Safety problems with Generation III reactors

The Case of the French EPR

Yves Marignac

International Consultant on Nuclear and Energy Issues, Director of **WISE-*Paris***

yves.marignac@wise-paris.org

Nuclear Energy Conference 2016

"Nuclear Energy–Expansive Gamble"

Smetana Hall, Czech Automobile Club
Prague

5 April 2016

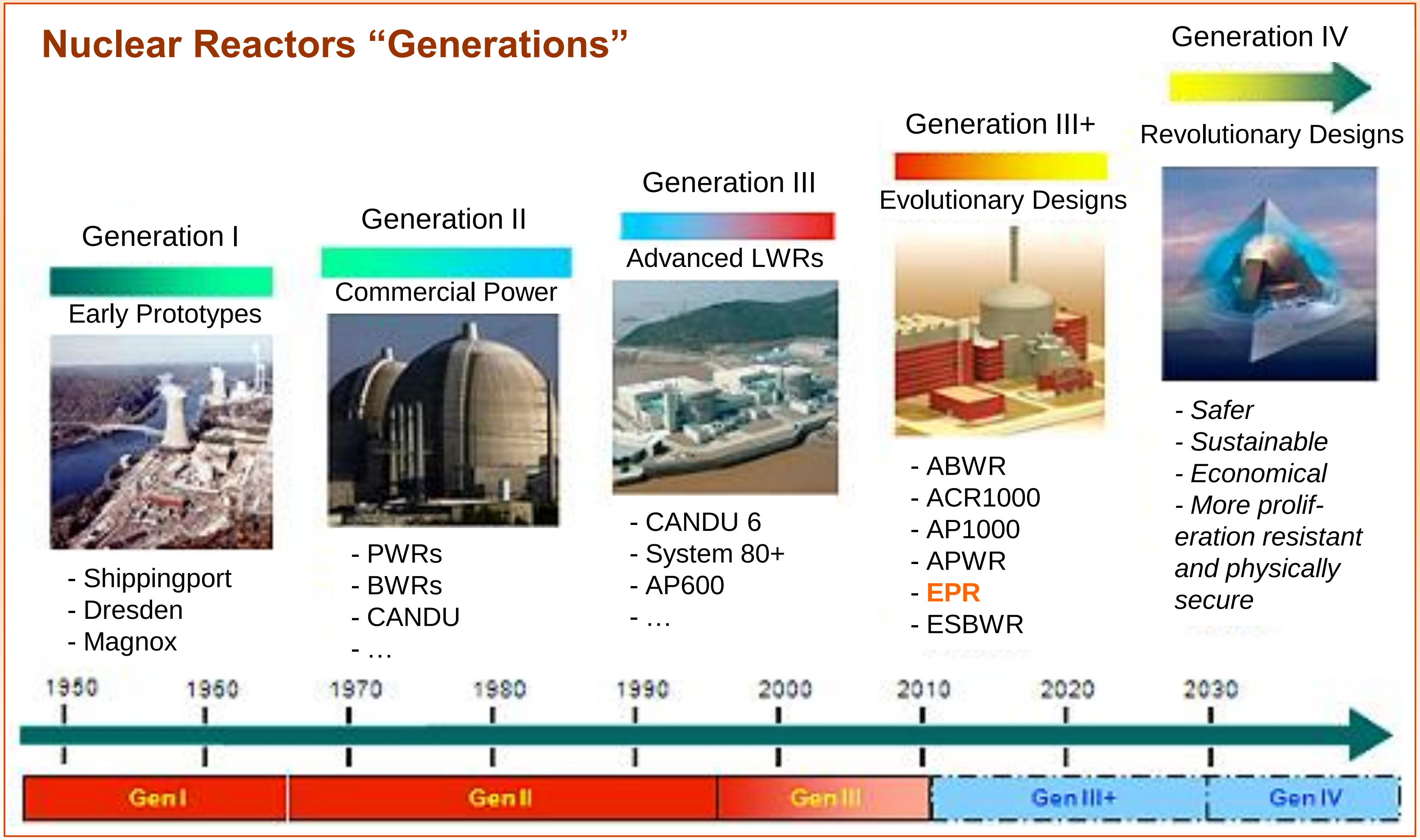
WISE-*Paris*: committed to independent expertise

- Information and consultancy independent agency created in 1983
- Non profit status and general interest goal
- A service to institutional players, academics, NGOs, medias…
- A large but intrinsically consistent range of issues covered

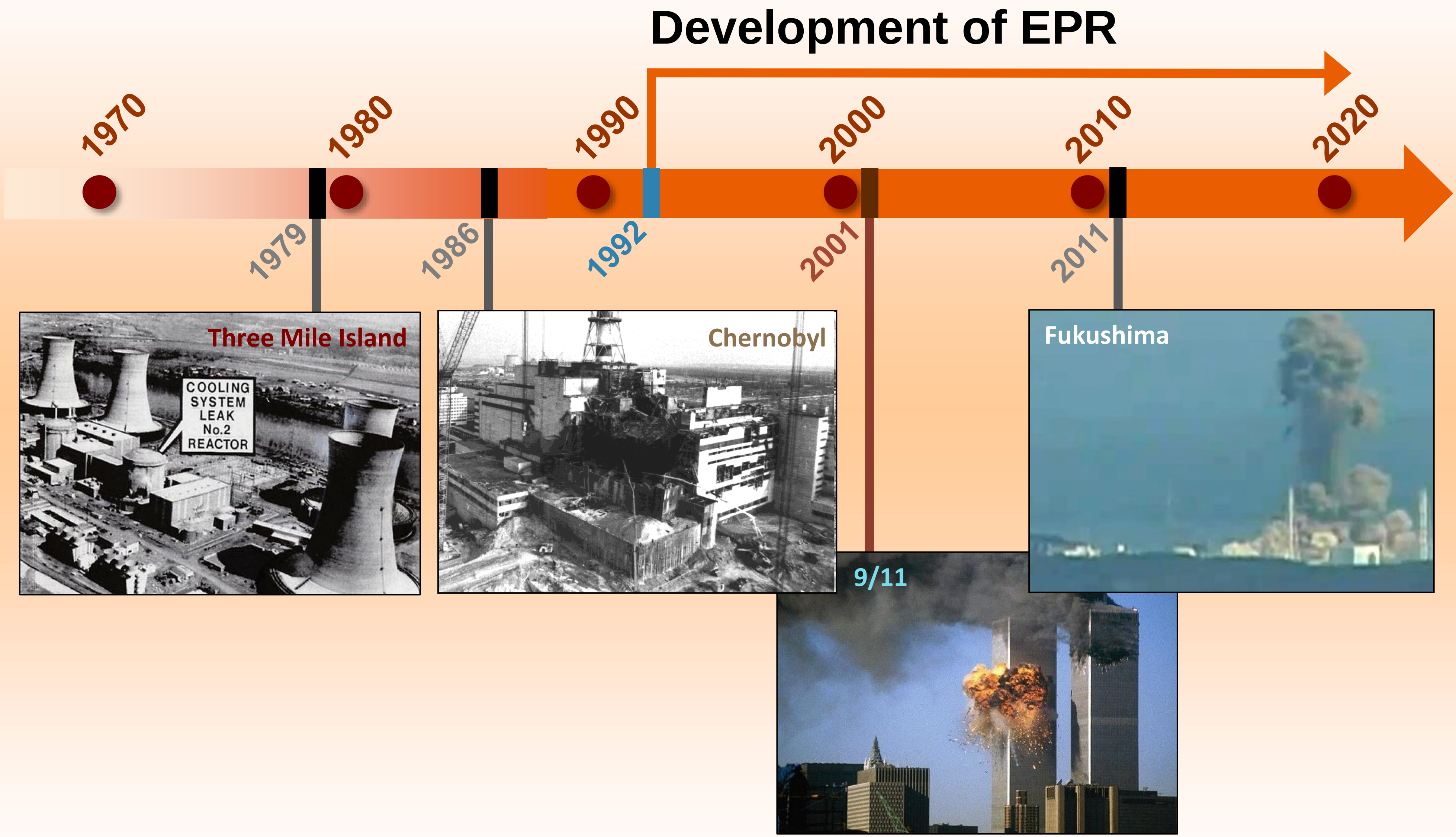
- Systemic analysis of issues, international approach
- Non institutional but professionnal expertise
- Critical thinking but no activist activities
- Strong commitment to developing pluralist expertise

Note than since the early 1990s WISE-Paris has no tie with any other WISE organisation

- **Generation III / IV** is a concept introduced in the 1990s to promote new reactors
- **EPR is part of Generation III+ so-called "evolutionary designs"**



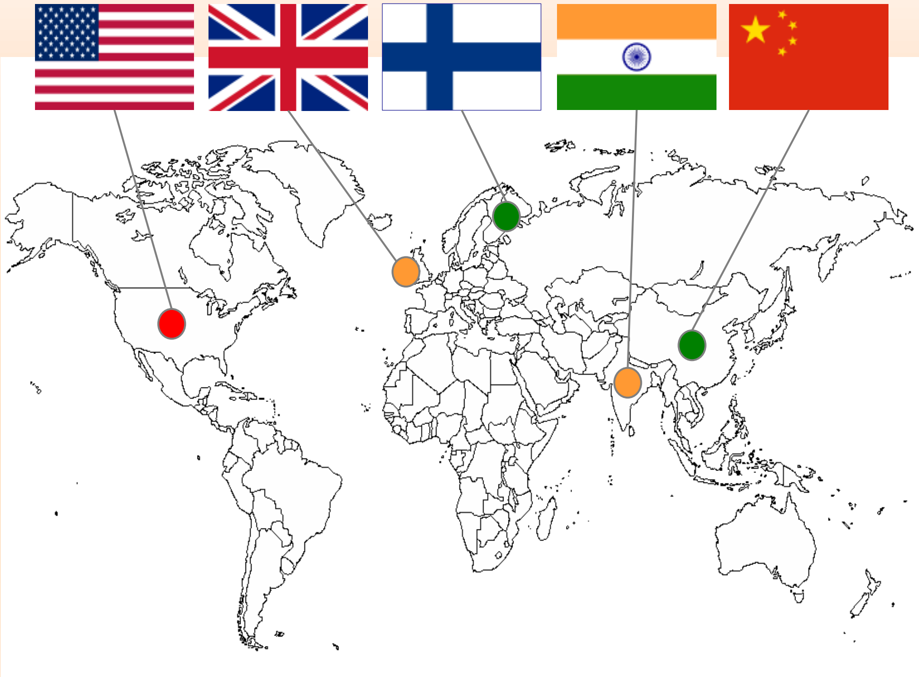
Project History (1/2)



Brief EPR project history:

- French/German development of a new up to 1,800 MWe design, project started in 1992s
- 1996-97, global design complete
- 2003, French decision to order a French EPR to prepare for future replacement (anticipate)
- In parallel, EPR project in Finland as international showcase, key to big export expectations
- 2005, final decision to build an EPR in Flamanville
- 2007, construction license is granted, EDF plans to get it built by 2012

The international EPR programme

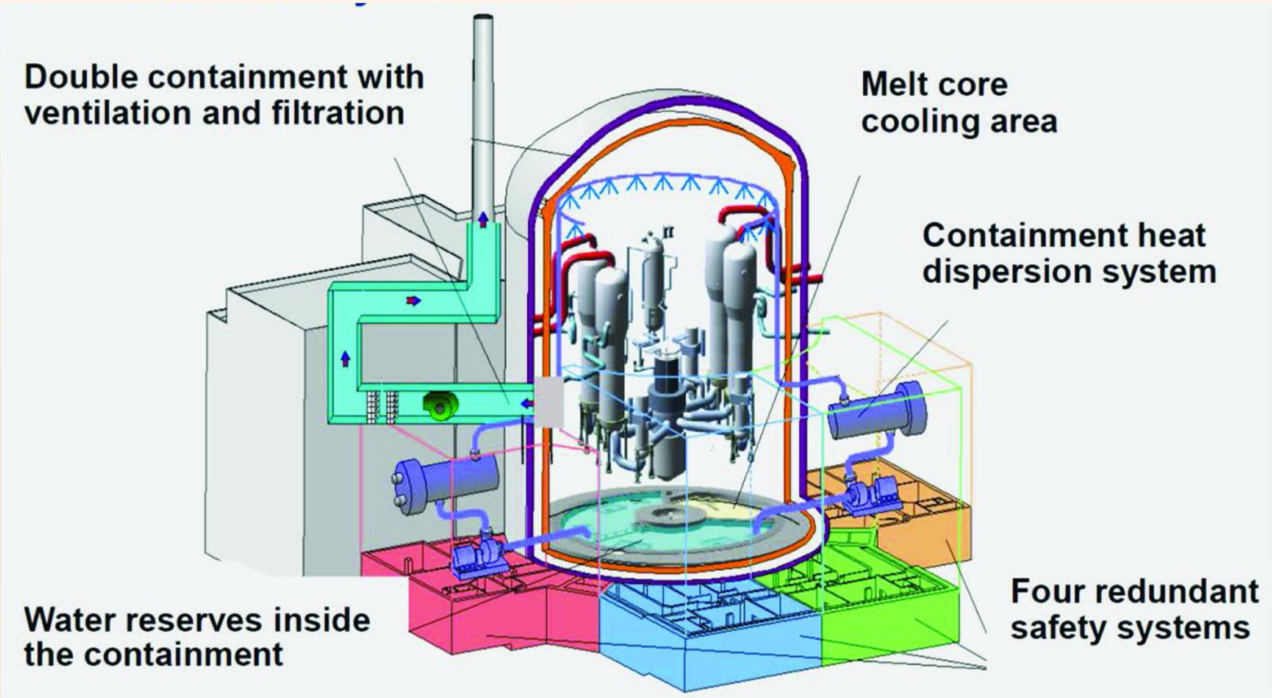


- **Finland:**
  one unit under construction (Olkiluoto-3)
- **China:**
  two units under construction (Taishan-1 and 2)
- **USA:**
  projects developed now abandoned
- **United-Kingdom:**
  project to build two reactors (Hinkley Point-C), investment decision “imminent” for some years
- **India:**
  project to build up to six units in Jaitapur, slow progress in commercial negociations

International development remain very far from initial (and continuing?) expectations
Areva and EDF had planned for tens of orders

Projects were started in 2003 in Finland and 2005 in France before design was complete
with the hope to be frontrunner of the “nuclear renaissance” market

Main safety features introduced in EPR



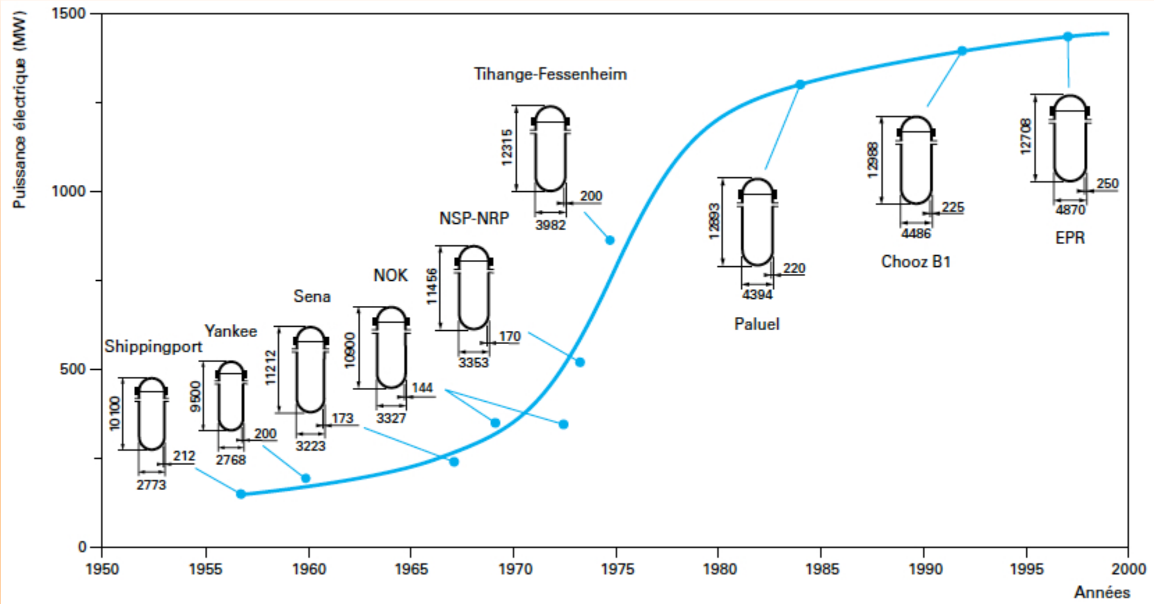
Source: WNA, 2015

- The evolutionary descendant of the Framatome N4 and Siemens "Konvoi" reactors
- Combines in a multiple layer approach their improvements
- Reinforced containment, reinforced and more redundant safety features
- New features (“core-catcher”)
- Objective: reduce maximum core damage frequency to 10^{-7}/y and **eliminate the need for evacuation of populations**

- New safety features introduced in the design of EPR mark a real improvement compared to previous existing design, but remain pre-Fukushima based
- After Fukushima, French nuclear safety authority said this kind of catastrophy is possible on French reactors, including EPR when it will be operating

- Design output 1,600 MWe, up to 1,800 MWe: the most powerful reactor ever built
- Aims for increased fuel burn-up (up to 70 GW.d/t)
- Aims for the possible use of up to 100% MOX fuel (mixed uranium-plutonium fuel)
- Unprecedented radioactivity inventory both in the reactor core and in the spent fuel pool
- Unprecedented thermal output in the core and the pool

Evolution of PWRs pressure vessel size through time



Source : Techniques de l'Ingénieur

The increased size of components (pressure vessel, pumps, steam generators, etc.) means they are bound to face heavier loads in operation

While the safety features are reinforced, the **potential for danger is increased** too through size and fuel performance increases

Head of reactor pressure vessel:

Oct. 2010: Numerous flaws in welding on tubes on reactor vessel head

ASN granted Areva to do repairs (instead of fabricating a new one)

During repairs, an even more important issue was found (smearing thickness)
New repairs proposed by Areva, almost completed

ASN will give its final approval once repairs completed

Basement:

Cracks found in the nuclear island concrete following its pouring in Dec. 2007, due to shrinkage

Non conform location of reinforcement steel found after concrete pouring in the basement of the fuel building (March 2008) and the safeguard building (May 2008)

ASN stopped the construction site from 26 May 2008 to 18 June 2008

Containment:

Anomaly of prestressing tendons location before pouring (November 2009)

Other non-conforming location of part of prestressing tendons in May 2011
ASN stopped the construction site during one week.

Gap in concrete poured in some cylindrical shaft (Jan. 2014) and in 2 prestressing tendons guides (July 2014) of the reactor building

Metal liner:

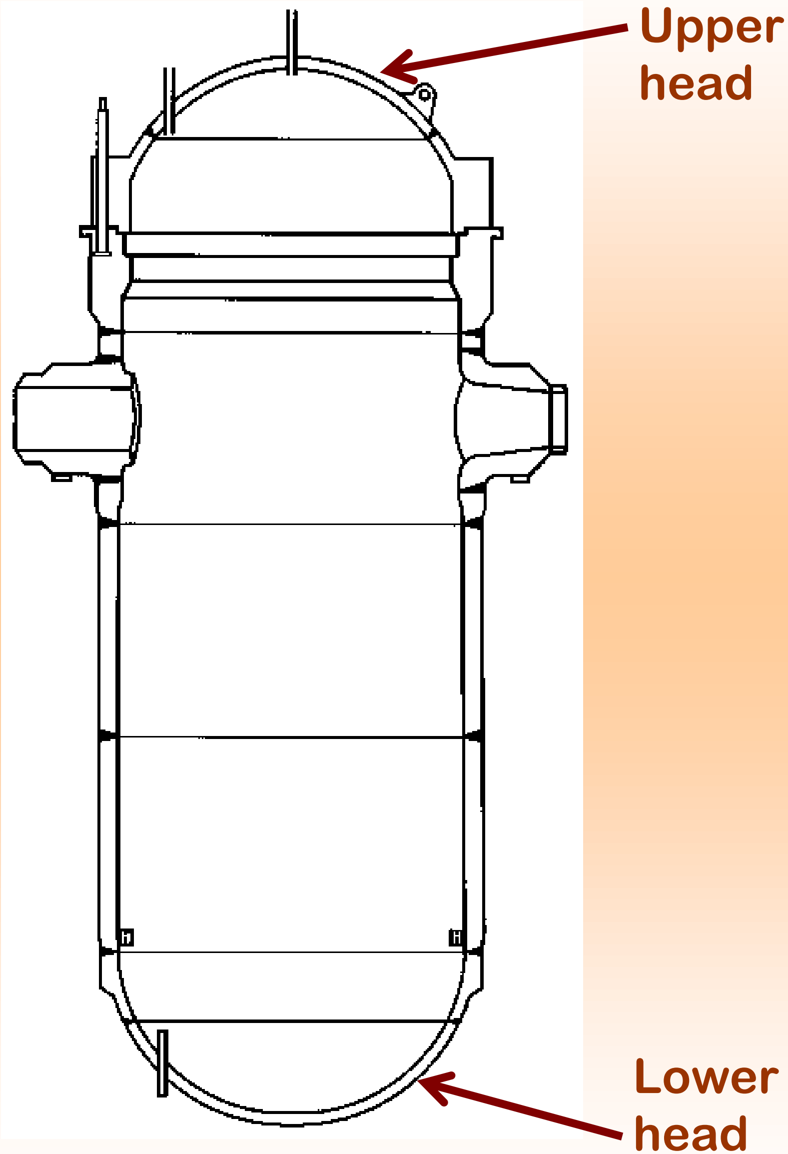
- Non conform metal liner welding (June 2008) and other manufacturing deviations
- During a test of the heavy circular crane, metallic pieces are projected, one piercing the metallic liner (Oct. 2013), repair completed in 2014

Spent fuel pool:

- Several rock pockets in pool walls due to non homogenous concrete pouring (Jul. 2011)
- Voids found behind the pool cofferdams (March 2012)

Miscellanous:

- Non conform fabrication of piping for the pumping station (Jul. 2008)
- Non conform pouring of the concrete of internal structures in reactor building (May 2009)
- Anomaly detected on a steam generator component (end 2009), needed to be replaced
- Non conform welding of the heavy circular crane (Dec. 2011), had to be re-welded
- 4 valves of the security injection system mounted upside down (Jul. 2013), ASN stopped assembly operations for some months
- An overall concern with the Instrumentation & Control system, final approval only granted by ASN around 2012-2013
- Safety valves of the pressuriser failed qualification tests, still under examination (2015)



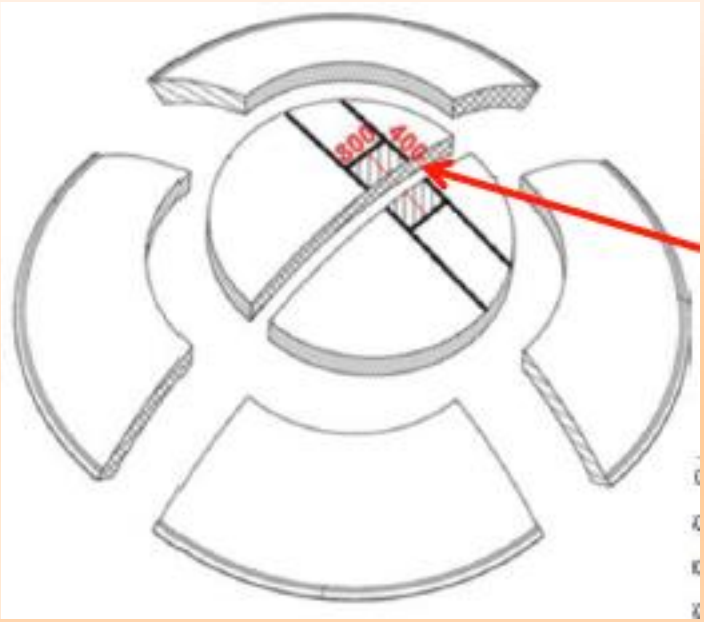
- 7 April 2015: ASN announced an "anomaly" with the mechanical properties of the upper and lower heads of the reactor pressure vessel of Flamanville-3

- Unlike the rest of the components which were forged in Japan, those were forged at Areva's plant of Le Creusot, in France

- ASN later qualified the "anomaly" of "very serious" in a Parliament hearing

- Defects jeopardize the licensing of the vessel under "pressurized nuclear equipment" regulation

Safety issue: basic and seemingly serious defect



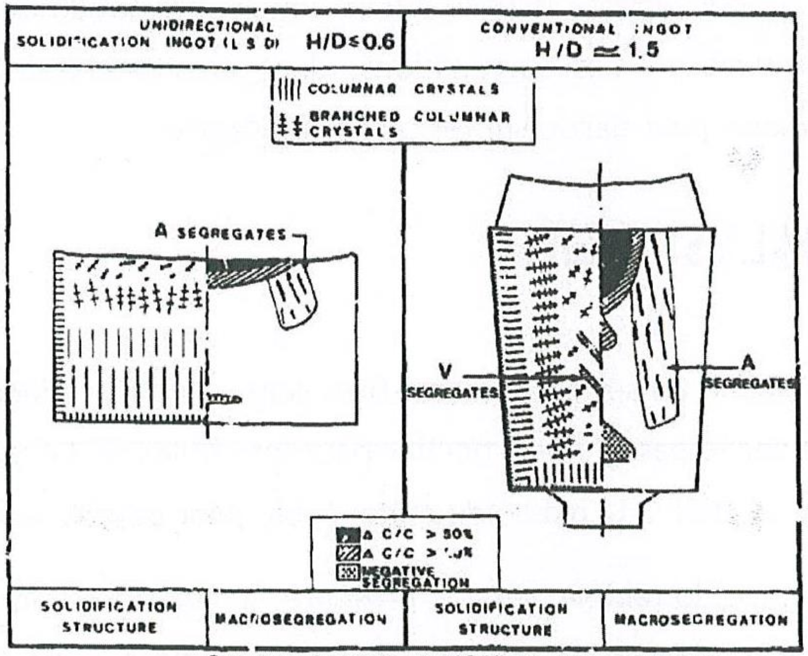
Source : IRSN, 2015

- Pieces made of 16MND5 steel
- Carbon segregation in a certain area of the upper and lower heads: insufficient elimination during the forging process of the ingot’s higher part
- Destructive tests results (on a US EPR head) don’t meet carbon concentration and machnical requirements (tenacity)
- New destructive tests will be performed using heads forged for the US and Hinkley Point - Results expected end of year 2016
- Taishan EPRs are concerned too (but not Olkiluoto)

Areva has then to present an alternative safety demonstration:
less tenacity could be guaranteed but less tenacity would be required

Considering the preliminary results, the result is very uncertain

Quality issue: requirements not met



SOLIDIFICATION STUCTURE AND MACRO-SEGREGATION OF "SHORT" L S D INGOT AS COMPARED WITH CONVENTIONAL INGOT

Source : IRSN, 2015 d'après Benhamou – Poitrault, 1985

- Areva chose to use a process that was used for smaller ingots but never used for that size
- IRSN called this choice a "technical regression" compared to the rest of the French reactors
- The risk of carbon segregation was known and increased (also by Areva's choice to raise the initial carbon concentration)
- Areva guaranteed it would manage but failed
- Technical conclusion by ASN and IRSN:

  Areva failed to meet the regulatory requirement of using a qualified process corresponding to the best available technology

First level of defense in depth (conception and fabrication) is irreversibly degraded

ASN calls for Areva / EDF to propose reinforcements of second level (operation)

Third level (mitigation) doesn't exist as it is initially excluded

Trust and/or competency issue

- Apr. 2015: ASN announced that fabrication defects had been found
- Dec. 2014: Areva informed ASN about the results on the tests
- Oct. 2014: Areva performed the tests
- Jan. 2014: pressure vessel put in place in its pit, welding starts
- Oct. 2013: pressure vessel delivered to the Flamanville site
- Sept. 2012: Areva proposes ASN destructive testing program (part of the qualification)

(…)

- 2006: head and bottom of the Flamanville pressure vessel forged

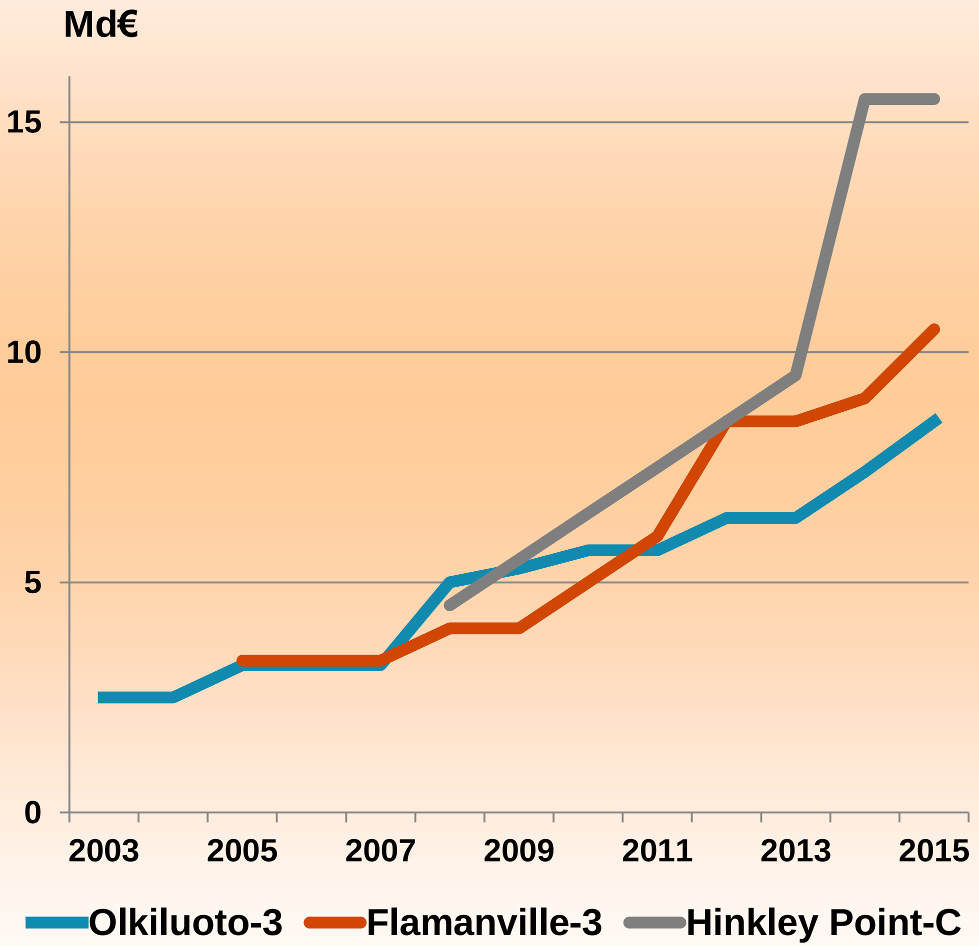
EPR Flamanville: official costs soaring

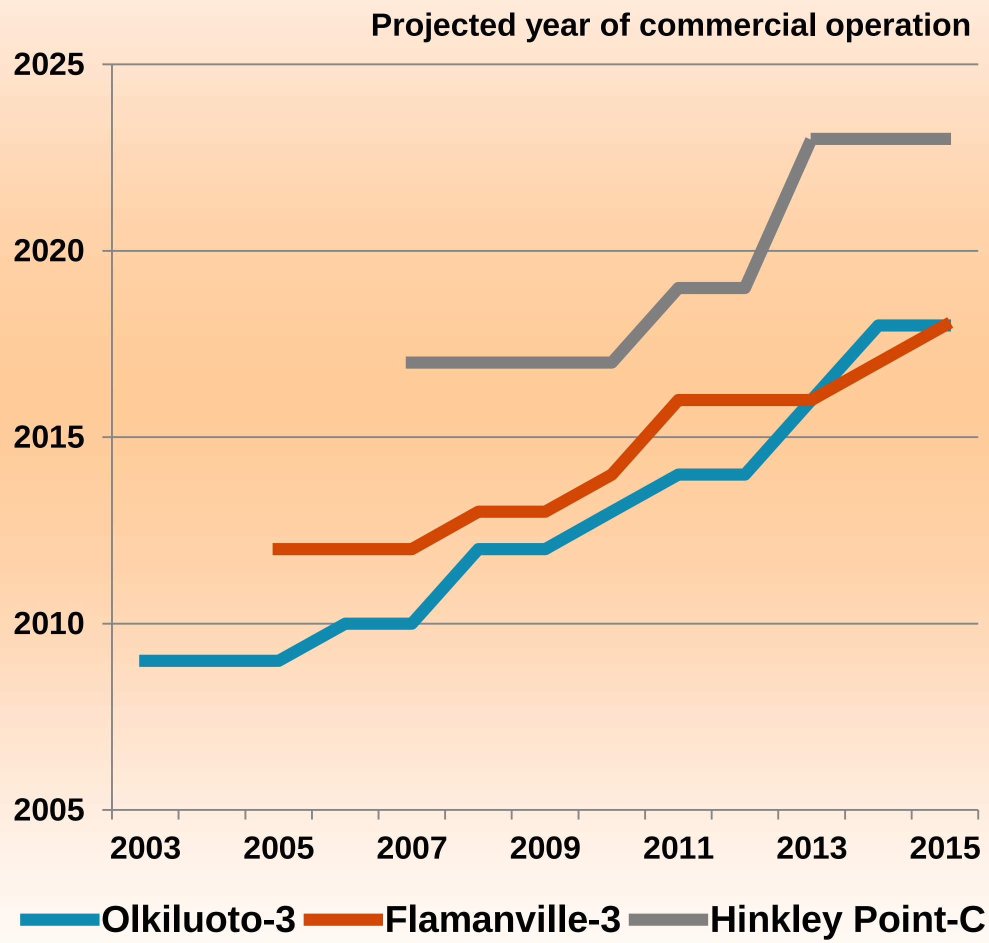
	Construction cost (€/kW)	Complete generating cost (€/MWh)
DGEMP 2003 (Government)	**1 043**	**28,4**
EDF 2005		**43**
EDF 2006	**2 060**	**46**
EDF 2008	**2 500**	**54**
EDF 2008 - 2nd EPR		**60**
Court of Auditors 2014	**5 300**	**90**
Current estimate	***6 250***	***> 100***

- **Initial decision:** EPR projected generating cost lower than existing reactors
- **Projected cost multiplied by 3.5** compared to the basis for political decision

Current status of delays and overcosts

Official final cost estimates and time of completion through years





Experience with the construction of Generation III+ Reactors

- **Goals:** “Passive safety”, “modularisation”, “standardisation” to reduce delays/costs…
- **Results:** No Gen III+ design in operation

  3 designs with 18 reactors under construction:

  - 4 EPRs (AREVA)

  - 8 AP1000s (Toshiba/Westinghouse)

  - 6 AES-2006s (Rosatom) – Little reliable information
- **EPR:**

  - Cost estimates now 4 times over budget

  - Site quality (welding, concrete) major causes of delay

  - Instrumentation & Control serious regulatory concern

  - Flamanville and Taishan threatened by manufacturing errors in pressure vessel heads
- **AP1000:**

  - Construction experience from 2009 in China and from 2013 in USA

  - Longer delays in China than for EPRs, and delays of US units as European EPRs

  - Module production facilities in US: Coolant pumps caused serious problems in China

Generation III+ Reactor Construction - Key Findings

- No evidence new designs cheaper than predecessors

  Fukushima lessons mean costs likely to continue to increase

- Claims that design could be simplified were an illusion

  EPR based on old design with added safety could hardly get simpler

  AP1000 more modern but high cost and delays suggest no reduction in complexity

- Modularisation moved quality problems from site to factory

- Standardisation for 40 years with no success

  Technology still not mature, ordering rates too low, national regulators' requirements too different

  Generic design approval impossible without standardisation

The safety of the EPR reactor

- EPR was iconic of Generation III+ safety improvements
- These include strong reinforcements to reduce the frequency of accidents
- These improvements were introduced after Chernobyl but before Fukushima
- Severe accidents remain possible on EPR reactors
- Increased size and radioactive inventory increase the potential for catastrophy
- The size and complexity of the reactor are challenging for real implementation
- The French nuclear industry fails to deliver with the required quality

The EPR reactor is possibly the safest reactor in the world on paper
It is also the most dangerous by its intrinsic power
Its improved safety is undermined by complexity and poor construction quality

Thank you for your attention

More information :


© B. Runtz

Yves Marignac, Director of **WISE*-Paris***

E-mail: yves.marignac@wise-paris.org
Tel: +33 6 07 71 02 41
Twitter: @YvesMarignac