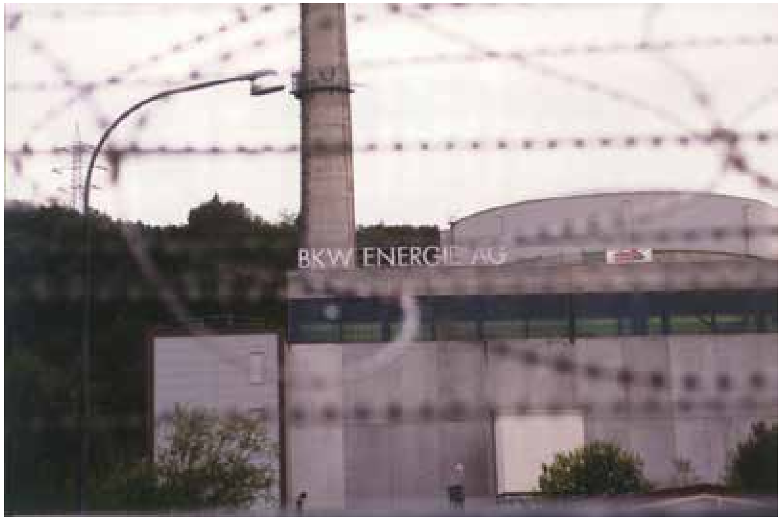
www.oeko.de

Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology

Risks of Nuclear Ageing

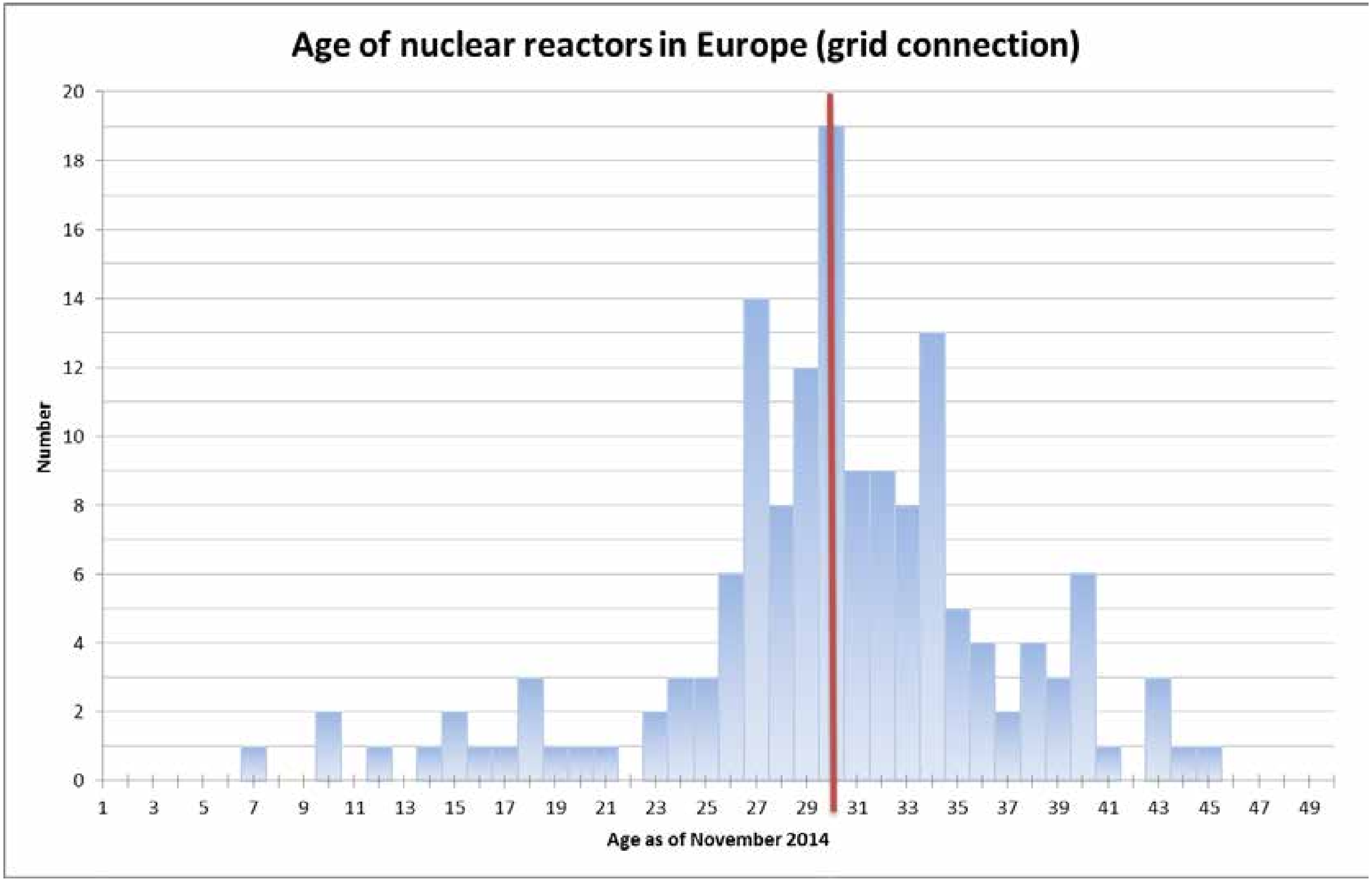
Technical characteristics of ageing processes and their possible impacts on nuclear safety in Spain



S. Mohr, S. Kurth

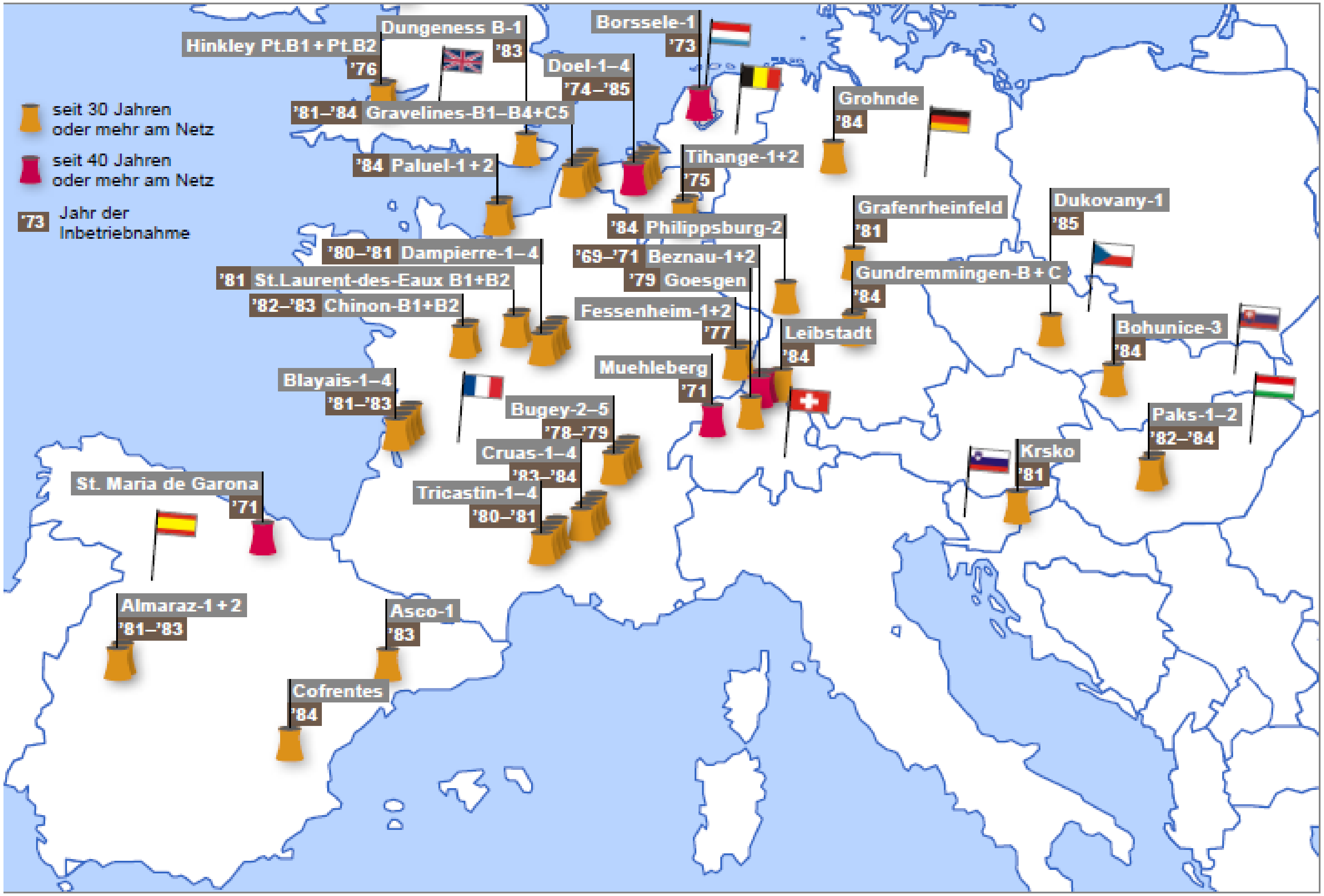
Greenpeace, Valencia, November 2014

Age of European NPPs (grid connection)



Source: based on International Atomic Energy Agency: Power Reactor Information System (PRIS), http:/ / www .iaea.org/PRIS, as of Novembre 2014 .

Age of European NPPs (grid connection)



Orange NPPs: more than 30 years

Red NPPs: More than 40 years

Black: year of grid connection

Source: based on International Atomic Energy Agency: Power Reactor Information System (PRIS), http:/ / www .iaea.org/PRIS, as of Novembre 2014 .

Spanish NPPs

Reactors	Type	Design Capacity (MWe)	Capacity (Mwe)	Grid connection	Owner (%); operator	Status	Licenced to
St. Maria de Garona	BWR-3	440	446	1971	Nuclenor, S.A.	long term shutdown	**????**
Almaraz 1	PWR-W-3-loop	900	1011	1981	Iberdrola 53%, Endesa 36%, Gas Natural Fenosa 11%; CNAT	operational	Jun 20
Almaraz 2	PWR-W-3-loop	930	1006	1983		operational	Jun 20
Asco 1	PWR-W-3-loop	888	995	1983	Endesa (100%); ANAV	operational	Okt 21
Asco 2	PWR-W-3-loop	888	997	1985	Endesa (85%); ANAV	operational	Okt 21
Cofrentes	BWR-6	939	1064	1984	Iberdrola (100%); Iberdrola	operational	Mrz 21
Trillo 1	PWR-3-loop	990	1003	1988	Iberdrola (48%), Gas Natural Fenosa (34.5%); CNAT	operational	Nov 24
Vandellos 2	PWR-W-3-loop	930	1045	1987	Endesa (78%); ANAV	operational	Jul 20

July 2014: the CSN voted in favour of issuing a technical instruction to the operator Nuclenor on documentation and additional requirements for the Garoña operating licence renewal, and the company submitted a work plan for meeting these requirements. Nuclenor wants to restart the NPP within a year.

Source: http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Spain/

Physical and conceptual Ageing

- The design lifetime is the period of time during which a facility or component is expected to perform according to the technical specifications to which it was produced.
- Life-limiting processes include an excessive number of reactor trips and load cycle exhaustion.
- Physical ageing of systems, structures and components is paralleled by conceptual ageing, because existing reactors allow for only limited retroactive implementation of new technologies and safety concepts.

Physical Ageing of the Reactor Pressure Vessel (RPV)

The RPV, its vessel head and its internals have to withstand operational impacts:

- neutron radiation that causes increasing embrittlement of the steel and weld seams;
- material fatigue due to mechanical and thermal stresses from operating conditions, including changing loads, fast reactor shutdowns (scrams) and other events throughout the operational lifetime;
- corrosion mechanisms caused by adverse conditions such as chemical impacts and mechanical stress/strain. Especially stress corrosion cracking is caused by tensile stress and aggressive chemical environment and irradiation

Replacement of the RPV is nearly impossible for economic and practical reasons (like the replacement of the containment) .

Case study: RPV-Ageing in Doel 3 and Tihange 2

- In June 2012 underclad flaws were detected in the whole cylindrical part of the RPV of the Belgian Doel 3 reactor (nearly 9000 flaws identified). Similar flaws were revealed in September 2012 in the RPV of the Tihange 2 reactor. Both reactors were disconnected from the grid.
- In May 2013 the Belgic Federal Agency for Nuclear Control (FANC) wrote: *"However, there is little literature or experience about the influence of irradiation on flaw propagation in zones with hydrogen flakes. Hence, the potential evolution of the flaws under irradiation cannot be completely ruled out at this stage."*
- While comparable RPVs would never have entered operation in Germany, the Belgian authorities permitted continued operation of Doel 3 and Tihange 2 in spite of reduced safety margins concerning the integrity of the RPVs and uncertainties as to the further development of the flaws. Both reactors were reconnected to the grid in June 2013.

Sources: FANC. 2013. Doel 3 and Tihange 2 reactor pressure vessels: final evaluation report. May 2013.

Case study: RPV-Ageing in Doel 3 and Tihange 2

- March 2014: According to tests with comparable materials with flaw indication the mechanical material characteristics, especially the fracture toughness was strongly limited. Both reactors were disconnected from the grid again.
- Oktober 2014: Operator Electrabel has initiated the third test series to prove that operation of Doel 3 und Tihange 2 is safe.
- FANC is conducting a review to prove the operators line of arguments as sufficient for safety certification.
- The Spanish NPPs Cofrentes and St Maria de Garoña RPVs have been manufactured by Rotterdam Droogdok Maatschappij, just like the RPVs of Doel 3 and Tihange 2.

Sources: FANC. 2013. Doel 3 and Tihange 2 reactor pressure vessels: final evaluation report. May 2013.

Case study: RPV-Ageing

- The Spanish Nuclear Safety Council CSN said that preliminary investigations show that the vessel of the Cofrentes plant is not affected by the same defects found in Belgium as a different manufacturing process was used.
- St. Maria de Garoña's vessel was constructed using the same process as that for Doel 3. CSN noted significant differences between the Garoña and Doel 3 vessels - including the size, thickness, number of forged pieces and the type of reactor.
- CSN said that it will continue to review the manufacture of the vessels and the parameters determining the possible appearance of these defects, as well as analyzing the results of inspections conducted in different areas of the vessels.

Sources: FANC. 2013. Doel 3 and Tihange 2 reactor pressure vessels: final evaluation report. May 2013.

Case study: Containment Ageing

In 2009 the Belgian nuclear operator GDF-Suez/Electrabel realized that the containment building of the Tihange 2 reactor had been damaged.

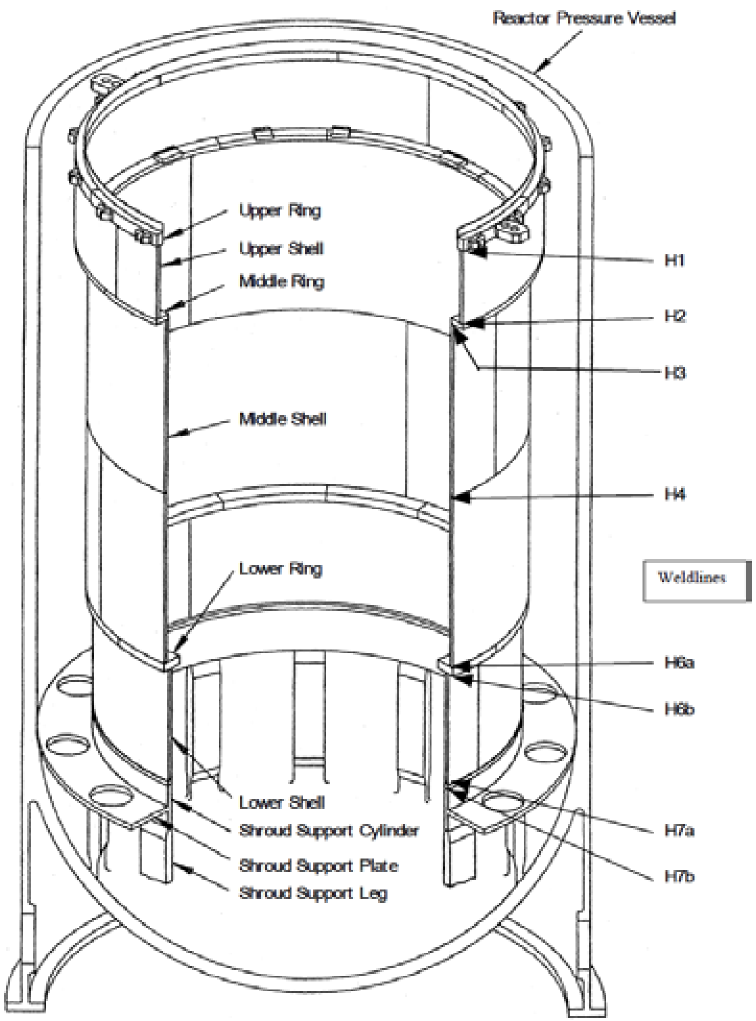
.

Sources: : Tihange: Alain Vincent/Greenpeace
.

NPPs Almaraz 1 and 2

Sources: : wikimedia

Case Study: Physical Ageing of Reactor Pressure Vessel Internals



NPP Mühleberg: Cracks at the core shroud welds

The critical crack length, which should be the criterion for obligatory replacement, was recalculated twice before the cracks had exceeded the initially calculated critical value.

Thus the original safety margins have been gradually decreased.

Physical Ageing Case Study: Core Shroud Cracks in Mühleberg NPP

The safety functions of RPV-Internals like core shrouds are:

- support of the nuclear core under all loading conditions,
- maintaining of a coolable geometry,
- assure control rod insertion and reactivity control,
- allow recovery to safe shutdown conditions.

Core Shroud Cracks were also detected in St. Maria de Garoña (~1993) and in Cofrentes (1996)

Physical Ageing Case Study: transgranular stress corrosion cracking (NPP Cofrentes)

- In 2006 leckages were detected at the feed lines of the control rod drive mechanism under the reactor pressure vessel. Following a video-endoscope inspection, these through-wall cracks were determined to be from 7 insertion and 1 withdrawal lines of the hydraulic control rod drive mechanisms, all located in quadrant 2 of the drywell penetration.
- The ageing mechanism occurred at an area of the NPP that is inaccessible due to the high level of radiation. As a result, the plant decided to replace all the lines during the refuelling outage in 2007.
- The incident might have had an impact on the integrity and function of the system:
  - The control rod mechanism assures control rod insertion and reactivity control.
  - The control rod mechanism allows recovery to shutdown conditions during accidents.

Conceptual Ageing

Basic design of protection against earthquake and flooding

Source: Tepco

Conceptual Ageing

Flooding at Fort Calhoun nuclear power plant, United States, 2011.

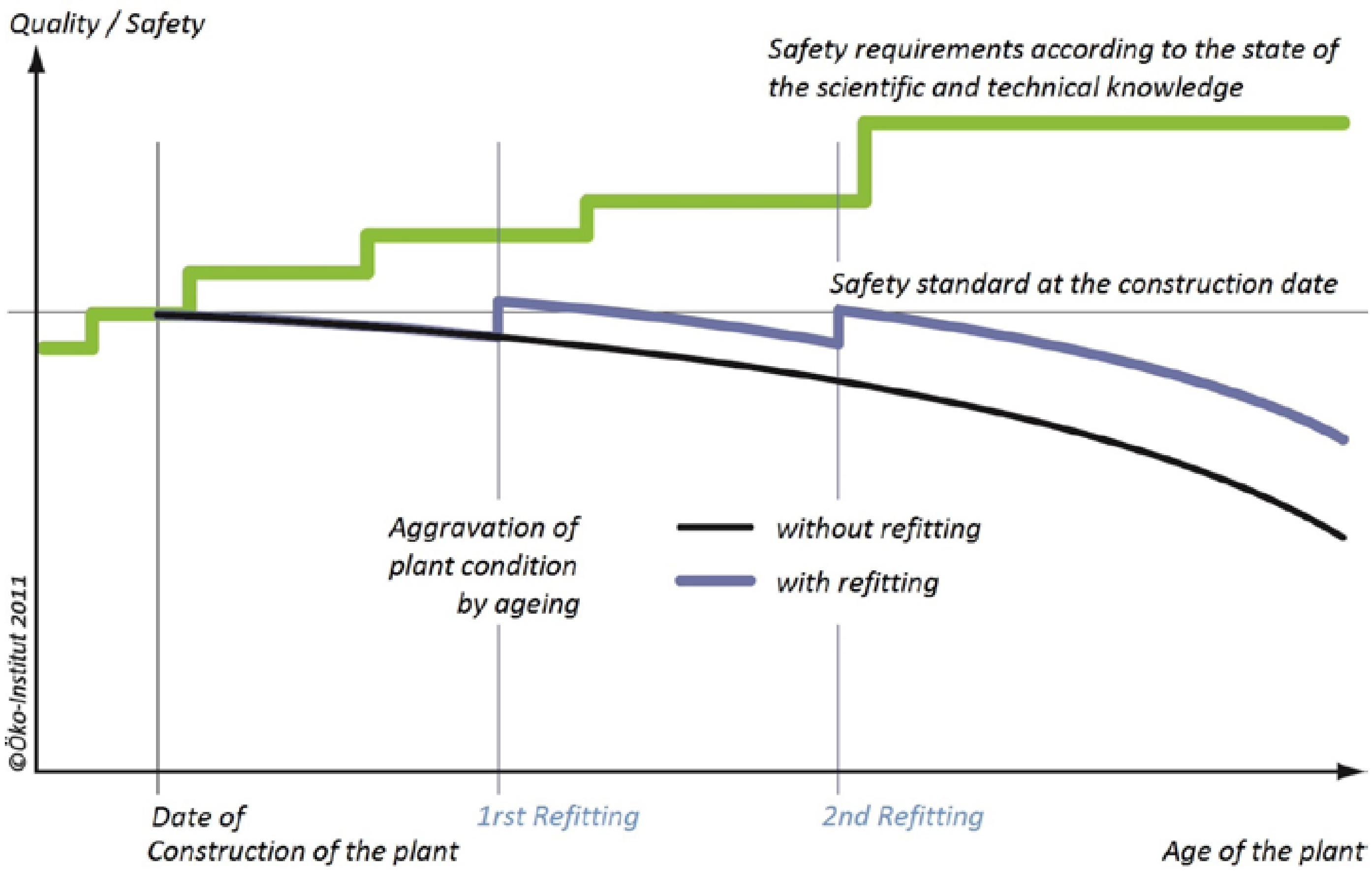
Source: Larry Geiger,
http://cryptome.org/eyeball/ne-npp-flood/ne-npp-flood.htm#Larry Geiger

Conceptual Ageing of Cofrentes

- Cofrentes - as well as other Spanish NPPs - has only a two-train essential service water system. The two redundancies are supplying cooling to safety-related equipment such as the reactor‘s residual heat removal system.
- All of Cofrentes emergency diesel generators are cooled by the essential service water system as well. During possible loss of the primary heat sink of the river the ultimate heat sink is only provided by a spray pond. The spray pond only guarantees 30 days cooling capacity.
- Refitting of old safety system concepts is usually not satisfying. In most cases the operator suggests mobile equipment and emergency measures like containment venting before core degradation .

Sources: ENSREG

Ageing: decreasing safety margins

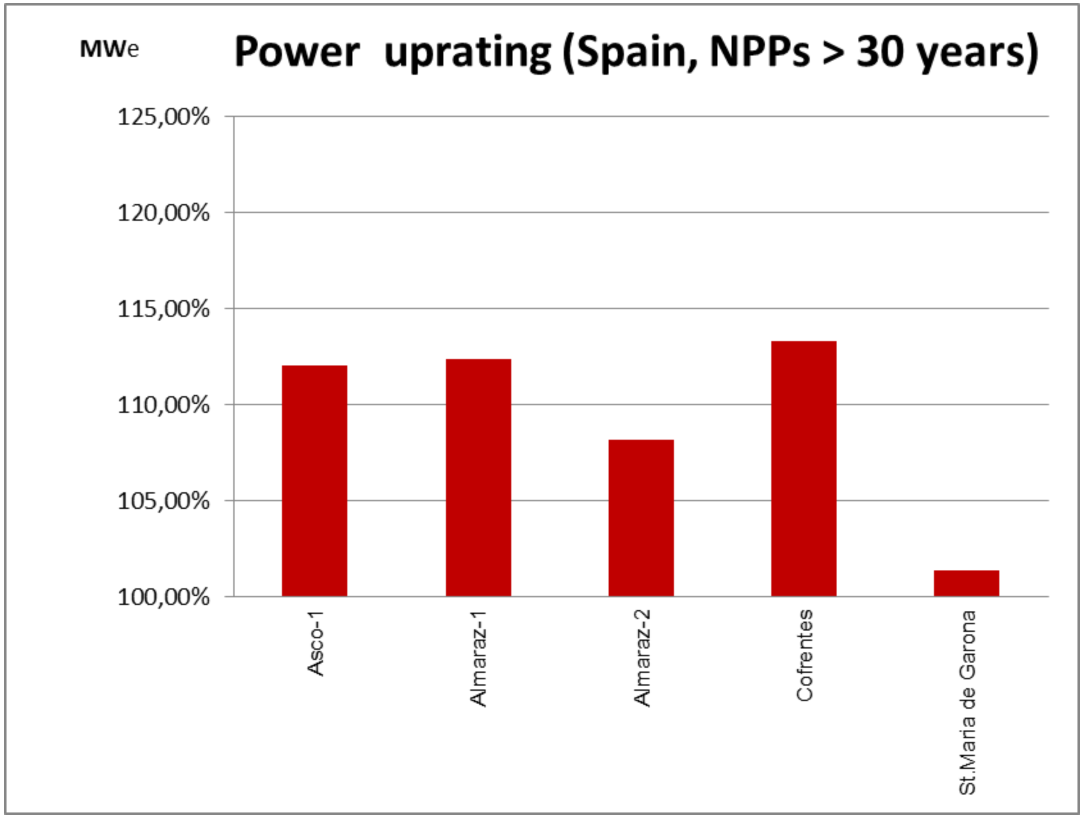


Schematic diagram showing the progression of nuclear reactor ageing

Power Uprating

- The process of increasing the maximum power level at which a commercial reactor may operate is called a plant power uprate (PPU). To increase the power output, the reactor will be refueled with either slightly more enriched uranium fuel or a higher percentage of new fuel.
- A power uprate forces the reactor to produce more thermal energy, which results in an increased production of the steam that is used for electricity generation. A higher power level thus produces a greater flow of steam and cooling water through the systems, and components such as pipes, valves, pumps and heat exchangers must therefore be capable of accommodating this higher flow. Moreover, electrical transformers and generators must be able to cope with PPU.
- The components must be able to fulfill the more demanding conditions that exist at the higher power level. Power uprating means higher stress to the reactor and additional reduces the safety margins.

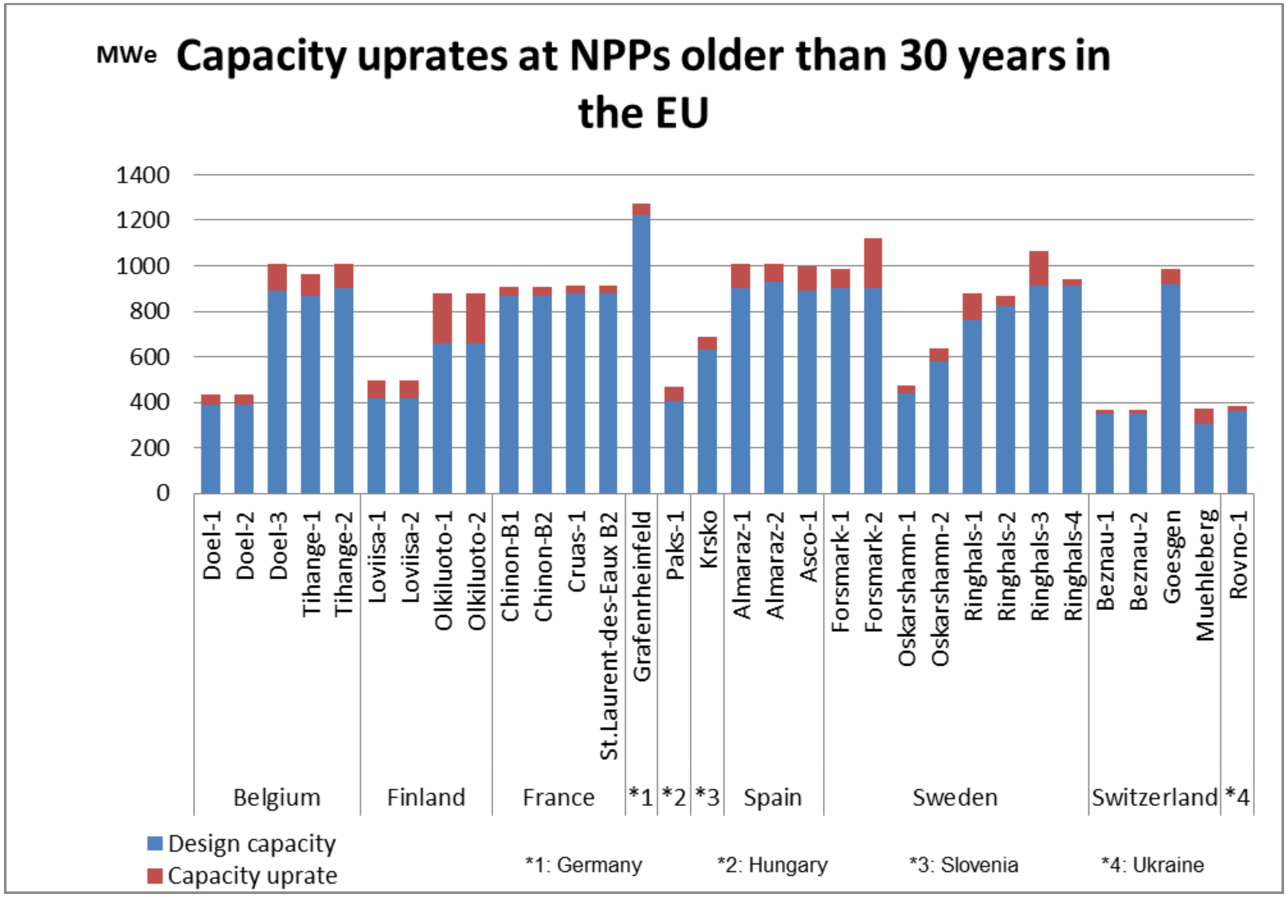
Power Uprating



Status of November 2014

Source: International Atomic Energy Agency: Power Reactor Information System (PRIS), http://pris.iaea.org/PRIS.

Power Uprating



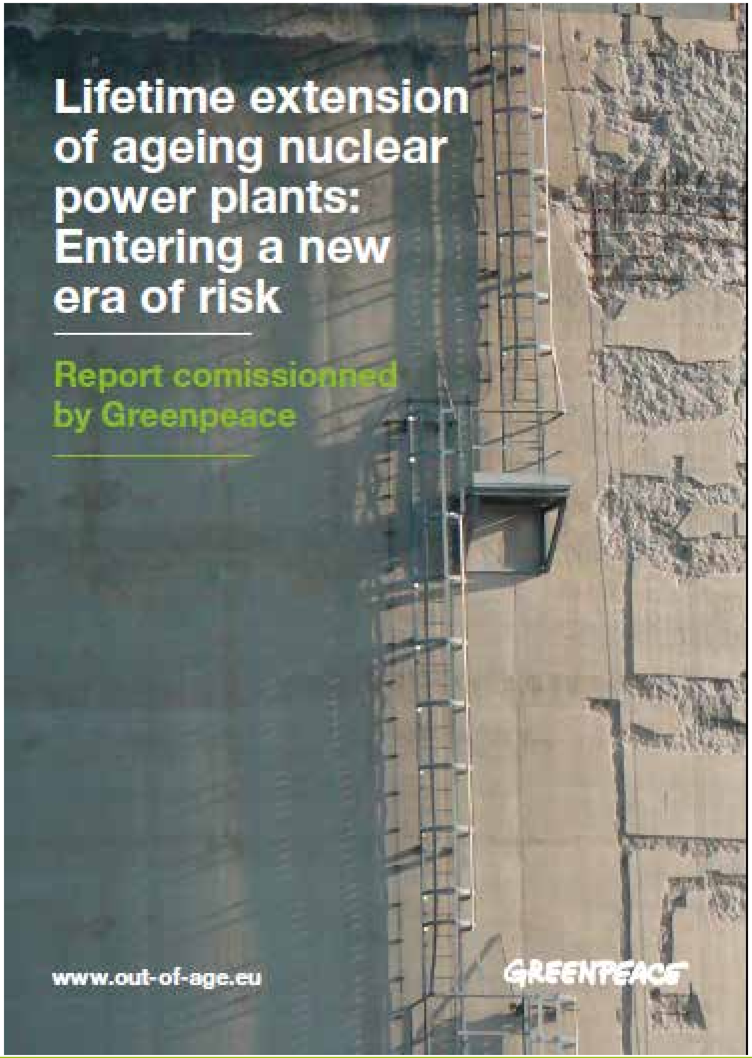
Status of January 2014: Comparable upgrades only in Sweden, Finland and Belgium.

Source: International Atomic Energy Agency: Power Reactor Information System (PRIS), http://pris.iaea.org/PRIS.

General Conclusions

- Physical ageing can affect RPVs, containments and the control rods of NPPs seriously. An increasing level of material degradation is lowering the original safety margins.
- The site specific design basis of older nuclear power plants is usually rather weak concerning external hazards. Comprehensive retrofitting is difficult to implement in older power plants due to conceptual ageing.
- Power uprating imposes significant additional stresses on nuclear power plant components. Ageing mechanisms can be exacerbated by these additional stresses.
- Reactor lifetime extension and power uprating can particularly become a problem in the case of incidents when the reactor is subject to more severe conditions than during normal operation.
- Ageing can initiate incidents and worsen the course of accidents.

More information



Contact

Dipl.-Ing. Simone Mohr

Öko-Institut e.V.

Büro Darmstadt
Rheinstraße 95
D-64295 Darmstadt

Telefon: +49 6151 8191-146
E-Mail: s.mohr@oeko.de

Dipl.-Ing. Stephan Kurth

Öko-Institut e.V.

Büro Darmstadt
Rheinstraße 95
D-64295 Darmstadt

Telefon +49 6151 8191-107
E-Mail: s.kurth@oeko.de