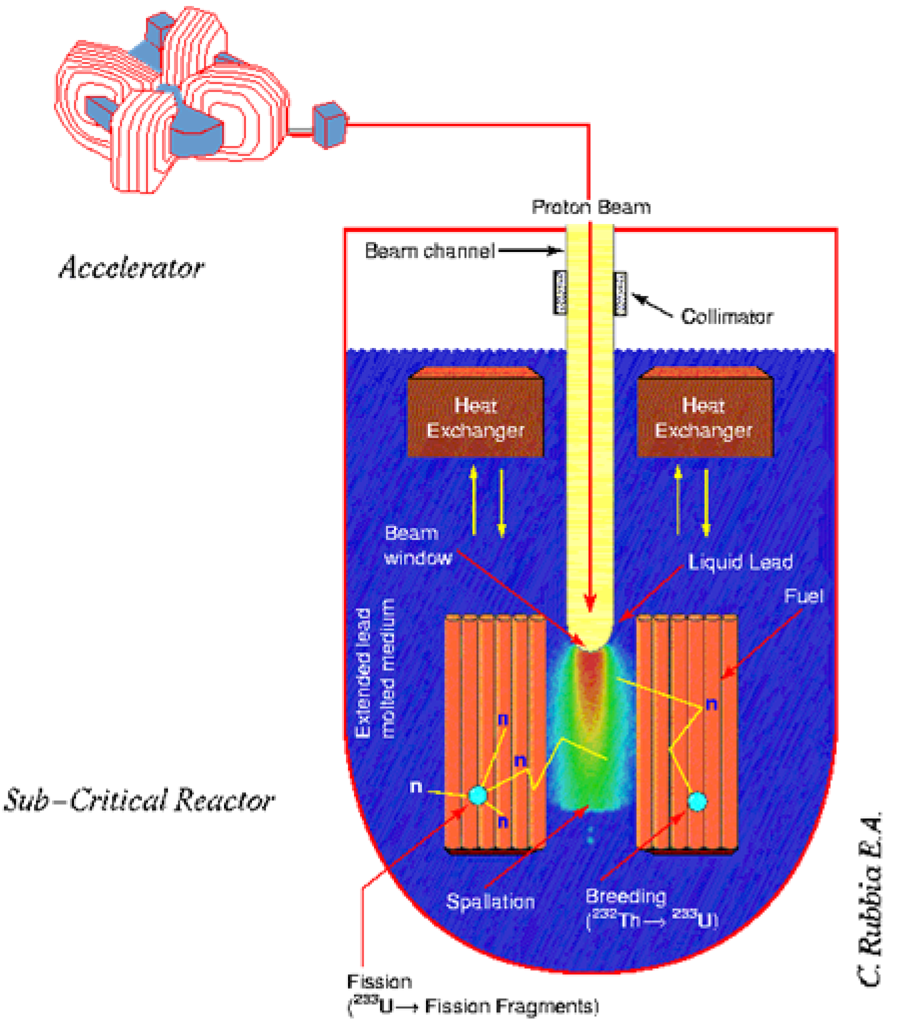
Start Operation*		REACTOR	TYPE	MWe (net)
2009	India, NPCIL	Rawatbhata 5	PHWR	202
2009	India, NPCIL	Kaiga 4	PHWR	202
2009	India, NPCIL	Kudankulam 1	PWR	950
2009	India, NPCIL	Rawatbhata 6	PHWR	202
2009	Iran, AEOI	Bushehr 1	PWR	950
2009	Russia, Energoatom	Volgodonsk 2	PWR	950
2009	Japan, Hokkaido	Tomari 3	PWR	912
2010	India, NPCIL	Kudankalam 2	PWR	950
2010	Canada, Bruce Power	Bruce A1	PHWR	769
2010	Canada, Bruce Power	Bruce A2	PHWR	769
2010	Korea, KHNP	Shin Kori 1	PWR	1000
2010	China, CGNPC	Lingao 3	PWR	1080
2010	Argentina, CNEA	Atucha 2	PHWR	692
2010	Russia, Energoatom	Severodvinsk	PWR x 2	70
2011	India, NPCIL	Kalpakkam	FBR	470
2011	Taiwan Power	Lungmen 1	ABWR	1300
2011	Russia, Energoatom	Kalinin 4	PWR	950
2011	Korea, KHNP	Shin Kori 2	PWR	1000
2011	China, CNNC	Qinshan 6	PWR	650
2011	China, CGNPC	Lingao 4	PWR	1080
2011	Pakistan, PAEC	Chashma 2	PWR	300
2012	Finland, TVO	Olkiluoto 3	PWR	1600
2012	China, CNNC	Qinshan 7	PWR	650
2012	Taiwan Power	Lungmen 2	ABWR	1300
2012	Korea, KHNP	Shin Wolsong 1	PWR	1000
2012	France, EdF	Flamanville 3	PWR	1630
2012	Russia, Energoatom	Beloyarsk 4	FBR	750
2012	Japan, Chugoku	Shimane 3	PWR	1375
2012	Russia, Energoatom	Novovoronezh 6	PWR	1070
2012	Slovakia, SE	Mochovce 3	PWR	440
2012	China, CGNPC	Hongyanhe 1	PWR	1080
2012	China, CGNPC	Ningde 1	PWR	1080
2013	China, CNNC	Sanmen 1	PWR	1100
2013	China, CGNPC	Ningde 2	PWR	1080
2013	Krea, KHNP	Shin Wolsong 2	PWR	1000
2013	Russia, Energoatom	Leningrad 5	PWR	1070
2013	Russia, Energoatom	Novovoronezh 7	PWR	1070
2013	Russia, Energoatom	Rostov/ Volgodonsk 3	PWR	1070
2013	Korea, KHNP	Shin Kori 3	PWR	1350
2013	China, CGNPC	Yangjiang 1	PWR	1080
2013	China, CGNPC	Taishan 1	PWR	1700
2013	China, CNNC	Fangjiashan 1	PWR	1000
2013	China, CNNC	Fuqing 1	PWR	1000
2013	Slovakia, SE	Mochovce 4	PWR	440

Start operation	Start construction		Reactor	Type	MWe (each)
2016	2011	Bulgaria, NEK	Belene 2	PWR	1000
2018	?	Japan, Tepco	Higashidori 2 (Tepco)	ABWR	1320
2016-17	2010	Japan, JAPC	Tsuruga 3 & 4	APWR	1500
2018	?	Japan, Chugoku	Kaminoseki 2	ABWR	1373
2016		Korea, KHNP	Shin-Ulchin 2	APR-1400	1350
2017		Slovenia, NEK	Krsko 2	PWR?	1000?
2017	2012	UAE, ENEC	?	?	

Réacteur Hybride

réacteur sous-critique, auquel les neutrons sont fournis par un accélérateur

Démonstrateur projeté: Myrrha (Mol, Belgique)



Radio-toxicité

	Dose annuelle en millisievert	Équivalent en paquets de cigarettes par an
Irradiation naturelle	3	15
Radon	2	10
Rayons cosmiques	0.3	1.5
Rayons X médicaux	0.4	2
Habiter à 2000m	0.6	4
Irradiation moyenne en France due à Tchernobyl dans la première année suivant l'accident	0.05	0.25

LPSC Grenoble

RADONTHERAPIE


Norme européenne : moins de 400 Bq/m3 bâtiment sain
plus de 1000 Bq/m3 bâtiment impropre à l'habitation

Mines de Badgastein : 16600 Bq/m3
Radonthérapie : cure de 3 heures/jour pendant 2-3 semaines

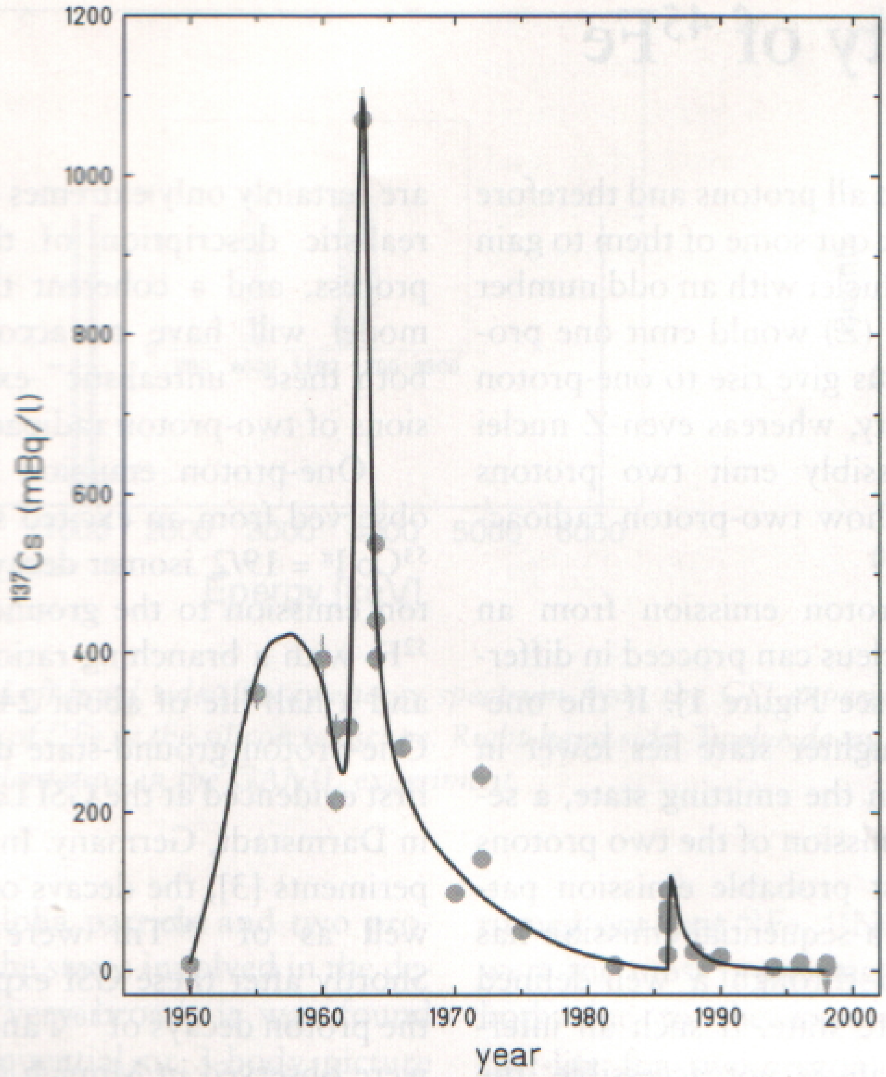


Figure 1. *Cesium activity in the Bordeaux wine as a function of the millésime.*