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Institut für angewandte Ökologie
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Risks of Nuclear Ageing

Technical characteristics of ageing processes and their impacts on nuclear safety

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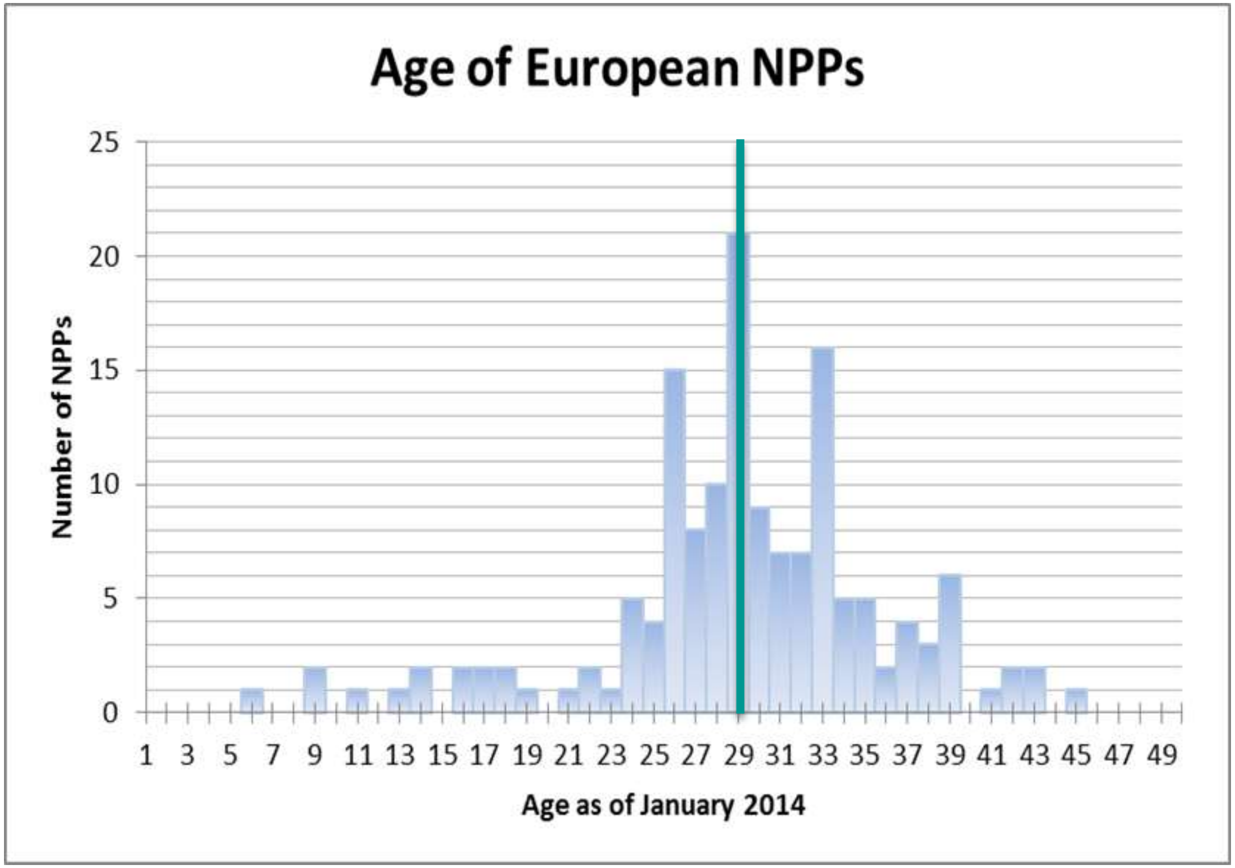
Design lifetime

- Design lifetime as defined by the International Atomic Energy Agency (IAEA): “The period of time during which a facility or component is expected to perform according to the technical specifications to which it was produced.”
- Plant Lifetime extension (PLEX) means operation when the original design lifetime is exceeded. It means operation near or above the design-limits.
- Plant Life Management (PLiM) programs get essential. Objectives of PLiM are:
  - to identify ageing degradation mechanisms that can lead to an unexpected or unplanned functional failure.
- Some countries already have advanced PLiM programs while others still have none.”

Source: IAEA. 2007. IAEA safety glossary. Terminology used in nuclear safety and radiation protection, 2007 edition.

Age of European NPPs (grid connection)



NPPs of the European Union, Switzerland and Ukraine

Source: based on International Atomic Energy Agency: Power Reactor Information System (PRIS), http:/ / www .iaea.org/PRIS, as of 10 January 2014 .

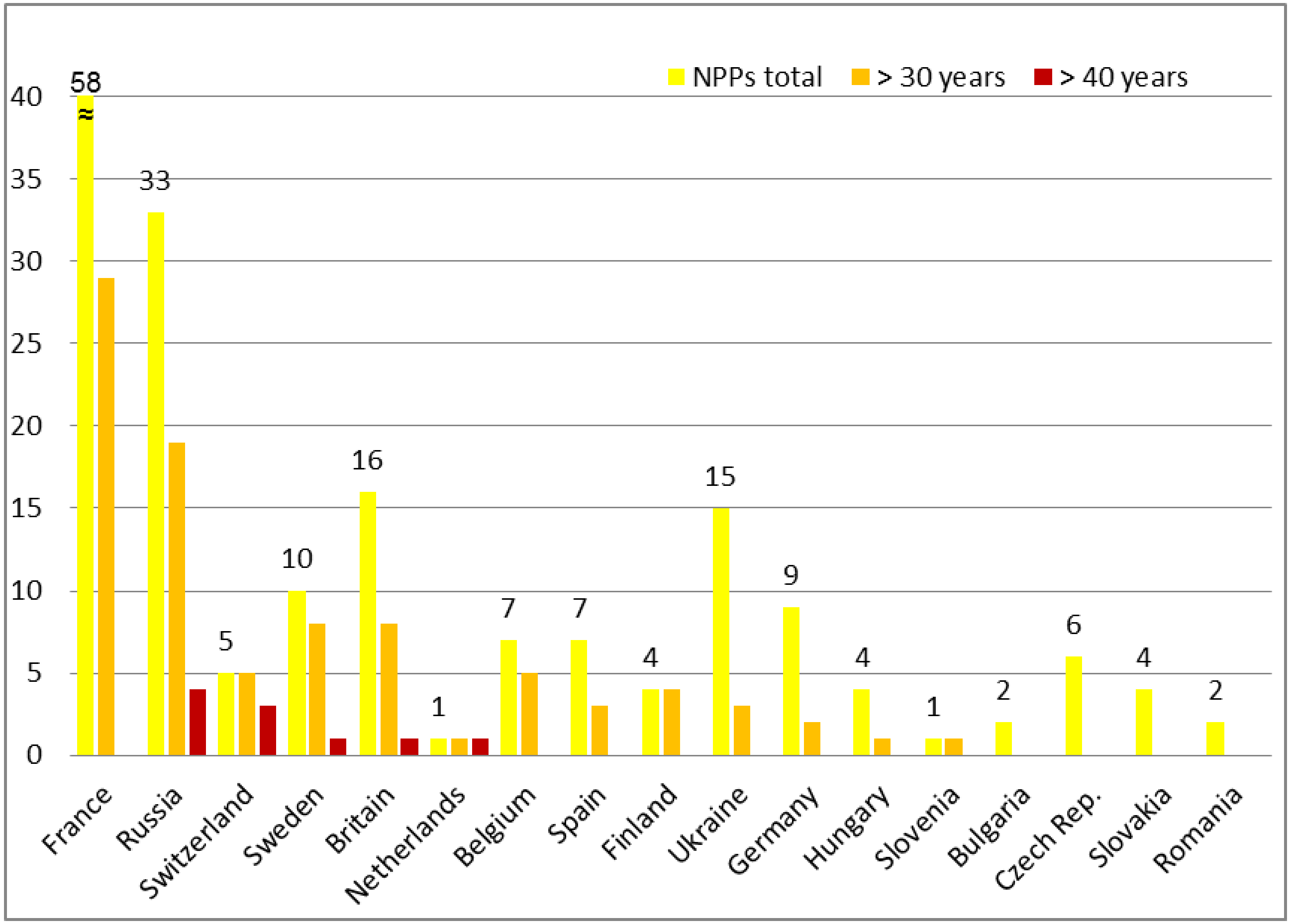
Design Lifetime and Lifetime Extension

Country	Total number of reactors	Original design lifetime (years)	Currently planned lifetime (years)
Belgium	7	30 - 40	40 - 50
Czech Republic	6	30	60
Finland	4	30	50 - 60
France	58	40	40 - 60
Germany	9		32 - 36
Hungary	4	30	50
Netherlands	1	40	60
Slovakia	4	30	40
Slovenia	1	40	60
Spain	8		40 - 60
Sweden	10	40	50 - 60
United Kingdom	16	35	35 - 45/60
Switzerland	5		50+
Russia	33	30	45 - 55
Ukraine	15	30	50

Plant lifetime extension in the EU, Switzerland, Ukraine and Russia.

Source: WNA et al, December 2013. (Age of reactors starting from first connection to the grid: source: PRIS (IAEA)).

Age of European NPPs (grid connection) II



Age structure

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

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

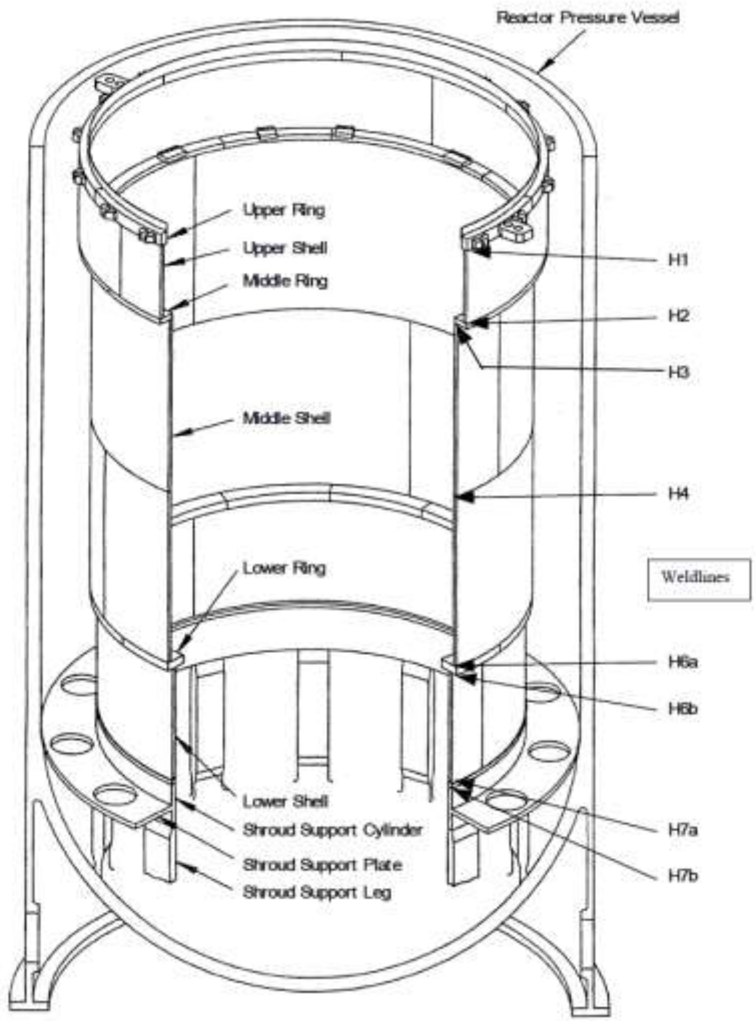
Replacement of the RPV is nearly impossible for economic and practical reasons (like the replacement of the containment) .

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

- In June 2012 underclad defects 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, also nearly 30 years old. 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: 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,
- direct and ensure emergency cooling flows,
- assure availability of monitoring instruments and
- allow recovery to safe shutdown conditions.

Conceptual and technological 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

Physical and Conceptual Ageing of Electrical Components

- The unit transformers are often as old as the reactor itself.
- Comprehensive test procedures are conducted on ageing transformers instead of replacement . Nevertheless, ageing unit transformers and their protection systems often give rise to incidents resulting in reactor scrams and even compromising mechanical components of the NPP.
- Case study Swedish reactor Forsmark 1 (25 July 2006):
  - a two-phase short circuit in the transmission network caused a voltage drop at the unit transformer and a disconnection from the network.
  - Further propagating failures of electrical components caused a severe incident, which nearly resulted in a complete station blackout of the power plant. Due to the outdated electrical design the external transient was able to propagate in the safety-related components of the reactor.
- On 30 May 2013 another serious incident affected Forsmark 3 due to failures of electrical protection equipment

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

Case Study: Physical Ageing of Electrical Components

Date	NPP	Event	Reason	Comment
28.06.2013	Isar-2	Trip of electrical protection of generator transformer, Scram	Insulation breakdown of generator transformer	Generator transformer exchange
01.01.2012	Grafenrheinfeld	Trip of electrical protection of generator transformer, Scram	Investigation not finished	Later both generator transformers were exchanged
07.08.2011	Brokdorf	Trip of electrical protection of generator transformer, Scram	Reason Unknown	Both generator transformers exchanged
24.07.2009	Emsland	Trip of electrical protection of generator transformer, Scram, unintended rise of steam generator fill level	Several events in connection with grid problems	Electrical protection systems exchanged
04.07.2009	Krümmel	Short-circuit of generator transformer, trip of electrical protection, auxiliary power changeover	Reason unknown	Generator transformer exchange
28.06.2007	Krümmel	Short-circuit and fire of generator transformer, disconnection of second generator transformer, scram	Reason Unknown	Exchange of generator transformer

Reportable events with generator transformers in German NPPs in the last years

Source: BfS, Listing of Reportable Events

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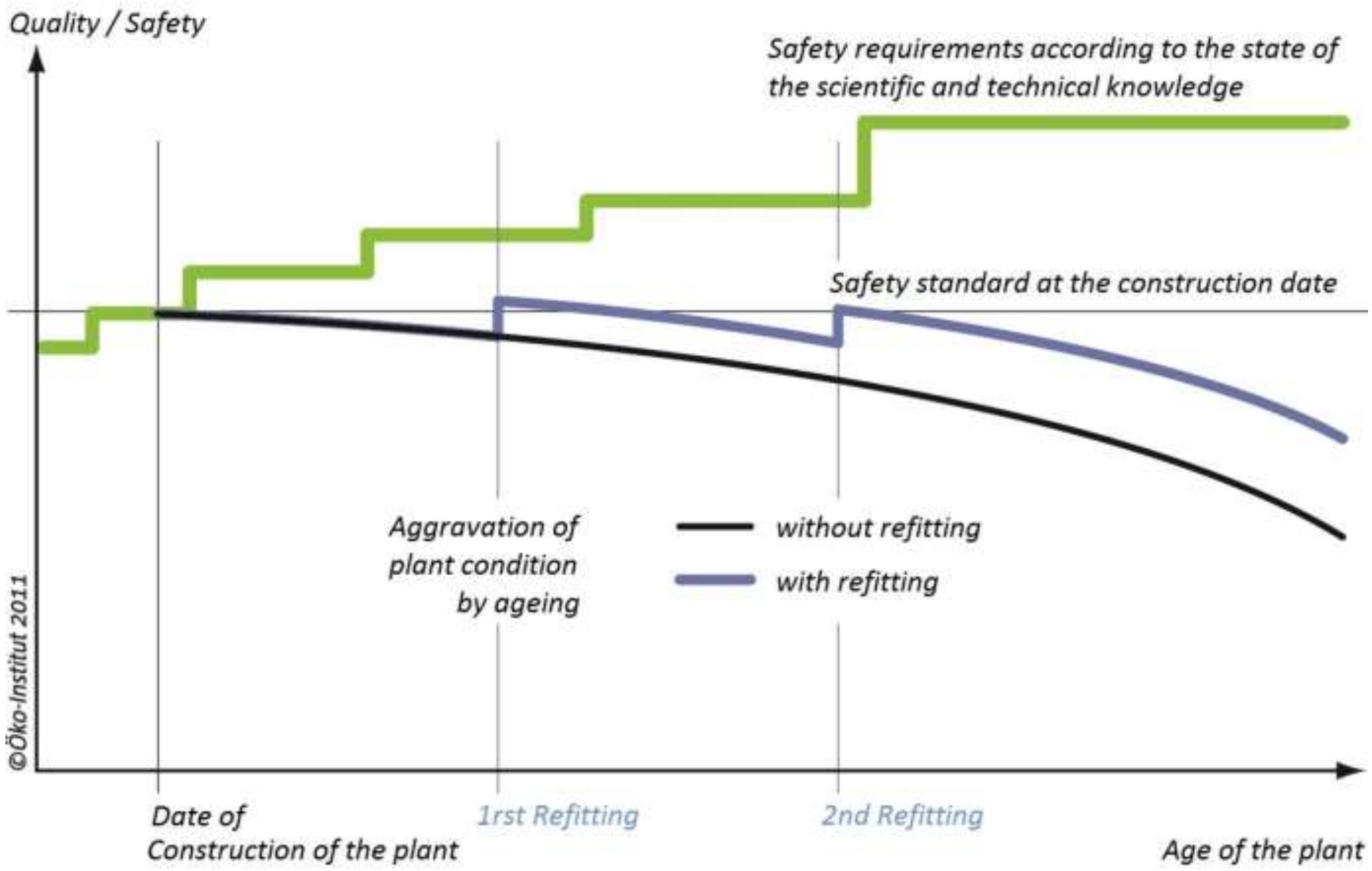
Ageing: decreasing safety margins



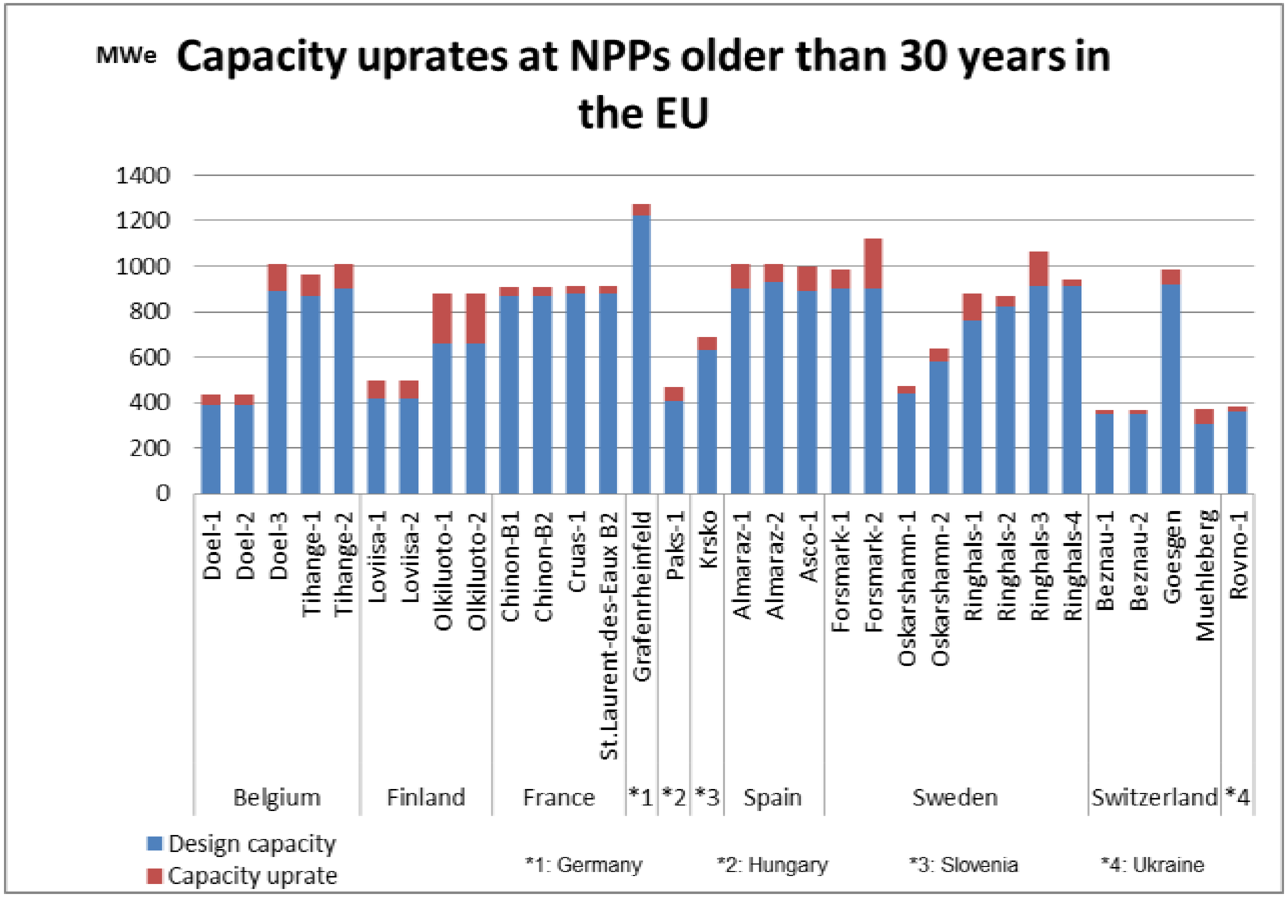
Schematic diagram showing the progression of nuclear reactor ageing

Source: Öko-Institut

Power Uprating I

- 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 II

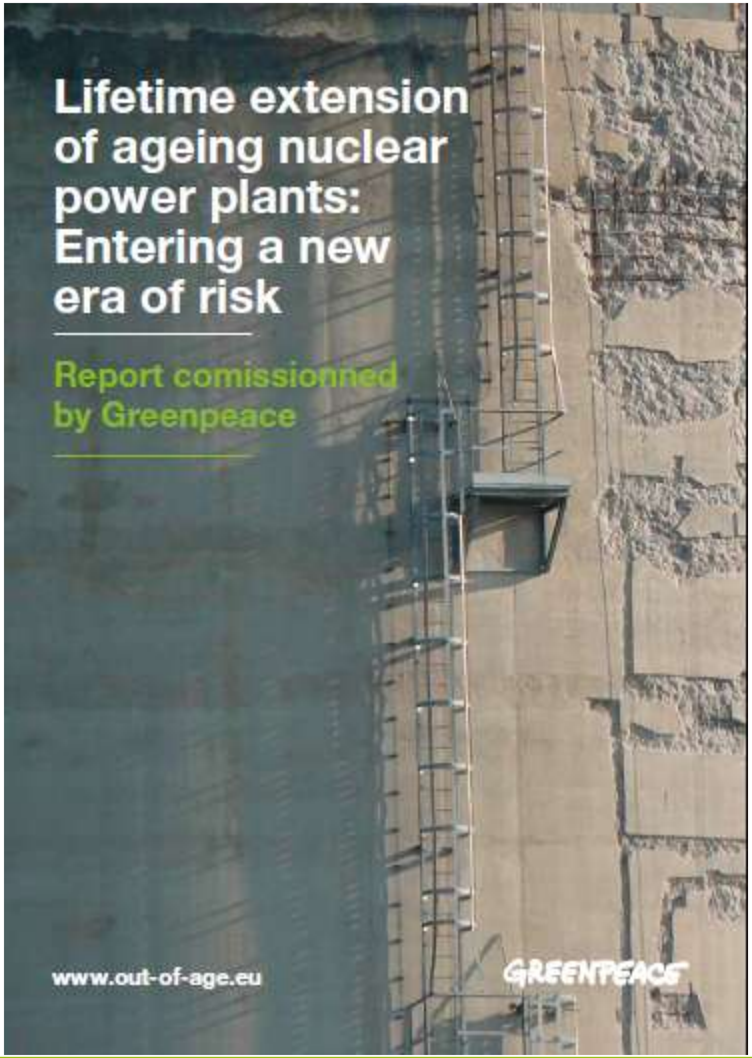


Source: International Atomic Energy Agency: Power Reactor Information System (PRIS), http://pris.iaea.org/PRIS.

General Conclusions

- Physical ageing of components in nuclear power plants leads to degradation of material properties. An increasing level of material degradation is lowering the original safety margins.
- The site specific design basis of older nuclear power plants was usually rather weak concerning external hazards. Comprehensive retrofitting is difficult to implement in older power plants.
- 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 are leading to a progressive decrease in the safety level of the older reactors in Europe. That 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



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