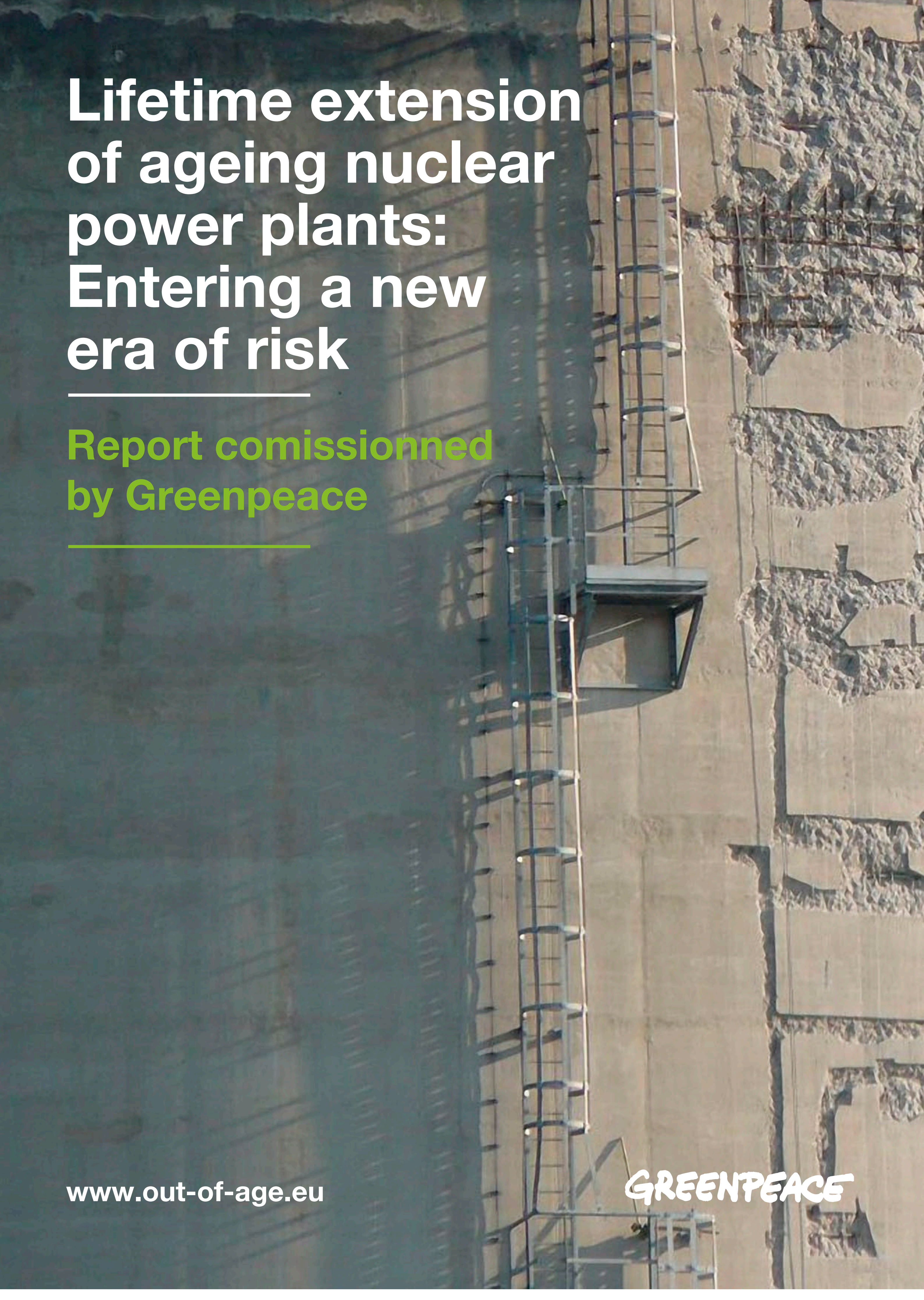

# Lifetime extension of ageing nuclear power plants: Entering a new era of risk

## Report comissionned by Greenpeace

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GREENPEACE

**Lifetime extension of ageing nuclear power plants:**
**Entering a new era of risk**
A report commissionned by Greenpeace

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**Ageing damaged outside wall of the reactor building at the Belgian nulcear power plant Tihange**

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# Contents

# Introduction

# Introduction

The heyday of nuclear power plant construction was the 1970s and 1980s. While most of the first generation of reactors have been closed down, the following second generation of reactors are largely still operational. By 11 March 2014, the third anniversary of the Fukushima nuclear disaster, the 25 oldest reactors in Europe (excluding Russia) will be over 35 years old.

| | country | power station | type reactor | reference unit power | starting date | age (years) | |
|---|---|---|---|---|---|---|---|
| 1 | CH | Beznau 1 | PWR | 365 | **17.07.1969** | **44** | X |
| 2 | UK | Wylfa 1 | GCR | 490 | **24.01.1971** | **43** | X |
| 3 | ES | Santa Maria de Garona | BWR | 446 | **02.03.1971** | **43** | X |
| 4 | CH | Muehleberg | BWR | 373 | **01.07.1971** | **42** | X |
| 5 | SE | Oskarshamn 1 | BWR | 473 | **19.08.1971** | **42** | X |
| 6 | CH | Beznau 2 | PWR | 265 | **23.10.1971** | **42** | X |
| 7 | NL | Borssele | PWR | 482 | **04.07.1973** | **40** | X |
| 8 | SE | Ringhals 2 | PWR | 865 | **17.08.1974** | **39** | X |
| 9 | BE | Doel 1 | PWR | 433 | **28.08.1974** | **39** | X |
| 10 | SE | Oskarshamn 2 | BWR | 638 | **02.10.1974** | **39** | X |
| 11 | SE | Ringhals 1 | BWR | 865 | **14.10.1974** | **39** | X |
| 12 | BE | Tihange 1 | PWR | 962 | **07.03.1975** | **39** | X |
| 13 | BE | Doel 2 | PWR | 433 | **21.08.1975** | **38** | X |
| 14 | UK | Hinkley Point B2 | GCR | 435 | **05.02.1976** | **38** | X |
| 15 | UK | Hunterston B1 | GCR | 430 | **06.02.1976** | **38** | X |
| 16 | UK | Hinkley Point B1 | GCR | 435 | **30.10.1976** | **37** | X |
| 17 | FI | Loviisa 1 | PWR | 495 | **08.02.1977** | **37** | X |
| 18 | UK | Hunterston B2 | GCR | 430 | **31.03.1977** | **36** | X |
| 19 | FR | Fessenheim 1 | PWR | 880 | **06.04.1977** | **36** | X |
| 20 | FR | Fessenheim 2 | PWR | 880 | **07.10.1977** | **36** | X |
| 21 | FR | Bugey 2 | PWR | 910 | **10.05.1978** | **35** | |
| 22 | FI | Olkiluoto 1 | BWR | 880 | **02.09.1978** | **35** | |
| 23 | FR | Bugey 3 | PWR | 910 | **21.09.1978** | **35** | |
| 24 | CH | Goesgen | PWR | 970 | **02.02.1979** | **35** | |
| 25 | FR | Bugey 4 | PWR | 880 | **08.03.1979** | **35** | |

**age on** **11 March 2014**
🟥 > 40 years
🟧 35 – 40 years

X = less than three years from its original technical design life-time
X = older than its original technical design life-time

BWR = boiling water reactor
PWR = pressurised water reactor
GCR = gas cooled reactor

**Table 1.1**. - 25 Oldest nuclear power stations in the EU and surrounding countries – operating reactors.
Age shown as of 11 March 2011
Source: IAEA PRIS database – http://www.iaea.org/pris.
11.03.2014

Almost half of those are older than their original design lifetime. In Europe excluding Russia, 46 out of 151 operational reactors are older than their original design lifetimes or within three years of reaching that date. However, only a few of those reactors will be closed down in the near future – most have had, or are set to have, their lifetimes extended for a further 20 years or more. In the United States, meanwhile, more than two-thirds of the ageing reactor fleet have received extended licences to take them to 60 years of operation. As a result, we are entering a new era of nuclear risk.

This study, commissioned by Greenpeace, consists of four chapters that address different aspects of Europe's ageing reactor fleet and issues relating to its lifetime extension. In Chapter 1, the German Öko-Institut investigates the technical aspects of nuclear ageing, building on earlier work commissioned by Greenpeace in 1986[1] and 2005.[2] In Chapter 2, Prof. Stephen Thomas of the University of Greenwich assesses the role of economics in decisions on the lifetime extension of old nuclear reactors. In Chapter 3, Prof. Tom Vanden Borre of the University of Leuven in Belgium and Prof. Michael Faure from the University of Maastricht assess the implications of an ageing reactor fleet for nuclear liability – in particular the question of the extent to which, if an accident befalls one of these older reactors, victims can count on receiving adequate compensation. They have also produced a longer, more in-depth study that will be published on the internet together with this report.[3] In Chapter 4, Ir. Jan Haverkamp assesses the public's role in decisions to extend the lifetimes of old nuclear reactors, and considers whether there are adequate opportunities for it to influence the decision-making process.

The opinions in the different chapters represent the opinions of the authors and do not necessarily coincide with those of Greenpeace.

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Simone Mohr holds a degree in mechanical engineering from the Rheinisch-Westfälische Technische Hochschule Aachen. After several years in industry she joined the Nuclear Engineering & Facility Safety research division of the Öko-Institut e.V. in 1995. Major activities in recent years include producing expert reports and providing scientific-technical advisory services for the German Federal Ministry for Reactor Safety and other competent authorities. She has participated at national and international levels in investigations related to plant-specific safety reviews following the Fukushima disaster. She has also focused on safety analyses of different reactor types and evaluation of nuclear programmes. Selected publications: 'Vulnerability analysis of the nuclear power plants in Dukovany, Czech Republic, with respect to the European Stress Test documents', 2012; 'Statement concerning the access records of citizens to technical safety documents of Mühleberg NPP in the context of the Federal Constitutional Court appeal by Ursula Balmer-Schafroth et al.", 2011; participation in the "Analysis of documents in the context of the strategic environmental assessment of the Polish nuclear power programme", 2011

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Stephan Kurth received a Diploma in Plant and Process Engineering from the Fachhochschule in Cologne. After several years as a project engineer and consultant in the chemical industry he moved to the Öko-Institut e.V. Since 1995 he has worked in the Nuclear Engineering & Facility Safety research division. At present he is head of the plant safety group and as a senior expert he is responsible for safety-related questions concerning nuclear and non-nuclear technologies. His focus is on incident analyses and the assessment of specific safety systems as well as safety concepts as a whole – including related issues of safety management. For many years he has been involved in the systematic evaluation of operational experience, especially of reportable incidents. He is a member of the Committee on Reactor Operation of the German Reactor Safety Commission and the Committee on Plant Safety (non-nuclear).

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Stephen Thomas is Professor of Energy Policy and Director of Research in the Business School of the University of Greenwich, London, where he has led the energy research since 2001. He has a BSc in Chemistry from the University of Bristol. He has worked as an independent energy policy researcher for 35 years. From 1979 to 2000 he was a member of the Energy Policy Programme at the SPRU - Science and Technology Policy Research, University of Sussex, and in 2001 he spent a year as a visiting researcher in the Energy Planning Programme at the Federal University of Rio de Janeiro.

He has published extensively on reforms to electricity industries worldwide and on the corporate policies of energy companies.

He was also a member of the team appointed by the European Bank for Reconstruction and Development to carry out the official economic due diligence study for the project to replace the Chernobyl nuclear power plant (1997). He was a member of an international panel appointed by the South African Department of Minerals and Energy to carry out a study of the technical and economic viability of a new reactor design, the Pebble Bed Modular Reactor (2001–02). He was part of an independent team appointed by Eletronuclear (Brazil) to carry out an assessment of the economics of completing the Angra dos Reis 3 reactor (2002).

Stephen Thomas has published extensively on economics and nuclear energy policy.

Selected publication: S. D. Thomas (2007) UK power plant projects: will the government's renewable targets be met?, in Green power markets: support schemes, case studies and perspectives (ed. L. Mez), Multi-Science Publishing, Brentwood, UK.

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Tom Vanden Borre graduated from Ghent University and the Catholic University of Louvain (UCL). He is an energy lawyer specialising in energy market regulatory issues: internal energy markets, nuclear energy etc. He is affiliated senior researcher at the Institute for Environmental and Energy Law (IMER) at the University of Leuven, where he teaches International and European Energy Law as well as Federal Energy Law and Policy. He also teaches International and European Energy Law at Malta University. He wrote his Law PhD on 'Liability and insurance of catastrophic risks (nuclear incidents)' at Maastricht University. He also works in the private energy sector.

Tom Vanden Borre previously worked at the European Commission and at the Commission for the Regulation of Electricity and Gas (CREG), the Belgian federal energy regulator. He was also formerly President of the Board of Directors of the Federal Agency for Nuclear Control (FANC), and energy advisor to the Belgian Prime Minister and the federal Minister of Energy. He started his career as legal counsel at the Belgian Nuclear Research Centre (SCK/CEN).

He is the author of several articles on energy law and policy (including nuclear energy and the internal gas and electricity markets) and regularly lectures at national and international conferences. Tom Vanden Borre is a member of the expert group on nuclear liability established by the European Commission in 2011.

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He was first a lecturer and then a senior lecturer at the Leiden University law faculty's department of criminal law (1988–99) and in September 1991 became academic director of the Maastricht European Institute for Transnational Legal Research (METRO) and Professor of Comparative and International Environmental Law in the law faculty of Maastricht University. He still holds both positions.

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Michael G. Faure publishes in the areas of environmental (including criminal) law, tort and insurance and economic analysis of law (including accident law). Recent publications include: Faure, M.G., Lixin, H. & Hongjun, S. (eds.) (2010) Marine pollution liability and policy: China, Europe and the US, Wolters Kluwer, Maatricht; Farber, D.A. & Faure, M.G. (eds.) (2010) Disaster law, Edward Elgar, Cheltenham; Faure, M.G. & van der Walt, A. (eds.) (2010) Globalization and private law: the way forward, Edward Elgar, Cheltenham; and Michael Faure (ed.) (2009) Tort Law and Economics, Edward Elgar, Cheltenham.

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Jan Haverkamp received a Candidate's (Bachelor's) degree in Biochemistry from Leiden University and a Master's degree (ir. - academic engineer) in Environmental Sciences from Wageningen University. He specialised in energy policy, air quality, nuclear physics and social and communication psychology.

Since 1987, he has supported the build-up of independent environmental organisations in the socialist German Democratic Republic (East Germany), Czech-Slovakia, Romania, Ukraine, Croatia and Albania. In 1997 he emigrated to the Czech Republic, where he became an energy campaigner for Friends of the Earth, Greenpeace and the World Information Service on Energy (WISE). He worked for four years as Greenpeace's EU nuclear policy advisor in Brussels. He is currently expert consultant for nuclear energy and energy policy for Greenpeace and WISE Brno.

Jan Haverkamp participated in the environmental impact assessments of the Temelín nuclear power plant in the Czech Republic, Belene in Bulgaria, Cernavodă 3 and 4 in Romania, Mochovce 3 and 4 in Slovakia and Visaginas in Lithuania, as well as the strategic environmental assessment procedure for the Polish nuclear energy policy.

He is a board member of Nuclear Transparency Watch, which deals with the implementation of the Aarhus and Espoo Conventions in the nuclear sector.

He teaches Environmental Facilitation and Environmental NGOs and Society at the Masaryk University in Brno, Czech Republic.

# Executive Summary

Nearly three years on from the Fukushima nuclear disaster, the 25 oldest nuclear reactors in Europe have all passed 35 years of operation. More than two-thirds of US nuclear reactors have received extended licences permitting 60 years of operation, far beyond their original design lifetimes. We are entering a new era of nuclear risk.

## RISKS OF NUCLEAR AGEING

**Dipl.-Ing. Simone Mohr, Dipl.-Ing. Stephan Kurth, Dr. Christoph Pistner,**
**Dipl.-Ing. Judith Breuer – Öko-Institut e.V., Darmstadt.**

At the time of writing (January 2014) the average age of European nuclear reactors has reached 29 years. An increasing number are reaching their design lifetimes of 30 or 40 years. New nuclear reactor construction in the EU is not capable of replacing all the reactors that are approaching the end of their design lifetimes, and the Fukushima disaster acted as a brake on new build programmes. Nevertheless we are seeing an increasing demand for new strategies to avoid a phase-out of nuclear energy, especially in countries that have not developed viable alternatives.

The current strategy of nuclear operators in much of Europe, including Switzerland, Ukraine and Russia, is targeted at a combination of extension of reactor lifetime (also called Long Term Operation) and power uprating. These factors taken together may have an important impact on the safety of the operational reactor fleet in Europe.

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 technological and conceptual ageing, because existing reactors allow for only limited retroactive implementation of new technologies and safety concepts. Together with ‘soft’ factors such as outmoded organisational structures and the loss of staff know-how and motivation as employees retire, these factors cause the overall safety level of older reactors to become increasingly inadequate by modern standards.

Measures to uprate a reactor’s power output can further compromise safety margins, for instance because increased thermal energy production results in an increased output of steam and cooling water, leading to greater stresses on piping and heat exchange systems, so exacerbating ageing mechanisms. Modifications necessitated by power uprating may additionally introduce new potential sources of failure due to adverse interactions between new and old equipment. Thus, both lifetime extension and power uprating decrease a plant’s originally designed safety margins and increase the risk of failures.

Physical ageing issues include those affecting the reactor pressure vessel (including embrittlement, vessel head penetration cracking, and deterioration of internals) and the containment and the reactor building, cable deterioration, and ageing of transformers. Conceptual and technological ageing issues include the inability to withstand a large aircraft impact, along with inadequate earthquake and flooding resistance. Some reactor types, such as the British advanced gas-cooled reactors (AGC) and Russian-designed VVER-440 and RBMK (Chernobyl-type) reactors  suffer specific problems.

Retrofits already recommended after the Three Mile Island accident in 1979 and the 1986 Chernobyl disaster have still not been implemented in every European nuclear power plant. Ageing management programmes so far implemented have not been sufficient to avoid the occurrence of serious ageing effects. Concrete examples exist where ageing of the workforce and consequent atrophy of the knowledge base as staff retire may affect occurrence of failures, as well as problems with retrofitting and refurbishment. Furthermore, there are considerable disparities in the responses of different operators and regulatory authorities to identified ageing problems.

Spent fuel storage presents a special risk for ageing nuclear power plants due to the build-up of large amounts of spent fuel. Examples of problems include inadequate protection against external hazards and the risks of a long-term loss of cooling (due to poor redundancy and low quality standards in spent fuel pool cooling systems), both issues illustrated by the Fukushima catastrophe. The re-racking of spent fuel elements into more compact storage units to increase the space available for the larger than expected amount of spent fuel is a further source of risk.

Site-specific risks change over time. New insights into earthquake risk require higher protection standards which cannot be fully met by modification of older nuclear power plants. The lack of emergency preparedness evident during the Fukushima disaster forces a reassessment of risks including those of flooding and loss of external infrastructure. Especially when seen in the light of the implications of climate change in terms of extreme weather and sea level rise.

The Fukushima disaster also highlighted the risk of an external event compromising multiple reactors at the same time – a situation hardly any multi-unit site is prepared for. Sources of common-cause failures include shared cooling inlets, pumping stations, pipelines, electricity infrastructure and so on – issues that were not sufficiently addressed in, for instance, the post-Fukushima EU Stress Test of nuclear reactors.

Perceptions of the most suitable locations for nuclear power plants have also changed over time. Many older plants are located in highly populated areas, obviously making emergency preparedness much more complex than for plants situated far from population areas, and greatly increasing the potential for harm.

The EU Stress Test furthermore did not explicitly cover ageing-related issues. The use of the original design basis to determine the robustness of reactors was particularly unsatisfactory, because design deficiencies and differences between different reactors were not fully taken into account. Because beyond design basis events had not been systematically analysed before, too little documentation was available and expert judgement played too large a part.

## ECONOMICS OF NUCLEAR AGEING

**Prof. Stephen Thomas – University of Greenwich**

If the cost of modifications is relatively low, life-extended nuclear power plants can be highly profitable to their owners because the capital cost of the plant (making up most of the cost of a unit of nuclear-generated electricity) will already have been paid off, leaving only the operations and maintenance cost to be paid. Other advantages to the owner include the fact that the plant is a known quantity.

The economic risks depend on technical, regulatory and political factors. In practice, plants are not retired on the basis of their design life, but according to these other factors.

In the USA, reactor retirements have mostly been due to economic reasons (including the prohibitive cost of repair), though some have been because of design reasons. In Germany most closures have stemmed from political decisions, though a few have been design-related. Elsewhere, reasons have been mainly economic (France) or technical and economic (Canada, Spain, the UK), political (Italy, Sweden) or political and design-related (Japan, largely in the wake of the Fukushima disaster).

National regulators are constantly increasing safety requirements, but for ageing reactors these can never be set at the level of the best available technology. For instance, design lessons from the 1975 Browns Ferry accident were applied to most designs developed after that, but those from the 1979 Three Mile Island accident and the Chernobyl (1986) and Fukushima (2011) disasters can only be taken into limited account.

Lifetime extension becomes an issue at different points in a reactor's life, depending on the country. In France, where licenses are open-ended, the decisive moment is the regulatory Periodic Safety Review (PSR), conducted every 10 years. In preparation of the 40 year PSR and because of additional post-Fukushima EU Stress Test prescriptions, EDF plans investments in its operational reactor fleet of around €50bn over the next 30 years. However, there is no clarity as yet about whether French reactors will receive a 20 yeas life-time extension as EDF has requested. In the USA, nuclear reactors operate under a 40-year licence. Well before the expiry of this licence, if lifetime extension is desired, a request must be made to the Nuclear Regulatory Commission for a 20-year extension. While the first such assessments took a few months, they are currently taking several years. So far, all reactors for which this assessment has been completed have had a 20-year extension granted. Nevertheless three plants (Vermont Yankee, Kewaunee and Crystal River) recently closed before lifetime extension was obtained because of excessive costs in the context of low electricity prices. San Onofre in California closed even before an extension was applied for, because of the cost of repairs.

Very few nuclear reactors have been retired because they have reached the end of their licensed or designed lifetime. Much more probable life-determining factors are: the economics of the plant; the existence of national phase-out policies; serious and unexpected equipment failures; and, for older designs in particular, existence of design issues that make continued operation unacceptable. However, in the 15 years since lifetime extension began to occur, the perception of the risk of granting a reactor a significantly longer life has increased. Permission for a reactor to operate for 60 years appears to be far from a guarantee that it will actually complete a 60-year life. A longer permitted lifetime has given utilities a reason to justify upgrades aimed at improving the economics of a plant, such as power upgrades. However, as the risks and costs of lifetime extension have become clearer, the case for this additional discretionary investment has weakened.

## LIABILITY OF AGEING NUCLEAR REACTORS

**Prof. Tom Vanden Borre – University of Leuven; Prof. Michael Faure – University of Maastricht**

The increasing risk posed by the ageing of nuclear reactors should be reflected in an increase in insurance premiums to cover the costs of a possible nuclear accident. Countries should only opt for reactor lifetime extension if the provision to compensate victims, of any accident, is substantially improved. Suppliers should be allowed to be held liable for accidents, and plant operators should face unlimited liability. Such increased liability will not only be beneficial for the victims of a nuclear accident but will also have an important preventive effect.

The principles of nuclear liability, fixed in the Paris and Vienna Conventions, include strict liability (liability for loss or damage regardless of negligence or other culpability); legal channelling of liability to the nuclear operator, with consequent exclusion of the supplier's liability; liability limitation for the nuclear operator in amount and time; compulsory coverage by financial security (insurance); and exclusive jurisdiction in the country of accident. Newer conventions such as the Convention on Supplementary Compensation (CSC) and the Protocols to the Paris and Vienna Conventions do not alter these principles. None of the Conventions, however, caters for reactor ageing issues.

The USA is not party to the Paris or Vienna Convention. Its Price-Anderson act enables nuclear operators to pool their liability resources. It provides for retrospective insurance for a top-up sum of liability in the event that an accident actually occurs. The amounts generated by this system are substantially higher than those under the international conventions; but conversely the nuclear operator's liability is capped just as it is under the conventions.

Given that the costs of a nuclear accident are potentially much higher than those covered in the limited liability coverage, liability limitation (capping) effectively gives the nuclear industry a two-fold subsidy: the limit itself, leading to lower insurance costs; and either top-up coverage by the state (in the case of Europe) or the opportunity to defer a portion of insurance costs to second-tier retrospective coverage (USA). These legal regimes thus protect nuclear operators and artificially decrease their risk costs, potentially creating three types of distortions:

1. The reduced cost of insurance gives nuclear energy an artificial competitive advantage because other electricity generation technologies (and market operators) have to internalise their full risk;
2. The liability cap reduces an operator's economic incentive to reduce the risk of a nuclear accident.
3. The cap, coupled (in the case of Europe) with inadequate top-up coverage, may result in a lack of or insufficient compensation for victims in the event of an accident.

The increasing risk posed by nuclear ageing should lead to an increase in operators' insurance premiums. With ageing nuclear reactors, adequate financial security to cover the costs of a potential accident becomes even more a necessity. It is important for society as a whole that objective calculations are made of the damage that a nuclear accident could potentially cause, and on that basis alternative systems of financing the coverage have to be investigated. It is obviously important to accompany this with a mandatory financial security requirement for operators, but the higher resulting costs resulting from such an analysis should not be a reason to limit liability. Pooling of the financial security by operators may be a good alternative to the current European nuclear insurance pools.

A new compensation model for nuclear damage should keep the positive elements of the international nuclear liability conventions: strict liability and compulsory liability insurance. It is especially important that compulsory insurance protects victims against insolvency of the operator. Conversely, the conventions, even as revised by their relevant protocols, allow for only up to about one per cent of the cost of an accident to be compensated for. The alternative is obvious: unlimited liability should be introduced.

Legal channelling of all liability to the operator is problematic. From the viewpoint of victims it would be preferable to be able to address a claim against several persons or corporations, as this would increase their chances of receiving compensation. It would also have a preventive effect since all parties bearing a share of the risk would have an incentive to avoid damage.

Countries considering plant lifetime extension should end funding part of the liability coverage with public means, extend liability to suppliers, and introduce unlimited liability for operators, while requiring the latter to have third-party liability insurance coverage or other financial security of a realistic level in terms of the actual scope for damage. Several possible financial schemes exist to fulfil this objective.

Countries should opt for reactor lifetime extension only if arrangements for the compensation of victims in the event of an accident are substantially improved. A higher level of liability would not only benefit the victims of a nuclear accident but would again have an important preventive effect. Pooling unlimited liability across Europe would encourage operators to monitor one another, since they would be reluctant to allow a bad risk into their system.

In conclusion, there are strong reasons for the EU's current state funding of financial security against a nuclear accident to be replaced by a collective system funded by the EU nuclear operators. Reactor lifetime extension should only be allowed if such an enhanced approach to nuclear accident compensation is adopted.

## POLITICS, PUBLIC PARTICIPATION AND NUCLEAR AGEING

**Ir. Jan Haverkamp – Greenpeace, Nuclear Transparency Watch**

There are various routes by which the public can influence decisions on the lifetime extension of nuclear reactors. Nuclear safety is the most obvious consideration, but economic or political arguments can play an overriding role, as for example during the German discussions on a nuclear phase-out. A high level of transparency (requiring public and media access to information) and public participation in decisions around ageing nuclear reactors can help to ensure the priority of nuclear safety. In Europe (excluding Russia, which is not considered here because it is not a party to the Aarhus and Espoo Conventions), reactor lifetime extension decisions have been recently concluded, are currently under consideration or will come under consideration in the coming three years in Belgium, the Czech Republic, France, Spain, Hungary, the Netherlands, Sweden, the UK, Switzerland and Ukraine. The point at which lifetime extension of a nuclear reactor becomes necessary for its continued operation is determined by the length of its operating licence (in countries where these are time-limited); or, in the case of an unlimited operating licence, by the national regulator after a periodic safety review, or on the basis of a political decision. The potential cost of upgrades, the likely cost recovery time, and the operator's ownership status and political influence can all act to reduce the priority accorded to nuclear safety during lifetime extension decisions. The independence of nuclear regulators is an important factor in counterbalancing such pressures. Public access to information (transparency) as guaranteed under the Aarhus Convention can also help, as can public participation and provisions to ensure that account is taken of critical public opinion. Referenda are a less clear-cut instrument.

Public participation under the Aarhus and Espoo Conventions and their implementing EU Directives can also influence decisions on the future of a country's ageing reactor fleet during strategic environmental assessment of national energy policies. A recent decision by the Espoo Convention Implementation Commission furthermore makes an environmental impact assessment including public participation compulsory for decisions concerning nuclear plant lifetime extension. Citizens of states party to these conventions also have avenues of legal recourse when they are not sufficiently included in these decision processes.

# Risks of Nuclear Ageing

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# 1 Introduction

As of 1 January 2014, 437 nuclear power reactors were in operation worldwide, 132 of them in the EU.[1] Most of these reactors were built in the 1970s and 1980s, and the average age of the nuclear fleet is continually growing. While originally reactor operation was typically foreseen for lifetimes of 30 or 40 years, many countries today prolong the planned lifetimes of their nuclear fleets. At the same time, reactor operators are keen to increase the power output of their plants. These factors taken together may have an important impact on the safety of the operational reactor fleet in Europe as well as worldwide.

Section 2 gives an overview of the current status of nuclear power in Europe. Section 3 discusses the safety implications of important aspects of the ageing of nuclear reactors and their associated infrastructure, such as physical ageing of systems, structures and components; the growing gap between old reactor designs and state-of-the-art of science and technology; and the ageing of organisational structures.

The increasing age of nuclear reactors also has a bearing on risks associated with the storage of spent fuel, as discussed in section 4. Furthermore, the perception and consideration of external hazards has changed with time, influencing the criteria for siting of nuclear power plants, an issue explored in section 5. Moreover, the major accident at the Fukushima Daiichi site in Japan on 11 March 2011 led to renewed discussion of reactor safety in Europe, as discussed in section 6. The need for important retrofits, especially for older reactors, has been identified in the framework of the European Nuclear Stress Tests following the Fukushima disaster.

Finally, section 7 summarises major aspects of the impact of ageing on the safety of nuclear reactors in Europe as well as worldwide.

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[1] Unless otherwise stated, reactor data in this study are based on the IAEA PRIS database: http://www.iaea.org/PRIS

# 2 Status and prospects of nuclear reactors

## 2.1 Age of nuclear reactors in Europe and worldwide

The age distribution of commercial nuclear reactors[2] in the European Union plus Switzerland and Ukraine is given in Figure 1.1.[3] The age distribution of reactors in the worldwide fleet is comparable.[4] The average age of reactors worldwide is over 28 years, while the average age of European reactors rose to 29 years in 2014.

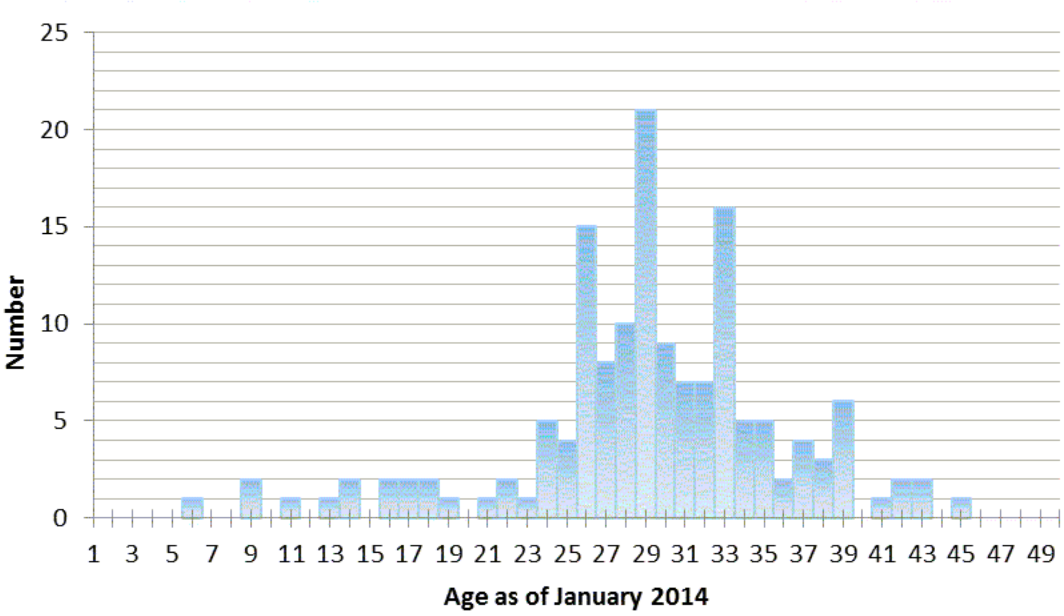

Figure 1.1 – Age (based on first grid connection) of operating nuclear reactors in the European Union, Switzerland and Ukraine.
Source: based on International Atomic Energy Agency: Power Reactor Information System (PRIS), http://www.iaea.org/PRIS, as of 10 January 2014 .

As of January 2014, more than 50 per cent of operational reactors worldwide were over 30 years old. Forty-five reactors have exceeded 40 years, 14 of them located in Europe including Russia. Beznau 1 in Switzerland is the oldest operational reactor in Europe and – together with Tarapur-1 and 2 in India – the oldest in the world at nearly 45 years. None of the reactors that have so far been permanently shut down worldwide has reached 50 years of operation since first grid connection. The British Calder Hall and Chapelcross reactors have come closest, reaching 44 and 47 years respectively. The reactors at both sites were small units with a power capacity of 60 MW each. The average age of shut down reactors worldwide is less than 25 years. From these numbers it is evident that little operational experience exists of nuclear reactors with more than 40 years of commercial operation.

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[2] http://www.iaea.org/PRIS

[3] Throughout this study, the age of a reactor is calculated on the basis of the date of first connection to the electrical grid. This date is relevant to several of the ageing phenomena discussed. In other studies, the age of a reactor is sometimes calculated on the basis of the beginning of commercial operation. This is a more relevant date for the economic aspects of nuclear power, but not as significant in the context of ageing.

[4] See also: Schneider, M., Froggart, A. et al. 2013. World nuclear industry status report 2013. Mycle Schneider Consulting.

## 2.2 Construction of new reactors

Around 1980, more than 200 reactors were simultaneously under construction. In the 1990s and 2000s this figure dropped to well under 50 reactors. Only recently has there been a modest increase in construction start-ups.

Enhanced safety requirements, generally decreasing acceptance of nuclear power in many countries and financial risks have prevented the European nuclear industry from building new reactors. Consequently, most reactors under construction today are located in Asia, as shown in Figure 1.2. Over the past 10 years, new reactors have been connected to the grid only in China (10), India (7), Japan (4), South Korea (4), Russia (3), Ukraine (2), Iran (1), Pakistan (1) and Romania (1). Particularly in emerging economies such as China, new reactors are intended to increase the country's total electricity generating capacity rather than to replace older reactors.

The only reactor newly connected to the grid in the EU in the last decade was the Cernavodă 2 reactor in Romania, the construction of which was started in 1983 but suspended between 1990 and 2001. It is 30 years since Europe reached its historic peak in the number of reactors being connected to the grid each year.

Several countries worldwide have announced plans to build new reactors. Topping the list of countries building new reactors are China and Russia; most countries building new reactors already have reactors in service, but the list includes two countries new to nuclear power, the United Arab Emirates and Belarus. As discussed for example in the World nuclear industry status report of 2013, prognoses for new-builds tend to be overoptimistic.[5] While forecasts have often predicted a total global installed nuclear capacity of well above 1000GW, even today less than 400GW of net electrical power are installed worldwide.[6] It still remains to be seen which projects will actually be completed (or started, in the case of those whose construction has not yet begun) and whether announced construction schedules will be met even approximately.

The European Pressurised Reactor (EPR) – a modern design of pressurised water reactor (PWR) propagated to have enhanced safety features – is of special importance for the European nuclear industry's situation. It is the only new reactor type under construction in the EU. Currently one EPR is under construction at Olkiluoto, Finland and another at Flamanville, France. Two further units are being built at Taishan, China. So far, though, not one EPR is in operation. Completion of the EPRs currently under construction has been delayed again and again. When construction started in 2005, Olkiluoto 3 was expected to begin operations in 2009. After several delays, in February 2013 the intended operator (Finnish utility Teollisuuden Voima, TVO) announced that commercial electricity production would most likely be delayed to 2016 due to repeated problems and soaring costs.[7] The Flamanville 3 EPR has been under construction since 2007 and commercial operation is intended to begin in 2016, meaning that plant is already four years behind schedule.[8]

In addition to entirely new construction, however, some dormant construction sites where work had been suspended have recently been reactivated in Europe. In 2009, construction of 2 VVER-440 type reactors was restarted in Mochovce in Slovakia, after several delays since 1993.

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[5] Schneider, M., Froggart, A. et al. 2013. World nuclear industry status report 2013. Mycle Schneider Consulting.

[6] See figure 12 in Öko-Institut. 2011,Streitpunkt Kernenergie. http://www.streitpunkt-kernenergie.de/index.php?id=19.

[7] http://www.reuters.com/article/2013/02/11/teollisuudenvoima-olkiluoto-idUSL5N0BBEZ520130211

[8] http://www.lefigaro.fr/societes/2013/01/17/20005-20130117ARTFIG00617-flamanville-edf-confirme-la-mise-en-service-en-2016.php

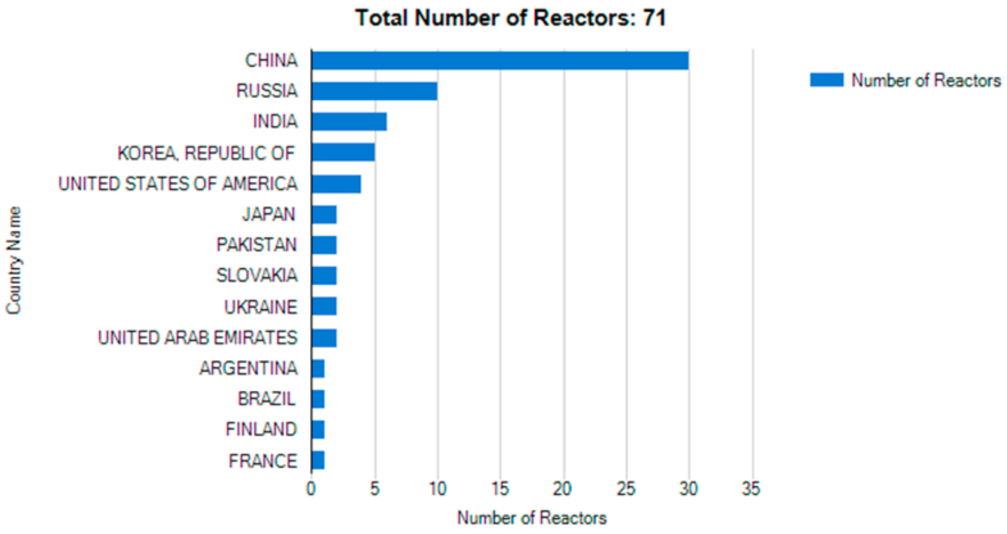

Figure 1.2 – Reactors under construction worldwide in November 2013.
Source: International Atomic Energy Agency: Power Reactor Information System (PRIS), http://www.iaea.org/PRIS

A special situation exists in Ukraine, which claims it will complete the construction of Khmelnytskyi 3 and 4, construction of which was halted in 1990. A modification of the VVER 1000/392B type is planned and will be financed by Russia. In Russia itself, ten reactors of different types are under construction, including one fast breeder and two small KLT-40S reactors.[9]

None of the reactors in in the Czech Republic, Slovakia, Bulgaria and Romania is over 30 years old. However, most of them will reach 30 years shortly and face the the need of life-time extension.

The Fukushima accident reinforced the trend towards low numbers of construction start-ups in Europe. Several countries have revised their nuclear programmes, for example Switzerland, where three new-build projects have been put on hold indefinitely.

The limited number of new-builds in Europe has resulted in an increasing demand for new strategies to avoid the phasing out of nuclear energy. More than half the reactors in France, the country with the world's second biggest reactor fleet with each a design life-time of 40 years, are at least 30 years old. A comparable situation exists in several other countries in Europe, as shown in Figure 1.3. Countries such as Belgium, the Netherlands, Sweden, Switzerland and Slovenia will be forced to close all their existing reactors in the near future if their lifetimes are not extended.

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[9] http://www.world-nuclear.org/info/Country-Profiles/

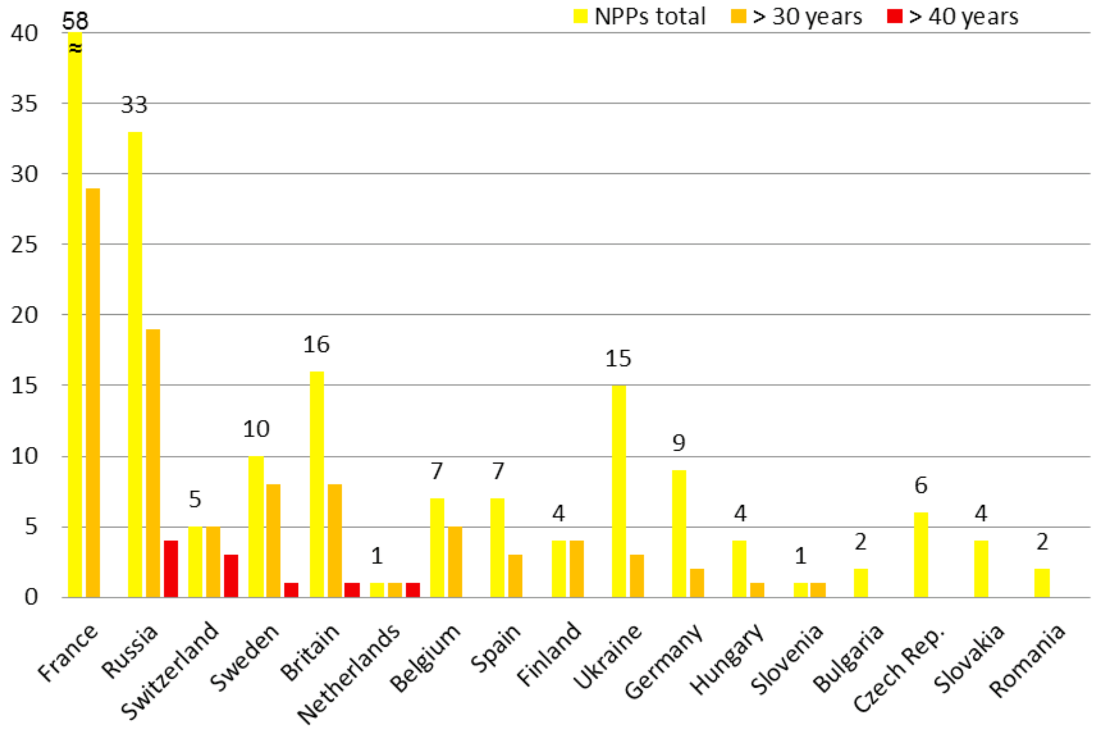

Figure 1.3 – Age of nuclear reactors in Europe, including Russia, as of January 2014.
Source: International Atomic Energy Agency: Power Reactor Information System (PRIS), http://www.iaea.org/PRIS

In order to maintain nuclear energy output levels, European governments and operators are following two strategic routes, both of which are seen as less expensive and politically more convenient than building new reactors:

- Plant lifetime extension (PLEX) of reactors; and
- Plant power uprating (PPU) of reactors.

Lifetime extension and power uprating allow electrical generating capacity to be maintained or enhanced with comparatively little effort in terms of financing, planning, licensing and technical implementation, compared to building a new reactor. These two strategic routes are discussed next.

## 2.3 Plant lifetime extension and power uprating

Design lifetime is defined by the International Atomic Energy Agency (IAEA) as:

> The period of time during which a facility or component is expected to perform according to the technical specifications to which it was produced. [10]

The systems, structures and components (SSCs) of nuclear reactors often fulfil safety relevant functions, either because the failure of a component may initiate an incident or accident, or because a system function is needed to cope with an incident or accident when it occurs. Because of this, the functioning of systems, structures and components within their specified parameters has to be guaranteed throughout the operation of a reactor.

Consequently, nuclear reactors themselves are initially designed for a specific design lifetime.

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[10] IAEA. 2007. IAEA safety glossary. Terminology used in nuclear safety and radiation protection, 2007 edition.

The term ‘physical ageing’ encompasses the time-dependent mechanisms that result in degradation of a component’s quality. After three or four decades of operation under high pressure, temperature, radiation and chemical impacts as well as changing load cycles, the risk of ageing becomes more and more significant. Unexpected combinations of various adverse effects such as corrosion, embrittlement, crack progression or drift of electrical parameters may result in the failure of technical equipment, leading to the loss of required safety functions. Life-limiting processes include the exceeding of the designed maximum number of reactor trips and load cycle exhaustion. Examples of physical ageing in reactors will be discussed in more depth in section 3.

Again and again throughout the world, incidents occur caused by reactor ageing. Even though the fundamental ageing mechanisms are well-known in principle, their potential to lead to incidents and accidents may not be fully recognised before the actual events take place. For example, failures due to, corrosion, pipe ruptures or leakages, or inappropriate maintenance are often reported. Nevertheless, a quantitative analysis of the impact of physical ageing on reactor safety is difficult, because reporting criteria differ from one country to another and there is usually only poor information available on ageing-related causes of incidents.

Besides the effects of physical ageing, today a more comprehensive understanding of ageing has become generally accepted. In addition to physical ageing, conceptual and technological ageing must now also be taken into account.[11]

With the continuous development of science and technology, new technical solutions become available that may enhance the safety level of systems, potentially making existing systems outdated until modified (technological ageing). Moreover, new regulatory requirements are introduced, often in reaction to operational experience, again making existing systems outdated (conceptual ageing). In these ways, a reactor design may become outdated, (see also section 3.2). The retroactive implementation of advanced technologies and modern safety concepts in existing facilities is possible only to a limited extent. In addition, some ‘soft’ factors such as outdated organisational structures or the loss of specific know-how and motivation are of importance to the safety of nuclear power plants (see section 3.3).

Taken together, the result of physical, technological and conceptual ageing is that the overall safety level of a nuclear reactor becomes increasingly inadequate over time, as shown in Figure 1.4.

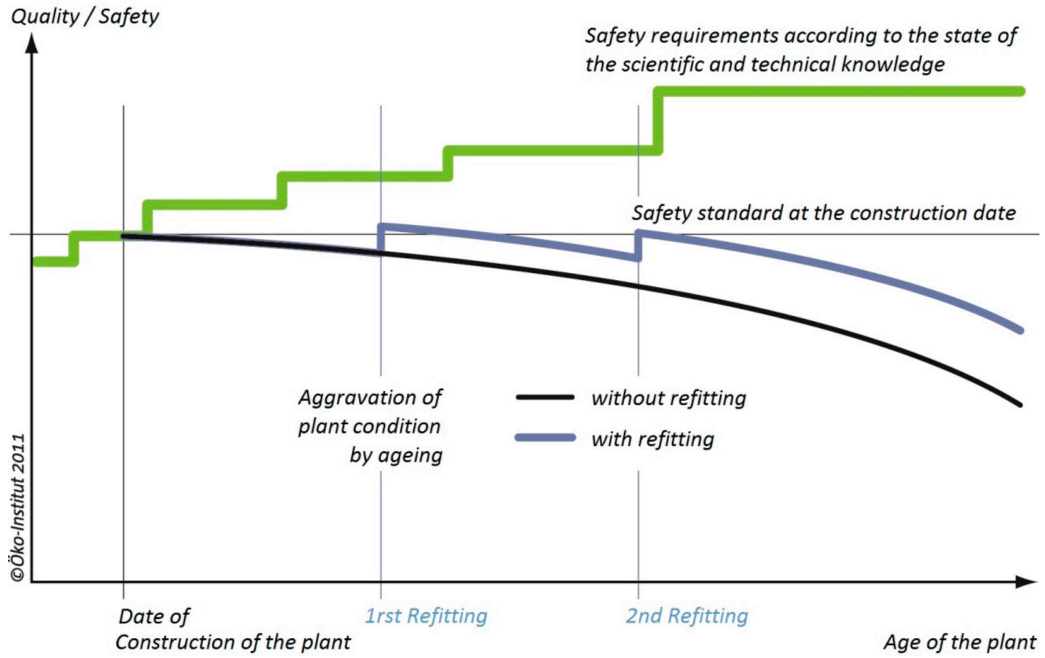

Figure 1.4 – Schematic diagram showing the progression of nuclear reactor ageing
Source: Öko-Institut

Many boiling water reactors (BWRs) and pressurized water reactors (PWRs) were originally designed for 40 years of operation, the Russian VVER-440 reactors for 30 years of operation. As reactors approach those limits, many operators hope to extend their operation beyond their design lifetime.

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[11] German Reactor Safety Commission. 2004. Beherrschung von Alterungsprozessen in Kernkraftwerken vom 22.07.2004, 374. Sitzung.

### 2.3.1 Plant lifetime extension

In some countries, the operating licences given to a nuclear reactor are limited to a certain lifetime, often coinciding with the design lifetime. When the reactor is approaching the end of its originally licensed lifetime, the operator may apply for an extension of the original licence or a new licence. In other countries, reactors receive an unlimited operation licence, but start-up permission procedures by the national nuclear regulator after reaching the reactor's design lifetime fulfil a similar function as the above mentioned re-licencing. Reactor operation beyond design lifetime is called plant lifetime extension (PLEX), or long term operation (LTO). Usually, for a reactor to operate beyond its design lifetime the operator will have to demonstrate that safety requirements imposed by the national regulator will be met.

Reactors operating beyond their original design lifetime may experience increasing safety risks due to ageing, for example the risk of component failure because of weakened and exhausted materials. Authorities therefore require special plant life management (PLiM) arrangements to deal with relevant aspects arising from long-term operation. The utilities are required to implement measures such as intensified monitoring, inspection and periodic testing as well as specific maintenance strategies. Evaluation and forecasting of ageing effects such as crack progression should ensure further plant operation.

At the same time, reactors have to meet higher standards as new materials, technologies and design concepts are developed, especially as a result of lessons learnt from operational experience and major accidents such as that at Fukushima.

The IAEA recommends taking 'measures to optimize the life cycle of operational plants' and defines PLiM as follows:

> National approaches in many countries showed an increase of interest in Plant Life Management (PLiM) for safe long term operation, both in terms of plant service life assurance and in optimizing the service or operational life of NPP [nuclear power plant].
>
> The safety considerations of a NPP are paramount and those requirements have to be met to obtain and to extend/renew the operating licence. To achieve the goal of the long term safe, economic and reliable operation of the plant, PLiM programme is essential. Some countries already have advanced PLiM programmes while others still have none.[12]

Objectives of PLiM are:

- to identify system, structures and components that are critical to plant safety and power generation; and
- to identify ageing degradation mechanisms that can lead to an unexpected or unplanned functional failure.

### 2.3.2 Plant power uprating

In addition to plant lifetime extension, operators of nuclear power plants may wish to enhance the power output of their reactors. 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 refuelled 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 the more demanding operating conditions that exist at the higher power level.

Power uprates of up to 7 per cent of initial design power can be achieved by adjusting the operational parameters (e.g. temperature, pressure) and control devices, with the actual increase in power depending on a plant design's specific operating margin. Furthermore, extended power uprates of more than 20 per cent can be achieved by replacement of steam generators, high- and low-pressure turbines, condensate pumps and motors, or electrical transformers.[13]

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[12] http://www.iaea.org/NuclearPower/PLIM-LTO/

[13] http://www.nrc.gov/reactors/operating/licensing/power-uprates.html

### 2.3.3 Problems of lifetime extension and uprating

Lifetime extension or power uprating of nuclear reactors often requires the replacement of heavy components such as steam generators or reactor pressure vessel (RPV) heads. Operational experience shows that replacement of heavy components can result in difficulties due to replacement work and incompatibilities between new and old parts of the reactor.

For example, while more recent nuclear power plants have equipment hatches for the replacement of large parts already included in the reactor building and containment, in older plants it may be necessary to cut a hole through the concrete, rebar, and steel liner of the reactor building and containment in order to exchange large components such as steam generators. The concrete must first be hydroblasted, sawn, or chipped away by jackhammer from the rebar and the steel liner of the containment, leaving them exposed to the environment. These methods can weaken the containment and the steel liner severely[14].

Figure 1.5 – Steam generator replacement through a hole cut into the containment at the Belgian nuclear power plant Doel 2, 2004. (© electrabel)

In 2009, uprating of the 32-year-old Crystal River 3 plant in Florida was to begin with steam generator replacement. Accordingly it was planned to cut a large hole in the concrete containment, which was strengthened with hundreds of tightened vertical and horizontal steel tendons. But after the tension in some of the tendons was relaxed, unexpected stresses inside the concrete occurred, causing delamination and cracking of the containment. The operator Progress Energy's repair attempts made the situation worse, and the plant was permanent shut down in February 2013.[15]

Another example of the pitfalls of heavy component replacement concerns the steam generator replacement in units 2 and 3 of the San Onofre nuclear power plant in California, which resulted in permanent shutdown of both plants. Severe and unexpected degradation of tubes appeared in the newly installed steam generators after only approximately 1.7 years and 1 year respectively of effective full power operation.[16] The excessive tube wear was caused by a combination of flow-induced vibration and inadequate support structures. The risk of the replacement became obvious in January 2012, when a tube in the unit 3 steam generator

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[14] IAEA. 2008. Heavy component replacement in nuclear power plants: experience and guidelines. IAEA Nuclear Energy Series, Technical Reports No. NP-T-3.2, October 2008.

[15] http://nuclearstreet.com/nuclear_power_industry_news/b/nuclear_power_news/archive/2010/09/03/mystery-crack-in-the-crystal-river-s-containment--building-solved.aspx

[16] http://www.nrc.gov/info-finder/reactor/songs/tube-degradation.html

experienced a coolant leak after only 11 months of operation. Steam generator tube ruptures are severe nuclear incidents which result in radioactivity transfer from primary circuit into secondary circuit and can also affect the core cooling due to loss of coolant.[17]

## 2.4 Country-specific outlook

In this section, country-specific information on reactor lifetime extension and power uprating is given for European countries with operational nuclear power plants. Information is based on the IAEA's Power Reactor Information System as of 1 January 2014, if not otherwise indicated.[18]

### 2.4.1 Belgium

Belgium's seven PWRs are located at two sites, Doel and Tihange. The oldest three reactors, Doel 1 and 2 and Tihange 1, had a design lifetime of 30 years[19] and are now approximately 40 years old. They have undergone power uprating of around 10 per cent. In July 2013, Belgium's Council of Ministers made an agreement to close the twin Doel 1 and 2 reactors in 2015. On 28 November 2013, the Belgian federal Chamber of Representatives adopted a new nuclear phase-out law,[20] which rescheduled the decommissioning calendar for the country's seven PWRs. According to this new legislation, all reactors must close at the age of 40, as had already been stipulated by previous legislation, with the exception of Tihange 1, which was awarded a lifetime extension of 10 years and must now close at the age of 50, i.e. by 1 September 2025. The newest of the remaining Belgian reactors will reach 40 years old in 2022 and 2025.[21]

Known problems of Belgian reactors include RPV embrittlement and flow-accelerated corrosion/erosion corrosion. Issues that have recently come to light are primary water stress corrosion cracking of Inconel 182 welds, RPV underclad defects and degradation of internal structures in cooling towers.[22] Multiple cracks have been found in the RPVs of Doel 3 and Tihange 2, as described in more detail in section 3.1.1.

### 2.4.2 Bulgaria

Bulgaria operates two PWRs at the Kozloduy nuclear power plant. Kozloduy 5 and 6 are currently licensed to 2017 and 2019 respectively. Licences are valid for 10 years and the operator can apply for licence renewal on the basis of a safety assessment report.

Following the commitments Bulgaria made regarding accession to the EU, Kozloduy's first four units (Kozloduy 1–4, VVER-440/V-230 reactors) ceased operation in 2002 and 2006.

### 2.4.3 Czech Republic

The Czech Republic's six reactors are located at the Temelín and Dukovany nuclear power plants. All are Russian reactor types: four VVER-440/V-213 reactors (2 twin units) at Dukovany and two VVER-1000/V-320 units at Temelín. Lifetime extension up to 60 years is foreseen for all reactors and power uprating has been carried out by up to 12 per cent for the Dukovany units and nearly 6 per cent for the Temelín units.

The Czech nuclear regulator, the State Office for Nuclear Safety (SÚJB) has allowed the operator ČEZ to upgrade the four VVER-440 units at Dukovany as preparation for a formal request for lifetime extension in the coming years. ČEZ has invested about €0.5bn.[23] A surveillance programme has been put in place for the RPVs. Furthermore, pressurised thermal shock calculations and assessment of the state of the RPVs have been performed.

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[17] Nucleonics Week. 2013. MHI has no liability limit for San Onofre steam generators: SCE7 November 2013.

[18] IAEA: Power Reactor Information System (PRIS). http://www.iaea.org/PRIS, as of 10 January2014.

[19] Response from the Minister of Economic Affairs, Melchior Wathelet, on the Parliamentarian question 968 of senator Jo Cuyvers of 19 February 1995: "In the design and construction of a nuclear power station, a minimal life expectancy is established for the nuclear and accompanying parts as well as the so-called classical equipment. These are 30 years for the power units Doel 1 and 2 and Tihange 1 and 40 years for the units Doel 3 and 4 and Tihange 2 and 3."

[20] Chambre des représentants de Belgique. 2013. Projet de loi modifiant la loi du 31 janvier 2003 sur la sortie progressive de l'energie nucléaire à des fins de production industrielle d'électricité. Texte adopté en scéance plénière le 28 novembre 2013. Doc 53 3087/006. http://www.dekamer.be/flwb/pdf/53/3087/53K3087006.pdf

[21] http://www.dekamer.be/FLWB/pdf/53/3087/53K3087006.pdf

[22] IAEA. 2006. Plant life management for long term operation of light water reactors. Technical reports series no. 448. IAEA, Vienna.

[23] http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/Czech-Republic/

## 2.4.4 Finland

Finland's four nuclear reactors are located at Loviisa and Olkiluoto. A fifth reactor is currently being built at the Olkiluoto site. Finland has aggressively uprated the capacity of its two Swedish-built BWRs at Olkiluoto by 33 per cent and that of its two Russian VVER-440/V-213 reactors at Loviisa by 18 per cent, resulting in nearly 600 MW of additional power. The VVER reactors have been granted a licence extension for a total of 50 years of operation, and the Swedish-built BWRs for up to 60 years. All reactors will be subject to a safety evaluation every 10 years.

## 2.4.5 France

Nearly half of the 58 operational French reactors are already older than 30 years. The oldest reactors, Fessenheim 1 and 2 and Bugey 2, 3, 4 and 5, are between 35 and 37 years old. Twelve reactors have already been shut down. One reactor of the European Pressurised Reactor (EPR design is currently under construction at the Flamanville site.

Areva – the world's largest nuclear manufacturer – has joined forces with Electricité de France (EDF) – France's nuclear operator and the world's largest operator of nuclear power plants – in an EDF project to build new plants of the EPR type in France, China, the UK and possibly the USA. During his time in office, former French President Nicolas Sarkozy set up France's Nuclear Policy Council to focus the country's nuclear energy policy on optimising Areva's 1,650 MW EPR design and improving the maintenance and operation of EDF's current reactor fleet.

After President Hollande took office in 2012, national public debates led to a reversal of opinion and now consider possible routes to reduce the importance of nuclear power in France.[24] The French government is expected to introduce a range of legislation to shape its long-term energy policy. A new law on long-term energy planning is currently expected to be tabled before mid-2014, with the intention that it should be passed before the end of the year. Hollande committed as presidential candidate, and again as President, to reducing nuclear power's share of the country's total capacity from the current 75 per cent to 50 per cent by 2025.[25] Still, operation of at least some of the country's reactors for up to 60 years is under consideration.

After a 10 year periodic safety review, the French nuclear authority ASN gave EdF permission to continue operation of five reactors (Tricastin 1, Fessenheim 1 and 2 and Bugey 2 and 4) beyond 30 years up to 40 years. These individual permissions are formally conditional on the implementation of safety requirements, which can be quite demanding. The same 10 year extension is expected to be granted for the other 21 reactors that are approaching 30 years since grid connection.[26] Nevertheless, despite the lifetime extensions granted to the Fessenheim plant, Hollande has made a strong political commitment to have the oldest reactors Fessenheim 1 and 2 shut down by 2016 at an age of 39 years.

The French reactors have the highest degree of standardisation in the world: all units are PWRs of three standard Framatome-designed types[27] (the first two being derived from US Westinghouse types, with only four units of 1,450 MW being of wholly French design). Plant power uprating has been carried out only on five older reactors in France.

The oldest reactors, Fessenheim 1 and 2 and Bugey 2, 3, 4 and 5, have not undergone any power uprating.

One major issue in France was an RPV head replacement programme that became necessary because of control rod drive penetration leakage through primary water stress corrosion, and cracking of Alloy 600. More than two-thirds of the reactor vessel heads have been replaced. A steam generator replacement programme was also carried out due to Alloy 600 cracking. Alloy 182 and 82 welds, associated J welds and bottom-mounted instrumentation areas will need treatment.[28]

Other recent major issues include the first appearance of cracks in penetrations at the bottom of an RPV at the Gravelines plant, and a series of problems affecting steam generators (chemical clogging and flawed fixations, both giving rise to vibration and cracking). There is also growing concern at the loss of impermeability of the concrete containments of the reactor buildings, especially those of the 1,300 MW and 1,450 MW reactors, which have a double wall of concrete but no internal steel liner.

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[24] http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/France/

[25] Environmental conference for ecological transition. 2013. Opening address. Palais d'Iéna, 20 September 2013. http://www.elysee.fr/assets/pdf/discours-d-ouverture-de-la-conference-environnementale-pour-la-transition-ecologique.pdf

[26] http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/France/

[27] Framatom was France's state owned nuclear constructor until it was in 2001 included under the name Areva NP into the nuclear state company Areva.

[28] IAEA. 2006. Plant life management for long term operation of light water reactors. Technical reports series no. 448. IAEA, Vienna.

## 2.4.6 Germany

Germany has nine operating nuclear reactors, which are aged between 24 and 32 years. There has never been a formal lifetime extension programme, as reactor operating licences are not time-limited. In 1997 the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety required all operating nuclear power reactors to undergo a periodic safety review every 10 years.[29]

In 1998, the new Social Democratic Party (SPD)/Green Party coalition government decided to amend the country's Atomic Energy Act. Instead of promoting nuclear energy, the purpose of the Act became to phase out commercial nuclear energy in a structured manner. In 2001 an agreement was signed between the government and the four main energy companies, which limited the lifetime of the 19 reactors then operational to an average of 32 years. It also prohibited the construction of new reactors.

In September 2009 the newly elected conservative/liberal coalition government reversed the country's energy policy, with the aim of prolonging the lifetimes of still operational reactors. At the end of October 2010 two new amendments to the Atomic Energy Act passed the upper and lower houses of the German parliament. Two groups of reactors were defined according to age. Reactors built before 1980 were awarded a lifetime extension of around eight years, while newer reactors were awarded a lifetime extension of around 14 years.[30]

Only five months later, however, in reaction to the Fukushima incident of 11 March 2011, a safety review of the 17 reactors then operational in Germany was conducted by the German federal Reactor Safety Commission. Additionally, a new energy policy was developed by the Government, based on the recommendations of a specially convened ethics commission. As a result, Germany's decision to phase out nuclear energy was renewed and the lifetime extensions of 2010 were withdrawn. The immediate permanent shutdown of the seven oldest reactors (Brunsbüttel, Isar 1 and Philippsburg 1 (all BWRs of the SWR-69 type); Biblis A and B, Neckarwestheim 1 and Unterweser (all PWRs of a second generation type)), as well as of Krümmel (the only other BWR of the SWR-69 type), was ordered. For the remaining nine reactors (two BWRs ot the SWR-72 type, four PWRs of the pre-Konvoi type and three of the Konvoi type) fixed shutdown dates were set in the Atomic Energy Act. The last reactor in Germany will thus be shut down on 31 December 2022.[31]

In 1989 and 1990, soon after the German reunification, four reactors of the Russian VVER-440/V-230 type and one of the VVER-440/V-213 type located at Greifswald in the former German Democratic Republic were permanently shut down. The federal technical support organisation GRS (Gesellschaft für Anlagen- und Reaktorsicherheit mbH) had carried out an in-depth safety analysis and concluded that both VVER-440 reactor types had serious safety deficiencies.[32] Decommissioning started in 1995 and has made considerable progress.

## 2.4.7 Hungary

Hungary has four operational reactors. The two twin units of the Russian VVER-440/V-213 type are located at the Paks site near the Danube. Paks was originally granted an operating licence limited to 30 years, with a possibility of renewal. To this end, an environmental impact assessment had to be submitted to the regulator; this was concluded in 2012. The Hungarian regulator HAEA (Hungarian Atomic Energy Agency) has granted Paks' first reactor a 20-year lifetime extension and is currently assessing the case for reactor 2, with a decision expected in September 2014. A power uprate to 470 MW has been carried out on all reactors. [33]

The post-Fukushima European Stress Test peer review report for Hungary made recommendations with respect to deficits arising from the multi-unit structure of the Paks plant and a lack of protection of cooling systems against external hazards.[34]

An earlier IAEA report found fouling of steam generators. Copper condensers had to be replaced due to problems with the water chemistry. There are open questions with respect to the control of pressurised thermal shocks in the event of a loss-of-coolant accident in the RPVs of reactors 1 and 2.[35]

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[29] Bekanntmachung der Leitfäden zur Durchführung von Periodischen Sicherheitsüberprüfungen (PSÜ) für Kernkraftwerke in der Bundesrepublik Deutschland vom 18. August 1997 (BAnz. 1997, Nr. 232a)

[30] The lifetimes of reactors in Germany were not set in terms of specific dates. Instead, a maximum amount of electricity to be produced by each individual reactor was defined. As transfers of electricity production rights were allowed in principle, no definitive shutdown dates for individual reactors can be given.

[31] Gesetz über die friedliche Verwendung der Kernenergie und den Schutz gegen ihre Gefahren (Atomgesetz – AtG), 2013. http://www.bfs.de/de/bfs/recht/rsh/volltext/1A_Atomrecht/1A_3_AtG_0114.pdf

[32] Gesellschaft für Reaktorsicherheit with Kurtschatow-Institut, OKB Gidropress and Atomenergoprojekt. 1988. Sicherheitsbeurteilung des Kernkraftwerks Greifswald, Block 5, 1988.
Gesellschaft für Reaktorsicherheit 1990. Sicherheitsbeurteilung des Kernkraftwerks Greifswald, Block 1 – 4, eine Dokumentation der bisherigen Untersuchungen. June 1990.

[33] Kovac. P. 2006. Impacts of nuclear power plant life management and long-term operation. NEA News, 2006,Volume 24, Number 2

[34] ENSREG Stress Test Peer Review Board. 2012. Peer review country report: stress tests performed on European nuclear power plants: Hungary.

[35] IAEA. 2006. Plant life management for long term operation of light water reactors. Technical reports series no. 448. IAEA, Vienna

### 2.4.8 Netherlands

The only operational reactor in the Netherlands, at Borssele, was designed and built by the German Kraftwerk Union (Siemens). It is operated by the Electricity Generating Company for the Southern Netherlands (EPZ) and is owned by DELTA (70%) and Energy Resources Holding BV (30%). In 2013, it reached 40 years since grid connection. However, in 2006 an extension of its operating licence to 2033 was permitted, corresponding to a lifetime of 60 years. While the reactor operated for its first 30 years at a power output well below its design net capacity, power uprating was conducted in 2006 from 452 MW up to 485 MW.[36]

### 2.4.9 Romania

Romania has two operational reactors of the Canadian CANDU type at the Cernavodă site. The reactors are 6 and 17 years old. No power uprating has yet been carried out on them.

### 2.4.10 Slovakia

Slovakia has two operational reactors of the Russian VVER-440/V-213 type located at the Bohunice site (units 3 and 4) and two more reactors of the same type at the Mochovce site (units 1 and 2). Two VVER-440/V-230 reactors (units 1 and 2) at Bohunice were shut down at the end of 2006 and 2008 respectively as a result of European safety concerns and as a precondition of Slovakia's accession to the EU. All the operational reactors have been uprated. There are plans to extend the lifetime of the two operational units at Bohunice up to 60 years, in case the planned construction of a 1,200 MW unit at Kecerovce in the east of the country does not go ahead.[37]

### 2.4.11 Slovenia

Slovenia has one nuclear reactor, located at the Krško site. Construction of the 2-loop Westinghouse reactor started in 1975, and it was connected to the grid in 1981. The reactor's reference unit power is 688 MW, about 9 per cent above the original 632 MW design net capacity.

Krško's design lifetime was initially 40 years, but a 20-year extension was applied for and granted. The decision to extend the reactor's operating lifetime required several years of administrative procedures and deliberation. In April 2012 the Slovenian Nuclear Safety Administration (SNSA) reached a partial decision, and in June 2012 it made a supplementary decision concerning the monitoring of equipment ageing and measures for long-term equipment maintenance.[38]

### 2.4.12 Spain

There are eight operational reactors in Spain, located at six different sites. They are between 25 and 42 years old.

In February 2011, a few days before the Fukushima disaster, the conservatives in Spain's parliament agreed to lift the by the earlier Socialist government decided 40-year lifetime limit on the country's reactors. Among others, this decision gave the green light for the Santa María de Garoña reactor – of the same type as unit 1 at Fukushima-Daiichi, and the oldest reactor in Spain – to operate for more than 40 years.

The Santa María de Garoña reactor was connected to the grid in 1971 and received a ten-year lifetime extension in 1999. On 3 July 2009 a new permit issued by Spain's Nuclear Safety Council (CSN) allowed the plant to operate until 6 July 2013, at which time the plant was to be permanently shut down.[39]

However, the CSN offered to permit the reactor's operation until 2019, contingent on increased taxes and a renovation programme. The owner and operator Nuclenor decided that these conditions made further operation uneconomical, and further negotiations between the political parties, the CSN and Nuclenor revolved around financial and safety aspects. Finally, in December 2012, the reactor was shut down and defuelled. Nonetheless, only a few weeks before the final shutdown date of 6 July 2013, the CSN offered another year of operation which was not taken up by Nuclenor.[40]

In the IAEA's country listings, however, the Santa María de Garoña power plant is still listed as 'Operational'.

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[36] http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/Netherlands/

[37] http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Slovakia/

[38] Nuklearna Elektrarna Krško. 2012. Krško Nuclear Power Plant, Annual Report, 2012. http://www.nek.si/uploads/documents/ANNUAL_2012.pdf

[39] https://www.csn.es/index.php?option=com_content&view=article&id=12766&Itemid=386&lang=es

[40] http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Spain/; http://www.nuclenor.org/public/prensa/ndp_20130705-1.pdf

In 2010, the CSN recommended a further 10-year operation permission for the Vandellòs 2 PWR. The Ascó 1 and 2 PWRs and the Cofrentes BWR all received permission for another 10-years in 2011. The extended operation will run until 2020 and 2024, allowing these reactors approximately 40 years of operation. The Trillo PWR is expected to receive permission for an additional 10 years of operation in 2014. However, the industry is seeking lifetime extensions of 20 years.[41]

### 2.4.13 Sweden

Sweden has ten operational nuclear reactors at three sites (Oskarshamn, Ringhals and Forsmark). Eight of the reactors are over 30 years old. The Oskarshamn-1 BWR is among the five oldest reactors in Europe at over 42 years. Oskarshamn 2 and Ringhals 1 and 2 are also nearly 40 years old. Previous plans to shut down all reactors by 2010 were abandoned after a change of government.

A lifetime extension programme for Oskarshamn 1 was conducted from 2002 to 2006 with the intention of extending its operational lifetime to 50 years. Oskarshamn 2 underwent an extension and power uprating programme between 2006 and 2012, with the intention of extending its operational lifetime initially to 60 years, with the option of a further extension to 80 years. The nuclear manufacturer Areva claimed the Oskarshamn 2 lifetime extension and power uprating programme as ‘one of the most challenging retrofitting projects ever carried out in a nuclear power plant’.[42]

All operational reactors in Sweden have undergone power uprates. Oskarshamn 3’s output was increased from an initial rating of 1,055 MW in 1985 to 1,400 MW in 2012 – an increase of 33 per cent. Sweden has the world’s most ambitious power uprating programme: so far it has brought an increase in electrical output of 1,200 MW, comparable with the output of a new reactor.

### 2.4.14 United Kingdom

There are 16 operational reactors in the UK, located at eight different sites.

Wylfa 1 is Europe’s third-oldest reactor and the last first-generation gas-cooled reactor (GCR) in the world, using Magnox fuel. It was designed in the 1950s, construction started in 1963 and it was connected to the grid in 1971. Wylfa 1 will be permanently shut down in September 2014 or December 2015, depending on a transfer of Magnox fuel from unit 2, which is already permanently shut down.

EDF, the UK’s main operator, stated in December 2010 that it intended to extend the operating lifetimes of four of its advanced gas-cooled reactors (AGRs) by five years, with extensions of the other 10 AGRs to follow.[43]

Further to this, in December 2012, EDF announced that four of the UK’s oldest reactors are to remain operational until at least 2023. The two reactors at the Hinkley Point B plant near Bridgwater in Somerset and those at the Hunterston B plant in North Ayrshire have been given a seven-year lifetime extension beyond their planned shutdown date of 2016. However, all four reactors are allowed to operate only at reduced power (70 per cent load) due to boiler temperature restrictions.[44]

### 2.4.15 Switzerland

In Switzerland, five reactors are in operation at four different sites. Three of them are among the oldest operating reactors in the world: the Beznau 1 PWR is the oldest operational reactor in Europe and arguably the oldest operational reactor in the world, at nearly 45 years old (Tarapur 1 and 2 units in India of similar age – the consideration of which reactor is older depends on the criteria used), while the Beznau 2 PWR is the fourth-oldest and the Mühleberg BWR the seventh-oldest operational reactor worldwide. Even the newest reactor in Switzerland, at Leibstadt, has already reached 29 years since grid connection. All Swiss reactors have had power uprates.

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[41] Nucleonics Week. 2011. Bill removes 40-year limit on Spanish reactor lifetimes 17 February 2011.

[42] OKG. 2011. Project Kent - Summary of Stress tests within OKG. (This is the Oskarshamn OKG operator report for the European post-Fukushima nuclear stress tests; http://www.stralsakerhetsmyndigheten.se/Global/Nyheter/2011/okg-2011-23986_Project%20Kent%20-%20Summary%20of%20Stress%20tests%20within%20OKG.pdf

[43] http://www.edfenergy.com/about-us/energy-generation/nuclear-generation/nuclear-power-stations/

[44] http://www.edfenergy.com/about-us/energy-generation/nuclear-generation/nuclear-power-stations/hunterston-b.shtml

The Mühleberg BWR is of the same reactor type as Fukushima-Daiichi 2. In October 2013 BKW FMB Energie AG, the operator of the Mühleberg plant, announced its intention to shut down the plant in 2019, at 48 years since grid connection, for economic reasons.[45] This announcement stands in the context of considerable retrofitting requirements that have been imposed by the national regulator as a precondition of further operation of the plant.

A nuclear phase-out decision was made in Switzerland in September 2011, in the wake of the Fukushima catastrophe. Projected new reactors at Mühleberg, Beznau and Niederamt[46] were cancelled. As a result, lifetime extension of existing reactors became crucial for Swiss nuclear operators. Lifetime extension is not fixed by law; the Federal Nuclear Safety Inspectorate (ENSI) has the power to permit extended operation to beyond 50 years. Beznau 1 and 2 currently operate with a time-unlimited licence.

### 2.4.16 Ukraine

Twenty-seven years after the disaster at the Chernobyl nuclear power plant in Ukraine, Ukraine's state-owned company Energatom still operates 15 reactors at four sites across the country. Six VVER-1000/V-320s are located at the Zaporizhya site, one VVER-1000/V-302, one VVER-1000/V-338 and one VVER-1000/V-320 at the South Ukraine site, two VVER-440/V-213s and two VVER-1000/V-320s at the Rivne site, and two VVER-1000/V-320s at the Khmelnytskyi site. In 2010, both VVER-440/V-213 reactors at Rivne received a lifetime extension of 20 years beyond their 30 year design lifetime.

The EU and the European Bank for Reconstruction and Development (EBRD) have already spent billions of euros on safety upgrade programmes in Ukraine. They plan to lend Ukraine a further €300m to carry out additional upgrading of 12 of its operating nuclear reactors. On the basis of this so-called Nuclear Power Plant Safety Upgrade Programme the State Nuclear Regulatory Inspectorate of Ukraine intends to permit the reactor fleet (most of which will reach the end of their design lifetime during the next five years) lifetime extensions of a further 20 years.[47] Ukraine has already announced a proposed lifetime extension of South Ukraine 1, originally scheduled to shut down in 2012 but now awaiting permission for further operation until 2032.

### 2.4.17 Russia

Most of Russia's 33 operational reactors are in the process for lifetime extension. Generally, reactors of the VVER-440 type and most units of the RBMK type are to be granted a 15-year lifetime extension. The VVER-1000 units are to be granted a lifetime extension of 25 years.[48]

Thus, while the EU has paid member countries for the early decommissioning of their VVER-440/V-230 (Slovakia, Bulgaria, Germany) and VVER-440/V-213 (Germany) type reactors because of known safety problems of the VVER-440 design,[49] Russia will prolong the lifetimes of its reactors of this type.

All eleven RBMK reactors (Leningradskaya units 1 to 4, Kursk units 1 to 4 and Smolensk units 1 to 3) – the same reactor type as was involved in the Chernobyl disaster – are to be granted extensions for operation up to 45 years. Additionally an Energy Ministry draft plan of July 2012 envisages uprating the power of the VVER-440 units by 7 per cent and that of the RBMKs by 5 per cent.[50]

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[45] http://www.bkw.ch/medienleser/items/ausserbetriebnahme-im-jahr-2019.html

[46] http://www.ensi.ch/de/kernanlagen/neue-kernkraftwerke/gutachten-des-ensi-zu-den-rahmenbewilligungsgesuchen-ekkb-ekkm-und-kkn/

[47] Nucleonics Week. 2013. EBRD to lend Ukraine $388 million for nuclear plant safety program. 21 March 2013.

[48] World Nuclear Association, 2014, Country profiles, nuclear power in Russia; http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Russia--Nuclear-Power/

[49] Gesellschaft für Reaktorsicherheit with Kurtschatow-Institut, OKB Gidropress and Atomenergoprojekt. 1992. Sicherheitsbeurteilung des Kernkraftwerks Greifswald, Block 5 (WWER-440/W-213).

[50] http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Russia--Nuclear-Power/

### 2.4.18 Summary of country-specific outlook

There appears to be a clear trend in Europe that life extension and power uprating are carried out simultaneously. Table 1.1 summarises the reactor lifetime extension situation in European Union countries, Switzerland, Ukraine and Russia.

| Country | Total number of reactors | > 30 years | > 40 years | Original design lifetime (years) | Currently planned lifetime (years) | Remarks |
|---|---|---|---|---|---|---|
| Belgium | 7 | 5 | 0 | 30 - 40 | 40 - 50 | Doel 1 and 2 granted 40-year lifetime,<br>Tihange 1 granted 50-year lifetime |
| Bulgaria | 2 | 0 | 0 | 30 | | Kozloduy 5 and 6 (VVER-1000/V-320) 30-year lifetime reached in 2017 and 2019 |
| Czech Republic | 6 | 0 | 0 | 30 | 60 | Dukovany 1-4 (VVER-440/V-213), 60-year lifetime intended by operator ČEZ |
| Finland | 4 | 4 | 0 | 30 | 50 - 60 | 2 VVER-440/V-213s granted extension to 50 years,<br>2 BWRs to 60 years |
| France | 58 | 29 | 0 | 30 | 40 -60 | Safety assessment/licence renewal every ten years. EDF has started lifetime extension programme giving up to 60 years lifetime |
| Germany | 9 | 2 | 0 | | 32-36 | Maximum lifetime fixed by law for every reactor, no extension, periodic safety assessments |
| Hungary | 4 | 1 | 0 | 30 | 50 | reactors currently undergoing 20-year extension programme |
| Netherlands | 1 | 1 | 1 | 40 | 60 | 20 year extension (until 2034) for single reactor at Borssele |
| Romania | 2 | 0 | 0 | | | Extension not yet an issue for CANDU 6 reactors |
| Slovakia | 4 | 0 | 0 | 30 | 40 | Bohunice 3 and 4, Mochovce 1 and 2 (VVER-440/V-213), 30 years lifetime 2015, extension to 40 years planned |
| Slovenia | 1 | 1 | 0 | 40 | 60 | Decision not yet made on application submitted to regulator to extend operation of Krško reactor until 2043 (60 years) |
| Spain | 8 | 3 | 0 | | 40 - 60 | Safety assessment/operation permission every ten years by CSN; lifetime extension from 40 to 60 years planned |
| Sweden | 10 | 8 | 1 | 40 | 50 - 60 | Extension programmes for reactor operating licenses are not time-limited. |
| United Kingdom | 16 | 8 | 3 | 35 | 35- 45/60 | Last Magnox reactor to be shut down in 2014 or 2015; lifetime extension of AGRs average 7 years |
| Switzerland | 5 | 5 | 3 | | 50+ | Regulator’s decision about Mühleberg is due; no licence limitation for Beznau |
| Russia | 33 | 18 | 2 | 30 | 45 - 55 | Most reactors are being permitted lifetime extension, depending on reactor type |
| Ukraine | 15 | 3 | 0 | 30 | 50 | Lifetime extension co-financed by the EU and EBRD |

**Table 1.1** – Reactor 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)).

Belgium, the Netherlands, Russia, Switzerland and Sweden have already been practising lifetime extension for approximately 10 years.

**Figures 1.6 and 1.7** show the uprating of the oldest reactors in the EU, Switzerland and the Ukraine in absolute and percentage terms. The uprating was calculated from PRIS data by dividing the reference unit power (net capacity) by the original design net capacity of each reactor. (cf. Errata page 36)

Even the oldest reactors in Europe have obtained a permission for power uprating.

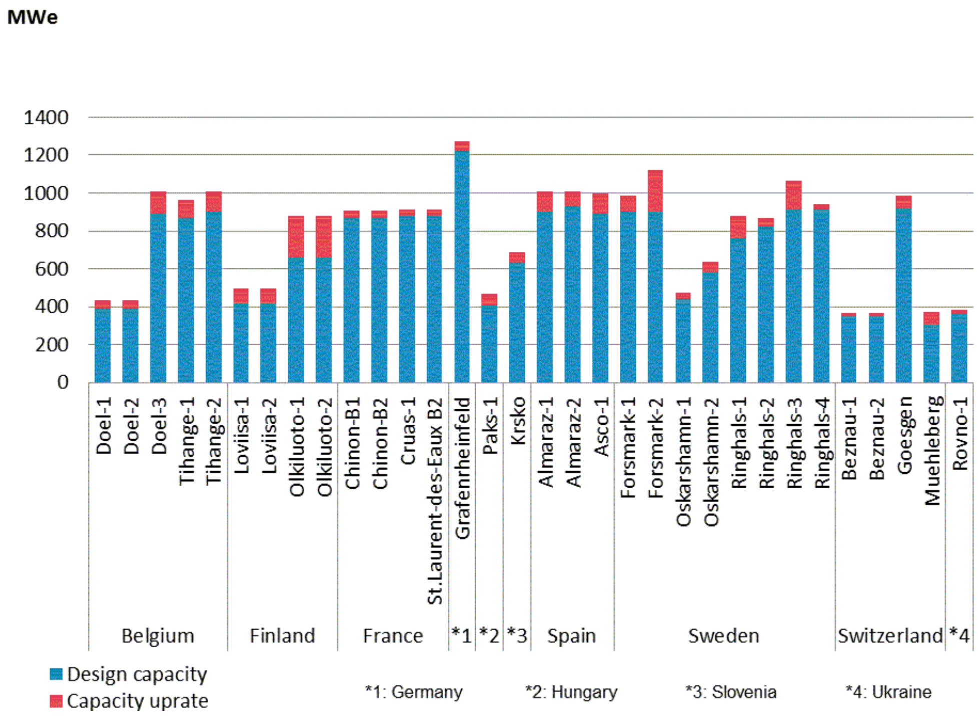

Figure 1.6 – Power uprating of European reactors older than 30 years.
Source: International Atomic Energy Agency: Power Reactor Information System (PRIS), http://www.iaea.org/PRIS.

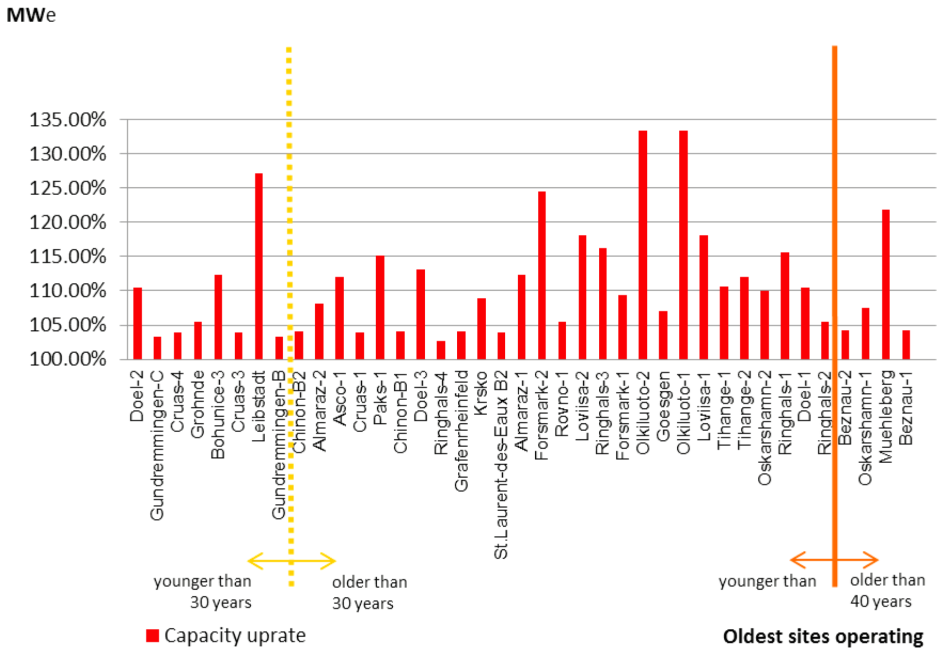

Figure 1.7 – Power uprating of oldest European reactors, in percentage terms.
Source: International Atomic Energy Agency: Power Reactor Information System (PRIS), http://www.iaea.org/PRIS.

**Table 1.2** lists all operational European reactors that have reached 30 years or more since first grid connection as on 31 December 2014. (cf. Errata page 36)

| Reactor | Country | Reactor type | Age (from first grid connection until January 2014) | Uprate as percentage of design net capacity |
|---|---|---|---|---|
| Beznau 1 | Switzerland | PWR | 45 | 4.3% |
| Wylfa 1 | Britain | GCR | 43 | |
| Mühleberg | Switzerland | BWR | 43 | 21.9% |
| Oskarshamn 1 | Sweden | BWR | 42 | 7.5% |
| Beznau 2 | Switzerland | PWR | 42 | 4.3% |
| Borssele | Netherlands | PWR | 41 | |
| Doel 1 | Belgium | PWR | 39 | 10.5% |
| Ringhals 2 | Sweden | PWR | 39 | 5.5% |
| Oskarshamn 2 | Sweden | BWR | 39 | 10.0% |
| Ringhals 1 | Sweden | BWR | 39 | 15.5% |
| Tihange 1 | Belgium | PWR | 39 | 10.6% |
| Tihange 2 | Belgium | PWR | 39 | 12.0% |
| Doel 2 | Belgium | PWR | 38 | 10.5% |
| Hinkley Point B2 | Britain | GCR | 38 | |
| Hunterston B1 | Britain | GCR | 38 | |
| Hinkley Point B1 | Britain | GCR | 37 | |
| Loviisa 1 | Finland | PWR | 37 | 18.1% |
| Hunterston B2 | Britain | GCR | 37 | |
| Fessenheim 1 | France | PWR | 37 | |
| Fessenheim 2 | France | PWR | 36 | |
| Bugey 2 | France | PWR | 36 | |
| Olkiluoto 1 | Finland | BWR | 35 | 33.3% |
| Bugey 3 | France | PWR | 35 | |
| Gösgen | Switzerland | PWR | 35 | 7.1% |
| Bugey 4 | France | PWR | 35 | |
| Bugey 5 | France | PWR | 35 | |
| Olkiluoto 2 | Finland | BWR | 34 | 33.3% |

| | | | | |
|---|---|---|---|---|
| Dampierre 1 | France | PWR | 34 | |
| Gravelines B1 | France | PWR | 34 | |
| Tricastin 1 | France | PWR | 34 | |
| Forsmark 1 | Sweden | BWR | 34 | 9.3% |
| Gravelines B2 | France | PWR | 33 | |
| Tricastin 2 | France | PWR | 33 | |
| Ringhals 3 | Sweden | PWR | 33 | 16.3% |
| Loviisa 2 | Finland | PWR | 33 | 18.1% |
| Dampierre 2 | France | PWR | 33 | |
| Gravelines B3 | France | PWR | 33 | |
| Rivne 1 | Ukraine | PWR | 33 | 5.5% |
| Dampierre 3 | France | PWR | 33 | |
| St.Laurent-des-Eaux B1 | France | PWR | 33 | |
| Forsmark 2 | Sweden | BWR | 33 | 24.5% |
| Tricastin 3 | France | PWR | 33 | |
| Almaraz 1 | Spain | PWR | 33 | 12.3% |
| Blayais 1 | France | PWR | 33 | |
| Gravelines B4 | France | PWR | 33 | |
| St.Laurent-des-Eaux B2 | France | PWR | 33 | 4.0% |
| Tricastin 4 | France | PWR | 33 | |
| Dampierre 4 | France | PWR | 32 | |
| Krško | Slovenia | PWR | 32 | 8.9% |
| Grafenrheinfeld | Germany | PWR | 32 | 4.1% |
| Rivne 2 | Ukraine | PWR | 32 | |
| Doel 3 | Belgium | PWR | 32 | 13.0% |
| Ringhals 4 | Sweden | PWR | 32 | 2.7% |
| Blayais 2 | France | PWR | 32 | |
| Chinon B1 | France | PWR | 31 | 4.0% |
| Paks 1 | Hungary | PWR | 31 | 15.2% |

| | | | | |
|---|---|---|---|---|
| South Ukraine 1 | Ukraine | PWR | 31 | |
| Dungeness B1 | Britain | GCR | 31 | |
| Cruas 1 | France | PWR | 31 | 4.0% |
| Blayais 4 | France | PWR | 31 | |
| Heysham A1 | Britain | GCR | 31 | |
| Hartlepool 1 | Britain | GCR | 30 | |
| Blayais 3 | France | PWR | 30 | |
| Ascó 1 | Spain | PWR | 30 | 12.1% |
| Almaraz 2 | Spain | PWR | 30 | 8.2% |
| Chinon B2 | France | PWR | 30 | 4.0% |
| Gundremmingen B | Germany | BWR | 30 | 3.2% |
| Cruas 3 | France | PWR | 30 | 4.0% |
| Leibstadt | Switzerland | BWR | 30 | 27.10% |
| Paluel 1 | France | PWR | 30 | |

Table 1.2 – Operational European reactors aged 30 years or more.
Source: International Atomic Energy Agency: Power Reactor Information System (PRIS), http://www.iaea.org/PRIS

**ERRATA figure 1.6**
**Power uprating of European reactors older than 30 years – the Doel 2 reactor is already 38 years old and should therefore be aligned more to the right in the figure.**

**ERRATA table 1.2**
**The Tihange 2 reactor has an age of 31 years, not of 39 years as erroneously stated.**

# 3 Ageing issues affecting reactors

The safety concept of nuclear reactors builds upon a systematic approach comprising technical and organisational measures. The following fundamental safety functions must be ensured for all plant states, whatever the type of reactor:[51]

- control of reactivity:
  - limiting the insertion of reactivity;
  - ensuring safe shutdown and long-term subcriticality; and
  - ensuring subcriticality during handling and storage of irradiated and new fuel assemblies;
- removal of heat from the core and from the spent fuel pool:
  - sufficient quantity of coolant and heat sinks;
  - ensuring heat transfer from the core to the heat sink; and
  - ensuring heat removal from the fuel pool;
- confinement of radioactive material:
  - confinement of radioactive material by effective barriers and retention functions;
  - shielding of people and environment against radiation; and
  - control of planned radioactive releases, as well as limitation of accidental radioactive releases.

The systems, structures and components which have to guarantee the safe operation of a reactor during normal operation, anticipated operational occurrences or design basis accidents may suffer malfunction due to ageing of the reactor.

As already discussed, there are various types of ageing that can affect a reactor. These are reviewed in detail in the following pages, with examples.

## 3.1 Physical ageing

A comprehensive range of physical ageing mechanisms is described in the IAEA safety guide on ageing management:[52]

Degradation of mechanical components can be caused by radiation embrittlement (affecting the RPV beltline region), general corrosion, stress corrosion cracking, weld-related cracking, and mechanical wear and fretting (affecting rotating components). Electrical and instrumentation and control components can be affected by insulation embrittlement and degradation (cables, motor windings, transformers), partial discharges (transformers, inductors, medium and high voltage equipment), oxidation, appearance of monocrystals and metallic diffusion.

Civil structures, especially concrete elements, can suffer damage due to aggressive chemical attacks and corrosion of the embedded steel, cracks and distortion due to increased stress levels from settling, and loss of material due to freeze–thaw processes. Pre-stressed containment tendons can lose their pre-stress due to relaxation, shrinkage, creep and elevated temperature.

Numerous further ageing mechanisms exist and often examination and analysis of fatigue cannot determine the precise cause of the damage. Choice of materials, design and manufacturing process all influence the occurrence and acceleration of ageing mechanisms. Due to lack of operational experience in the earlier years of construction of nuclear power plants, the choice of materials and production processes was not always optimal. The following sections present an overview of specific physical ageing effects, without claiming to be comprehensive.

### 3.1.1 Ageing effects on the reactor pressure vessel

The RPV and its internals are the most stressed components in a nuclear power plant. During operation the RPV has to withstand:

- neutron radiation that causes increasing embrittlement of the steel and weld seams;
- material fatigue due to frequent load cycles resulting from changing operational conditions;
- mechanical and thermal stresses from operating conditions, including fast reactor shutdowns (scrams) and other events throughout the operational lifetime; and
- different corrosion mechanisms caused by adverse conditions such as chemical impacts or vibrations.

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[51] WENRA. 2007. Reactor safety reference levels. January 2007.

[52] IAEA. 2009. Ageing management for nuclear power plants. Safety guide No. NS-G-2.12. IAEA, Vienna

Embrittlement under neutron radiation is of special importance for old reactors. At the time of their construction, knowledge of neutron-induced embrittlement was limited, so sometimes unsuitable materials were used.

Replacement of the RPV (like the replacement of the containment) is impossible for economic and practical reasons.[53] Consequently, if ageing mechanisms prevent further safe operation of these components, the reactor will have to be shut down. The risk of loss of RPV integrity increases under accident conditions, as the IAEA explains:

> If an embrittled RPV were to have a flaw of critical size and certain severe system transients were to occur, the flaw could propagate very rapidly through the vessel, possibly resulting in a through-wall crack and challenging the integrity of the RPV.[54]

The IAEA identifies such severe transients as:

> Pressurized thermal shocks (PTS), characterized by rapid cooling of the downcomer and internal RPV surface, followed sometimes by repressurization of the RPV (PWR and WWER reactor types)
>
> Cold overpressure (high pressure at low temperature) for example at the end of shutdown situations.

So the unidentified degradation of RPVs, such as cracks and flaws, therefore has the potential to escalate an incident into an uncontrollable accident, even though it does not cause problems during normal operation. During power operation the RPV is not accessible for inspections or intervention measures. As a result defects may remain undetected for longer periods of time.

Nevertheless, flaws and cracks have been identified in some older reactors in Europe, although they have been deemed acceptable for further operation.

Extensive research programmes are being conducted in order to gauge the resistance and stability of RPVs. At present there are conflicting scientific opinions concerning the current significance and further progression of ageing. Huge uncertainties are involved in estimating and predicting the progression of ageing and the long-term behaviour of materials, especially under accident conditions.

The original design safety margins of RPVs decrease continuously as there is no scope to eliminate the defects that arise. Operators conduct ageing management programmes, using inspection results and flaw evaluation to assess the status of the RPV.

**EXAMPLE:** in June 2012 underclad defects were detected in the whole cylindrical part of the RPV of the Belgian Doel 3 reactor, after 30 years of operation. Nearly 9,000 flaws were identified. The examination method involved a specific kind of ultrasound sensor. The technique – specifically designed to detect underclad cracks – was used for the first time for a full RPV check at Doel. 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. The Belgian regulator, the Federal Agency for Nuclear Control (FANC) informed other European nuclear regulators and suggested that the 21 RPVs manufactured by Rotterdamsche Droogdok Maatschappij N.V be investigated.

Soon afterwards the operator, Electrabel GDF Suez, submitted safety case reports on the Doel 3[55] and Tihange 2[56] RPVs to FANC.

Five months later, FANC published its final evaluation report. Despite many open questions, the report concurred with Electrabel GDF Suez, declaring that the most likely origin of the defects identified in the Doel 3 and Tihange 2 RPVs was hydrogen flaking during manufacture. FANC added:

> 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.[57]

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[53] IAEA. 2008. Heavy component replacement in nuclear power plants: experience and guidelines. IAEA Nuclear Energy Series, Technical Reports, No. NP-T-3.2. IAEA, Vienna.

[54] IAEA. 2010. Pressurized thermal shock in nuclear power plants: good practices for assessment. Deterministic evaluation for the integrity of reactor pressure vessel. IAEA-TECDOC-1627. IAEA, Vienna.

[55] Electrabel GDF SUEZ. 2013. Safety Case Report Doel 3 – Reactor Pressure Vessel Assessment. 26 April 2013.

[56] Electrabel GDF SUEZ. 2012. Safety Case Report Tihange 2 – Reactor Pressure Vessel Assessment. 19 December 2012.

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

In January 2013 the German Reactor Safety Commission (RSK) published an official investigation into the cracks in the Doel 3 RPV.[58] The RSK stated that in Germany manufacturing faults comparable to those in Doel 3 would have been detected during quality checks. Forgings with comparable hydrogen flaking had already been detected and rejected during the production process of German RPVs.

While comparable RPVs would thus 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. Their lifetimes were at that time intended to be extended to 40 (Doel 3) and 50 years (Tihange 2) of operation. For both reactors, power uprating of 12 and 13 per cent respectively was almost finalised.

### 3.1.2 Ageing of reactor pressure vessel head penetrations and primary circuit components

Leaks in the primary circuit components of PWRs due to ageing mechanisms such as stress corrosion cracking can lead to accidents involving loss of primary coolant.

For systems and components in the primary circuit, especially high quality standards are required to prevent loss of coolant and consequent loss of function. Over time, extensive concepts have been developed in order to verify adequate quality. Operational experience and technical advances have led to further improvements. In particular, the composition of the materials used has been changed to make them more suitable for use in nuclear reactors and so to avoid the early ageing effects identified in older reactors. However, practice has shown that retrospective application of these advances to older reactors is not entirely possible. Testing and documentation of material properties and manufacturing processes must be carried out during manufacturing and installation, and the absence of this cannot be fully compensated for in retrospect. As a result strict review concepts have been relaxed and insufficient remedial measures accepted.

A special problem arises from cracks in the RPV head penetrations – nozzles through which the control rods pass into the core. These nozzles are exposed to the high temperature and pressure of the RPV, the chemically aggressive primary coolant, and intense radiation combined with changes of load.

> **EXAMPLES:** RPV head penetration cracks were found at several French reactors in 1991, and later in other European countries (Switzerland, Sweden). The cracks affected PWRs using vessel heads made of the material Alloy 600, a heat-resistant nickel-chrome-iron alloy. Reactors in the USA, Japan and other countries were also affected.
>
> More recently, RPV head penetration cracks were discovered in nozzle wells in the Russian VVER-1000 reactor Novovoronezh 5 during its July 2004 outage. The cracks were caused by stress corrosion due to manufacturing defects and ageing of the 24-year-old reactor. All 109 nozzles were replaced on site during an unplanned extension of the regular outage until June 2005. Usually, vessel heads are transported to the manufacturer's facility for the replacement of the penetrations, or else are replaced in their entirety.[59]

Many European PWR vessel heads have already been replaced. In Switzerland, Beznau 1 and 2 still operate with their original RPV heads. Penetration cracks were detected several years ago, but they were repaired. Replacement of the RPV heads was initially planned for 2013, later put back to 2014. However, in 2010 the Swiss regulator ENSI recommended a number of retrofitting projects for long-term operation of Beznau 1 and 2, and the requested lifetime extension has been made conditional on these.[60] It is also planned to check the RPV in response to a recommendation of the Western European Nuclear Regulators Association (WENRA) following the RPV flaws discovered at Doel and Tihange.[61] Beznau 1 and 2 must also undergo important retrofits requested by the Swiss national action plan as drawn up under the country's European Stress Test.[62] Because of this, it is doubtful whether the Beznau power plant's RPV head replacements will be possible during 2014, even though their condition makes replacement desirable.

In Belgium, only the Tihange 1 reactor has undergone RPV head replacement. However, the reason for the deterioration of the heads was not completely resolved when replacement took place. It was assumed that the further operation would show no similar ageing effects.

Such a failure fully to resolve the reasons for ageing is to be avoided, as the following example demonstrates.

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[58] Reaktorsicherheitskommission. 2013. RSK-Stellungnahme „Ultraschallanzeigen am Reaktordruckbehälter des belgischen Kernkraftwerks Doel, Block 3 (Doel-3)“, (454. Sitzung am 17.01.2013).

[59] Nucleonics Week. 2005. 1 September 2005.

[60] ENSI. 2010. Sicherheitstechnische Stellungnahme zum Langzeitbetrieb des Kernkraftwerks Beznau, Block 1 und Block 2. ENSI, Brugg. 30 November 2010.

[61] http://www.ensi.ch/de/2013/08/29/ensi-folgt-wenra-empfehlungen-zur-uberprufung-der-reaktordruckbehalter/

[62] ENSI. 2012. EU Stress Test: Swiss National Action Plan: follow-up of the peer review, 2012 year-end status report.

In 2002, a cracked RPV nozzle was discovered in the Davis-Besse PWR in Ohio. During repair it was discovered that the resultant leakage had corroded the reactor's carbon-steel head down to the stainless steel cladding. Only this thin stainless steel liner, which had already started bulging, prevented a severe loss-of-coolant accident. The reactor was restarted in 2004 after replacement of the RPV head. The operator, FirstEnergy Nuclear Operating Company, was confident that the head would not be affected by cracking again. Thereafter, only visual inspections were conducted. But in March 2010 FirstEnergy detected flaws in 66 of the 69 nozzles during a refuelling and maintenance outage, while conducting planned ultrasonic examinations of the nozzles.[63]

### 3.1.3 Ageing of reactor pressure vessel internals

The main function of RPV internals is to keep the nuclear fuel elements in the reactor core in a stable position. Stable reactor core geometry is a prerequisite for reactor shutdown and fuel cooling. Distortion of internals due to cracks, as well as the release of fragments from internals, may affect the function of the control rods and thus prevent safe shutdown, and may also compromise the cooling of fuel elements. Foreign particles or fragments of RPV internal which are released and transported into the primary circuit can damage other important components such as coolant pumps, pipes or vessels which are connected to the RPV.

> **EXAMPLE:** the Mühleberg reactor in Switzerland faces problems with its core shroud (an RPV internal), which has lots of cracks in its welds. Nevertheless, the operator, BKW, has been refusing to replace the core shroud for several years, due to economic factors. Meanwhile, the length of the cracks has been continually increasing due to pressure in the RPV. There is a critical value of crack length beyond which severe damage of the core shroud must be expected, especially under exceptional loads, for example in the event of an earthquake, a loss of primary circuit coolant or strong transients. The critical crack length, which should be the criterion for obligatory replacement, was recalculated twice after the cracks had exceeded the initially calculated critical value. Thus the original safety margins have been gradually decreased. Despite this problem, the reactor output has been uprated by more than 20 per cent in recent years, increasing the stress on the core shroud weld seams.

ENSI recommended a core shroud reinstatement program for Mühleberg NPP many months ago.[64] In March 2012 the Federal Administrative Court in Bern decided that Mühleberg could operate only until June 2013 due to significant safety issues, namely the status of the core shroud as well as further defects due to ageing.[65] BKW and the Swiss Federal Department of the Environment, Transport, Energy and Communications (UVEK) challenged the judgement. BKW additionally submitted an application for lifetime extension and presented a new maintenance plan, that suggests repairing the cylindrical hull of the core inside the RPV with brackets, so as to avoid an expensive replacement of the core shroud.[66] Former used brackets, consisting of 240 separate pieces, had come loose and fragments had fallen into the core, causing additional safety problems.[67],[68] In March 2013 the Supreme Court reversed the Federal Administrative Court's ruling, and BKW announced that Mühleberg would continue to operate until 2019.

### 3.1.4 Ageing of the reactor building and containment

The reactor buildings and containments of the various reactor types are designed according to different requirements. The concrete structures of the reactor building are designed to protect the reactor against external events. The gas-tight steel inner containment liner is intended to prevent the release of radioactive material to the environment in the event of an accident. Some older types of reactor do not have a gas tight internal steel liner .

Steel and concrete structures are affected by ageing due to environmental impacts and material fatigue. Experience shows that ageing degradation of older concrete reactor buildings can be caused or accelerated by factors such as faulty design, use of unsuitable or poor-quality materials, construction defects, and exposure to aggressive environmental conditions or exceptional loads.[69]

> **EXAMPLE:** in 2009 the Belgian nuclear operator Electrabel GDF Suez became aware that the reactor building of the Tihange 2 reactor had been damaged (see Figure 1.8). Checks on the concrete structure of the building showed damage cracks up to 30cm deep in some places.

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[63] Nucleonics Week. 2010. Flaws on Davis-Besse head nozzles lead groups to question inspections. 18 March 2010.

[64] ENSI. 2012. Sicherheitstechnische Stellungnahme zum Langzeitbetrieb des Kernkraftwerks Mühleberg. 11/1700. ENSI, Brugg. 20 December 2012.

[65] Bundesverwaltungsgericht Bern. 2012. Abteilung I, Urteil vom 1. März 2012, Aufhebung der Befristung der Betriebsbewilligung für das Kernkraftwerk Mühleberg.

[66] BKW. 2012. Mediengespräch Kernkraftwerk Mühleberg Verlängerungsgesuch und umfassendes Instandhaltungskonzept für den Langzeitbetrieb. BKW, Bern. 14 August 2012.

[67] ENSI. 2007. Sicherheitstechnische Stellungnahme zur Periodischen Sicherheitsüberprüfung des Kernkraftwerks Mühleberg.

[68] Öko-Institut. 2011. Kurzstellungnahme zur Akteneinsicht der Bürger in Sicherheitsunterlagen des Kernkraftwerks Mühleberg im Rahmen der Bundesverwaltungsgerichtsbeschwerde Ursula Balmer-Schafroth et. al. vom 31.01.2011 bis 02.02.2011. March 2011.

[69] AEA. 1998. Assessment and management of ageing of major nuclear power plant components important to safety: concrete containment buildings. IAEA-TECDOC-1025.

The Belgian regulator FANC commented as follows:[70]

> "It is a bit strange and is causing concern, but at the moment we have little information. GDF-Suez/Electrabel will have to show that the damage is not dangerous and that they can manage the situation. We also have to check whether or not there are problems in other buildings."

credit: Alain Vincent/Greenpeace

Figure 1.8: – Ageing damaged outside wall of the reactor building at the Belgian nulcear power plant Tihange. (© Alain Vincent/Greenpeace)

In April 2013 a presentation on 'Concrete degradation of the containment of Tihange 2 NPP in Belgium' was presented by Bel V, the safety inspection arm of FANC, at an OECD workshop.[71]

The presentation showed that alkali–silica reaction (ASR) had probably impaired the mechanical properties of the concrete, particularly at the top of the reactor building. An unexpected degree of degradation of the reactor building (around 50 per cent of the surface) was detected. The damage reached depths of up to 30cm. The swelling and cracking of the concrete surface had led to corrosion of the rebar, particularly along the cracks.

The presentation related how Electrabel GDF Suez and FANC handled the problem. In 2010, repair of the concrete started, but works were partially delayed until 2012 due to poor weather conditions. In 2012 new analyses revealed that the damage was predominantly due to ASR. Furthermore, the repair techniques had to be altered after assessment of the initial repairs. Further comprehensive analysis was scheduled for 2013, with a new assessment of structural integrity to be performed by the operator. Nevertheless, in June 2013 FANC permitted the restart of Tihange 2. Questions remain concerning the durability of the simple patch-up of Tihange 2. Cumulative ageing effects linked to swelling and tensions under the surface of the concrete containmentstructure may weaken the outer barrier of the reactor.

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[70] Flanders News, 2012. Nuclear reactor's casing damaged by erosion.1 September 2012;http://www.deredactie.be/cm/vrtnieuws.english/News/1.1417959

[71] Tang, Tchien Minh, 2013. Concrete Degradation of the Containment of Tihange 2 NPP in Belgium, Status as of December 2012. OECD Nuclear Energy Agency, Committee on the Safety of Nuclear Installations, IAGE – Concrete subgroup, 08 April 2013. OECD/NEA WG IAGE Meeting, Paris, France 8–12 April 8th-12th, 2013.

Even though two major and irreplaceable components of the reactor, the RPV and the reactor building, are thus compromised, continued operation of the reactor until 2023 is envisaged.

> **EXAMPLE:** France's reactors, especially several units of the 900MW reactor type, showed corrosion of the 6mm thick steel liner of the prestressed concrete reactor containment after 10–15 years of operation. The cause was identified as breakdown of the waterstop in conjunction with the presence of high humidity during construction and operation. Holes 1cm across which penetrated the liners had to be repaired. In some prestressed concrete containments, loss of tendon force was discovered. The IAEA has stated that the possibility of re-establishing the required prestressing forces is unlikely. As the cause of the greater than expected losses of prestressing force is uncertain, modelling studies have been conducted to address the delayed behaviour of the reactor containments (i.e. creep and shrinkage).[72]

### 3.1.5 Ageing of electrical installations

In the field of instrumentation and control equipment, cables are among the components of most concern in terms of ageing. During the operational lifetime of reactors, the plastics of the cable insulation are exposed to environmental influences that cause deterioration. Oxidation is the dominant ageing mechanism of polymer cable coating, leading to embrittlement of the material, which increases the potential for cracking.[73] Cracked cables can cause short circuits followed by electrical failures or even cable fires. Ageing cables therefore have the potential for serious common-cause failures of instrumentation and control equipment, especially under accident conditions.

Another problem affecting power plant electrical installations arises from the external power supply. The European network of transmission grids for electricity has grown beyond European frontiers in recent years, and has changed from a static to a dynamic system behaviour.[74] The increasing dynamic and higher volatility of the electricity network has various causes, of which the input of electricity from variable renewable sources is only one. It also results from increasing electricity transit through countries, changing characteristics of consumer behaviour and the impact of changing electricity markets. Moreover, the upgrading and extension of the transmission grid has often been neglected or addressed belatedly. The resultant increasing dynamic and higher volatility produces high overloads, frequency deviations and other instabilities.

As a result the electro-technical design and components of a power plant – especially the unit transformers at the interface with the transmission network, but also the network protection equipment, other transformers, rectifiers, circuit breakers and so on – have to meet high quality standards.[75] Otherwise short circuits or overloads can find affect electro-technical components and propagate up to failures of engineering components of the power plant.

> **EXAMPLE:** a problem developed in the Swedish reactor Forsmark 1 on 25 July 2006, when 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 several electrical components, including outage of two of the four emergency diesel generators, caused a severe incident, which nearly caused a complete blackout of the power plant. The conceptual ageing of the electrical design enabled the external transient to propagate in the safety-related components of the reactor. The same kind of incident had the potential to affect other Swedish reactors, such as the other Forsmark reactors, Oskarshamn 1, Oskarshamn 2 and Ringhals 2, as well as ageing reactors in other countries.

The incident was investigated in several EU countries, to avoid comparable problems in other reactors.[76] Nevertheless, on 30 May 2013 another serious incident affected Forsmark 3 due to failures of electrical protection equipment.

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[72] IAEA,1998. IAEA-TECDOC-1025 Assessment and management of ageing of major nuclear power plant components important to safety: Concrete containment buildings.

[73] Bartonicek, B., Hnat, V. & Placek, V. 2001. Ageing monitoring of plastics used in nuclear power plants by DSC. Journal of thermal analysis and calorimetry 64(2): 571-576.

[74] ENTSO-E & EURELECTRIC. 2011. Deterministic frequency deviations – root causes and proposals for potential solutions. A joint EURELECTRIC – ENTSO-E response paper, 2011.

[75] Reaktorsicherheitskommission. 2012. Stellungnahme „Netzstabilität“: Rückwirkungen von Stabilitätsproblemen im deutschen Stromnetz auf elektrische und leittechnische Einrichtungen von Kernkraftwerken und Sicherstellung der notwendigen elektrischen Energieversorgung dieser Anlagen aus dem Netz. 453. Sitzung am 13.12.2012.
IAEA. 2012. Electric grid reliability and interface with nuclear power plants. IAEA Nuclear Energy Series Technical Report No. NG-T-3.8 Guides. IAEA, Vienna.

[76] Nuclear Energy Agency. 2011. Status of OECD/NEA country regulatory responses to the Forsmark-1 event of 25 July 2006 and NEA/CSNI DiDELSYS Task Group report recommendations. March 2011.

The unit transformers, usually two per unit, are often as old as the reactor itself. Replacement of the transformers is usually not envisaged due to the high costs of necessary power outages. Instead, comprehensive test procedures are conducted on ageing transformers. Nevertheless, ageing unit transformers and their protection systems often give rise to incidents resulting in reactor scrams and even compromising mechanical components of the power plant. Older unit transformers can suffer damage due to network instabilities, which can then result in transformer fires. In many cases, the root causes cannot be identified due to the destruction of the transformer. After several incidents in Germany, most German nuclear power plants have had their unit transformers replaced.

## 3.2 Conceptual and technological ageing

The development of science and technology continuously produces new knowledge about possible failure modes, properties of materials, and verification, testing and computational methodologies. This leads to technological ageing of the existing safety concept in nuclear power plants. At the same time, as a result of lessons learnt from operational experiences such as the major accidents at Three Mile Island, Chernobyl and Fukushima Daiichi, power plants have to fulfil new regulatory requirements. Thus earlier safety concepts are themselves becoming obsolete, in a process of so-called conceptual ageing.[77] Very often, new regulatory requirements are applicable only to new nuclear reactors, while for existing plants different criteria are applied.[78] Changes in the safety philosophy can also be introduced by malicious acts. The 9/11 terrorist attacks in the USA showed the need for more robust protection against external hazards. Older nuclear power plants have not been designed to withstand the impact of an aircraft on the reactor building. While an accidental aircraft impact was required to be taken into account in the design of some newer power plants, not one nuclear power plant worldwide has been designed to withstand the intentional impact of a large commercial aircraft like an Airbus 380. Accordingly, it can be questioned whether any existing nuclear power plant would withstand such an attack.

Some examples of conceptual and technological ageing with safety implications are discussed in the following paragraphs.

### 3.2.1 Ageing PWR and BWR design concepts

The fundamental design principles of modern nuclear power plants consist among others of redundancy; conceptual segregation of redundant subsystems, unless this conflicts with safety benefits; physical separation of redundant subsystems; preference for passive over active safety equipment; and a high degree of automation.[79]

Reactors such as the two-loop PWRs Beznau 1 and 2, and Doel 1 and 2, have a limited number of safety subsystems. The original basic design of the Beznau reactors has only one emergency feedwater system and two core cooling subsystems (a small degree of redundancy). One common cooling pipe is used instead of the three or four independent subsystems typical of state-of-the-art modern reactors (therefore having no segregation of redundant subsystems). Although a lot of additional installations have been carried out at Beznau to compensate for the design shortcomings, their quality standards would not meet the current high standards for safety systems[80]. Retrofitting of additional safety systems under conditions of a shortage of space because main structures cannot be changed, can result in higher complexity and in interface problems between existing and retrofitted systems. Similar problems exist in older BWRs of two-loop design.

The Swiss nuclear regulator ENSI admits the possibility of serious damage to the reactor buildings of Beznau and Mühleberg in the event of an aircraft crash.[81] A lack of robustness of the reactor building to withstand external hazards is a problem common to many older reactors.[82]

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[77] German Reactor Safety Commission. 2004. Beherrschung von Alterungsprozessen in Kernkraftwerken vom 22.07.2004, 374. Sitzung.

[78] Compare for example: WENRA. 2007 WENRA reactor safety reference levels, January 2007, and WENRA. 2010. Statement on safety objectives for new nuclear power plants, November 2010.

[79] German Federal Ministry of the Environment, Nature Conservation and Reactor Safety. 2012. Safety requirements for nuclear power plants. 22 November 2012.

[80] Öko-Institut. 2012. Analyse der Ergebnisse des EU Stresstest der Kernkraftwerke Fessenheim und Beznau, Im Auftrag des Ministeriums für Umwelt, Klima und Energiewirtschaft Baden-Württemberg, Teil 1 und 2.

[81] Hauptabteilung für die Sicherheit der Kernanlagen. 2003. Stellungnahme der HSK zur Sicherheit der schweizerischen Kernkraftwerke bei einem vorsätzlichen Flugzeugabsturz. HSK-AN-4626. HSK, Würenlingen. March 2003.

[82] Öko-Institut. 2007. Analyse des Bedrohungspotenzials „gezielter Flugzeugabsturz“ am Beispiel der Anlage Biblis-A, Im Auftrag der EUROSOLAR Europäische Vereinigung für Erneuerbare Energien e.V., Darmstadt. 20 November 2007.

Concerning the only operational German BWRs, Gundremmingen B and C, two former members of the German federal nuclear regulator have produced a list of design deficits.[83] According to their analyses:

- the construction of the reactor vessel does not represent the technical state of the art
- only two of the required three redundancies of the emergency core cooling system are sufficiently qualified as safety systems;
- the determination of the design basis earthquake has not been reviewed for decades, and the peak ground acceleration of the current design basis earthquake (a key parameter) does not fulfil the IAEA's minimum requirements;
- some safety-relevant components and subsystems are not qualified to resist the design basis earthquake;
- the basic design of the spent fuel pool and its cooling system is outdated; and
- the basic plant design does not take into account the possibility of flooding as a result of a breach of a nearby weir on the Danube.

### 3.2.2 Gas-cooled reactors

The British graphite-moderated gas-cooled reactor types suffer design-specific defects. Fifteen of the 16 reactors in the United Kingdom are graphite-moderated gas-cooled reactors (one first-generation GCR and 14 AGRs). The AGRs, designed as twin units, are the only reactors of this type in the world.

The coolant gas, carbon dioxide at a temperature of 640°C, circulates through the core and then passes through the steam generator (boiler), which is located inside the concrete- and steel-lined RPV. The fuel and cladding have a lower melting temperature than the fuel used in light water reactors. The graphite used for moderation is combustible.

The oldest AGRs have had technical problems during operation, which caused extended outages. Special difficulties have resulted from the internal reactor structure known as the 'hot box dome'. This component, which separates the hot and cold gas flows through the core, has reached problematically high temperatures during operation. As a result some AGRs are allowed to operate only at 70 or 80 per cent of their design power. Problems can also be caused by degradation of the graphite moderator inside the core or the boiler pipes inside the RPV due to radiation in a high-temperature carbon dioxide atmosphere.[84]

### 3.2.3 VVER-440

The Russian VVER-440/V-213 PWR design (Dukovany 1–4, Paks 1-4, Bohunice V2 and Mochovce 1,2) suffers design problems concerning the emergency core cooling and emergency diesel generator systems. At Dukovany, external hazards may cause simultaneous loss of offsite power to all four reactors. In these circumstances, the simultaneous loss of function of the Jihlava River raw water pumping station, the raw water conditioning and the cooling-towers is unavoidable. As a consequence of the loss of cooling and the following overheating of the essential service water, a loss of the emergency diesel generators could also result. In this event only temporary emergency measures would be available for the cooling of the four reactors and their spent fool pools. Furthermore, the two pipes that supply the raw water for all four reactors are not protected against any external hazards. [85]

Comparable design deficits affect the other European VVER-440/V-213s. To overcome major shortcomings of the design, both Finnish VVER-440/V-213 reactors are equipped with Western-type containment and control systems.

The VVER-440 reactors are designed as twin units, sharing many operating systems and safety systems, for example the emergency feedwater system, the central pumping station for the essential service water system, and the diesel generator station. The sharing of safety systems increases the risk of common-cause failures affecting the safety of both reactors at the same time.

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[83] Renneberg, W. & Majer, D. 2013. Risiken des Betriebs des Kernkraftwerks Gundremmingen unter besonderer Berücksichtigung der beantragten Leistungserhöhung. Institut für Sicherheits- und Risikowissenschaften. Universität für Bodenkultur, Vienna. Commissioned by FORUM Gemeinsam gegen das Zwischenlager und für eine verantwortbare Energiepolitik e.V. , November 2013.

[84] EDF Energy. 2012. EU Stress Test, Hinkley Point B.
Health and Safety Executive – Nuclear Directorate HM Nuclear Installations Inspectorate. 2009 Hartlepool and Heysham 1 Periodic Safety Review: project overview report of NII, findings and decision on continued operation.
Nucleonics Week. 2010. Life extension for EDF's UK AGRs starts with Heysham A, Hartlepool. 23 December 2010.

[85] Öko-Institut. 2012. Auswertung der europäischen Stresstestberichte des Betreibers ČEZ sowie der staatlichen Organisation für nukleare Sicherheit SÚJB hinsichtlich sicherheitsrelevanter Schwachstellen der kerntechnischen Anlagen in Dukovany, Tschechische Im Auftrag des Amtes der NÖ Landesregierung, Abteilung Umwelttechnik sowie vom Amt der OÖ Landesregierung, Abteilung Umweltschutz. July 2012.

The IAEA has concluded that all VVER reactor designs feature some level of containment as a provision against release of radioactivity following a design basis accident, but the degree of containment varies widely between older and newer designs.[86] All VVER-440 type reactors with the exception of Loviisa in Finland have only a basic level of containment. External hazards such as earthquakes, chemical explosions or aircraft impacts were not taken into account in the original design of these plants.[87]

The earlier reactor type VVER-440/V-230 also faces serious safety problems similar to those affecting the VVER-440/V-213, which have resulted, for example, in the permanent shutdown of four reactors in Germany (Greifswald 1–4), two in Slovakia (Bohunice V1 and V2) and four in Bulgaria (Kozloduy 1–4). The permanent shutdown of VVER-440/V-230s in Slovakia and Bulgaria was financially supported by the European Union (Euratom) and the EBRD, and the financial compensation for the closures was extended and increased in November 2013.

Although it is not an EU Member State, Armenia announced interest in the European post-Fukushima reactor stress tests. Armenia 2, Armenia's sole operational reactor, is located at Metsamor near the eastern border of Turkey, 30 km from the Armenian capital Yerevan. Construction of this reactor was finished in 1980 as a VVER-440/270, a modified VVER-440/230 type. Another reactor, Armenia 1, had been completed at the same site four years earlier. On December 1988 the magnitude 6.8 Spitak earthquake occurred in the northern region of Armenia (then part of the Soviet Union), killing 25.000 people. After the earthquake, whose epicentre was 75 km from the plant, both Metsamor reactors had to be shut down. While Armenia -1's shutdown has become permanent, Armenia 2 was restarted in 1995, after six-and-a-half years. The reactor was originally designed for 30 years of operation, and after the restart its operational lifetime was scheduled to end in 2016. In late 2013, however, Russia announced an agreement with Armenia to finance and support lifetime extension of Armenia 2 for a further 10 years' operation, taking it up to 2026. The lifetime extension of Armenia 2 will mean the operation of an ageing plant with severe basic design defects in an area with extreme seismicity due to tectonic plate boundary interaction.[88]

Despite the defects of the type, it almost seems as though certain European countries are competing with one another to extend the lifetimes and uprate the power of their VVER-440/V-230 and V-213 reactors, as shown in Table 1.3. Finland and Hungary, in particular, intend lifetime extension up to 50 years and power uprating of 18 and 15 per cent respectively, while the Czech Republic and Slovakia are also planning lifetime extension and uprating.

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[86] IAEA. 1998. Assessment and management of ageing of major nuclear power plant components important to safety: concrete containment buildings. IAEA-TECDOC-1025.

[87] Gesellschaft für Reaktorsicherheit with Kurtschatow-Institut, OKB Gidropress & Atomenergoprojekt. 1992. Sicherheitsbeurteilung des Kernkraftwerks Greifswald, Block 5 (WWER-440/W-213).

[88] http://www.world-nuclear.org/info/Country-Profiles/

| Country | Reactor name | Reactor type | Age | Extension until | % upgrade |
|---|---|---|---|---|---|
| Armenia | Armenia 2 | V-270 | 34 | 2026 | no |
| Bulgaria | Kozloduy 1–4 | V-230 | 24 - 28 | shut down** | no |
| Germany | Greifswald 1–4 | V-230 | 22 - 17 | shut down | no |
|  | Greifswald 5 | V-213 |  | shut down | no |
| Czech Republic | Dukovany 1 | V-213 | 29 | 2025* | 11.5 |
|  | Dukovany 2 | V-213 | 28 | 2026* | 12 |
|  | Dukovany 3 | V-213 | 28 | 2026* | 11.5 |
|  | Dukovany 4 | V-213 | 27 | 2027* | 12 |
| Finland | Loviisa 1 | V-213 | 37 | 2027 | 18 |
|  | Loviisa 2 | V-213 | 34 | 2030 | 18 |
| Hungary | Paks 1 | V-213 | 31 | 2032 | 15 |
|  | Paks 2 | V-213 | 30 | 2034* | 15 |
|  | Paks 3 | V-213 | 28 | 2036* | 15 |
|  | Paks 4 | V-213 | 27 | 2037* | 15 |
| Russia | Kola 1 | V-230 | 41 | 2018 | no |
|  | Kola 2 | V-230 | 39 | 2019 | no |
|  | Kola 3 | V-213 | 33 | 2026 | no |
|  | Kola 4 | V-213 | 29 | 2029 | no |
|  | Novovoronezh 3 | V-179 | 42 | 2016 | no |
|  | Novovoronezh 4 | V-179 | 41 | 2017 | no |
| Slovakia | Bohunice 1 | V-230 | 28 | shut down** | no |
|  | Bohunice 2 | V-230 | 28 | shut down** | no |
|  | Bohunice 3 | V-213 | 30 | 2025* | 12 |
|  | Bohunice 4 | V-213 | 29 | 2025* | 16 |
|  | Mochovce 1 | V-213 | 15 | no | 13 |
|  | Mochovce 2 | V-213 | 14 | no | 13 |
| Ukraine | Rivne 1 | V-213 | 33 | 2030 | 5.54 |
|  | Rivne 2 | V-213 | 33 | 2031 | 2.08 |

**Table 1.3** Shutdown, lifetime extension and uprating of VVER-440/V-270, V-230, V-213 and V-179 reactors.
*expected, **co-financed by EBRD and Euratom
Source: International Atomic Energy Agency: Power Reactor Information System (PRIS), http://www.iaea.org/PRIS/

### 3.2.4 RBMK

The RBMK (Reaktor Bolshoy Moshchnosti Kanalniy) design from the former Soviet Union is a graphite-moderated reactor. The reactor's characteristic positive void coefficient and instability at low power levels caused the April 1986 Chernobyl disaster, when the reactor core exploded due to a power excursion and released high amounts of radioactivity across Eastern and Western Europe, contaminating areas.

There was a consensus during the 1992 G7 summit in Munich to close the last two European RBMK reactors outside Russia, located in Lithuania, due to strong concerns about the design. This decision was implemented as part of Lithuania's EU accession. Ignalina 1 was closed in December 2004 and Ignalina 2 at the end of 2009, leaving Russia as the only country which has operational RBMK reactors. The EU has agreed to pay Lithuania part of the decommissioning costs and some compensation for closure and extended and increased its financial help in November 2013[89].

## 3.3 Management of ageing

The overall lifetime management of a nuclear power plant is designed to

- optimise the operation, technical maintenance and lifetime of components;
- maintain the plant's safety level and availability as required; and
- maximise profitability.

Ageing management is one aspect of lifetime management. It is intended to deal with the safety-related aspects of ageing nuclear power plants.[90]

### 3.3.1 Rules and standards

On an international level, the IAEA has issued the Safety Guide NS-G-2.12 with recommendations on ageing management for nuclear power plants.[91] The guide covers general management considerations, but excludes soft factors such as staff ageing or knowledge management. An earlier methodological approach of limited scope was described in an IAEA Technical Report.[92] The detection and control of ageing effects are already among the required objectives of maintenance, surveillance and inspection during the initially approved operational lifetime, as set out in the IAEA Safety Guide NS-G-2.6.[93] In this regard they are part of the overall safety management system, but they become more crucial during long-term operation. Specific issues relating to long-term operation and power uprating, are addressed in the IAEA Technical Report No. 448,[94] which offers a broad approach covering technological, regulatory, economic and personnel issues. The IAEA's recommendations are intended to reflect international practice, but they are not binding. They may be useful to help a country build its own systematic approach. However, the definition of an appropriate procedure, as well as specific arrangements to cope with the required level of safety for extended operation, depends on individual case-by-case decisions. A homogeneous standard is not to be expected across all ageing reactors.

WENRA has established harmonised terms of reference for nuclear safety. Ageing management is addressed particularly in Issue I (Ageing Management) and Issue K (Maintenance, Surveillance, In-Service Inspection and Testing). However, the WENRA reference levels are defined at a minimum consensus level and do not go beyond the IAEA recommendations.

At a national level, several countries' regulations set out a general approach to ageing management (for example the German KTA 1403[95]) comparable to the IAEA standards. In general, the long-term estimation of specific ageing mechanisms (such as crack propagation) refers to standards and modelling that are well-known for the initial design. Some countries have set up specific lifetime extension and/or power uprating management programmes. In other countries assessments are performed on a case-by-case basis. Key elements of the ageing management programmes are monitoring, inspection and, where needed, replacement of systems, structures and components (for more details see IAEA Technical Report No. 448 or national reports). While in some countries it is seen as good practice to replace equipment known to be subject to ageing mechanisms on a regular basis, other countries require replacement only after ageing effects are actually observed.

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89 http://ec.europa.eu/energy/nuclear/decommissioning/ndap_en.htm
http://www.world-nuclear-news.org/WR-Funds-on-condition-for-EU-decommissioning-0301141.html

90 Reese, S. H, Brast, G., Schöckle, F, . 2009. Alterungsmanagement bei technischen Einrichtungen in Anlagen der E.ON Kernkraft GmbH; atw 54. Jg. (2009) Heft 11 – November.

91 IAEA. 2009. Ageing management for nuclear power plants. Safety Standard Series No. NS-G-2.12. IAEA, Vienna.

92 IAEA. 1992. Methodology for the management of ageing of nuclear power plant components important to safety. IAEA Technical Reports Series No. 338. IAEA, Vienna.

93 IAEA. 2002. Maintenance, surveillance and in-service inspection in nuclear power plants. IAEA Safety Standards Series No. NS-G-2.6. IAEA, Vienna.

94 IAEA. 2006. Plant life management for long term operation of light water reactors. Technical Reports Series No. 448. IAEA, Vienna

95 KTA. 2010. Ageing management in nuclear power plants, 2010–11 edition. KTA Safety Standard, KTA 1403:

Ageing management as explained so far is explicitly aimed at creating the conditions for the extended operation of old reactors. However, regulatory requirements for extended operation of existing plants do take into account the limited capabilities of ageing design features. Which means that they do not correspond to the safety requirements for new reactors. Against this background, regulation is intended to allow a large degree of flexibility in the case of lifetime extension. It is not intended to set strict limits. Consequently, clear and general accepted criteria for a maximum permitted degree of ageing are usually lacking, which is a major shortcoming in dealing with ageing effects.[96]

Furthermore, there are huge differences in the individual responses of operators and even of regulatory authorities to identified ageing problems. For example, in one case (Grafenrheinfeld, 2010) a single and relatively small crack in a primary cooling circuit nozzle resulted in a shutdown for detailed analysis and repair.[97] In other cases, plants remain in operation despite being affected by a large number of cracks and significant damage propagation (see sections 3.1.2 and 3.1.3).

### 3.3.2 Limiting ageing

The likelihood of system or component failure is commonly illustrated by the so-called 'bathtub curve' (Figure 1.9). A high incidence of early failures (mainly caused during design, manufacturing and installation) is followed by a significant decrease in failure probability. Later, the probability will increase again due to the increasing influence of ageing effects. The objective of ageing management is to keep the failure rate at a low level. Monitoring programmes and resulting measures such as maintenance, repair and precautionary replacement of components have to come into effect before the failure rate begins to increase significantly towards the end of the technical lifetime. Ageing plants are thus approaching the edge of the bathtub curve. Technical modifications and changing modes of operation which result in higher loads, especially power uprating, have the potential to increase failure rates. Consequently, for ageing plants even a modest increase in lifetime may cause a significant increase in failure frequency, leading to a loss of safety-related functions.

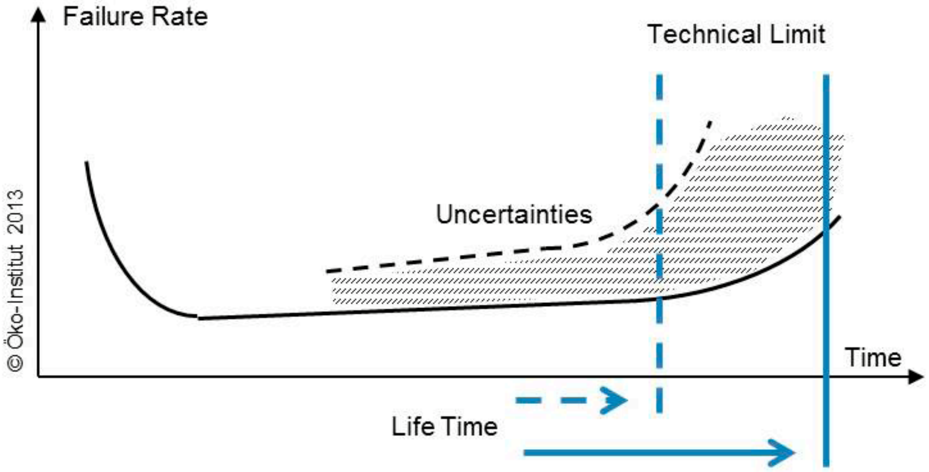

Figure 1.9 – Schematic 'bathtub curve' diagram of failure rate.
Source: Öko-Institut

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[96] WISE-Paris. 2004. Proposals for the development of shutdown criteria for nuclear power plants – a contribution to the Swiss debate. June 2004.

[97] Bundesamt für Strahlenschutz. 2010. Meldepflichtige Ereignisse in Anlagen zur Spaltung von Kernbrennstoffen in der Bundesrepublik Deutschland; Jahresbericht 2010.

It is difficult to produce an accurate estimation of the risk of ageing-related failures for an extended reactor lifetime of over 40 years. A simple bathtub curve will probably not reflect the reality Experience shows that a simple distribution of observed data must be qualified by the awareness of additional influences as follows:

- Non-technical ageing effects are not considered within the failure rate as illustrated by the bathtub curve. In principle, it is not possible to show a clear mathematical distribution of these impacts over time.
- Operational experience, which is an essential basis for the prediction of ageing-related failure rates, is in the case of most reactor types available for less than a 40-year lifetime and so does not cover the proposed lifetime extensions.
- Underestimated ageing mechanisms or new mechanisms which are constantly being discovered can result in unexpected damage and serious incidents. Additionally, the precautionary replacement of intact components prevents detailed evaluation of potential ageing mechanisms.
- Ageing management programmes as implemented so far have not proved sufficient to prevent the occurrence of serious ageing effects. Latent failures and damage at an early stage can remain undetected and cannot be observed in the failure rate.
- Technical modifications and changing modes of operation result in higher loads. Power uprating in particular may contribute to a more frequent occurrence of ageing-related failures.
- With increasing age, uncertainties in the assessment of the present condition and future performance of components may become more and more significant.
- As a result of all these factors, the technical limit of a reactor's lifetime may be exceeded earlier than initially assumed – contrary to the assumptions underlying extended operation.

Incidents due to extraordinary internal and external events, as well as human error, may contribute to the occurrence of failures. It is commonly assumed that such events and errors  are stochastically distributed over time at a constant level. However, this is not true if time-dependent factors are taken into account. Examples of time-dependent influences are the increasing risks posed by climate change, as well as the increasing likelihood of human error due to the ageing of staff and atrophy of the knowledge base (see section 3.3.3).

It is generally recognised that the safety margins of a nuclear reactor decrease as a function of time. The problem is to define a maximum admissible degree of these margins. A common understanding is that normal operational requirements, including the required safety margin, remain unchanged over a reactor's entire lifetime (e.g. IAEA Technical Report No. 338, Figure 1[98]). The actual safety margin may diminish continuously over time, but must always exceed the required value. In contrast, a frequently quoted safety principle indicates that the safety level must be maintained at least at a constant level and should ideally be continuously improved:

> The international nuclear community continues to examine nuclear plant life management issues regarding continuous safety improvements and economic life decisions of power reactors as they age. Additionally, there are growing expectations that existing nuclear reactors should meet enhanced safety objectives, closer to those of recent reactor design; the Fukushima Daiichi accident has shown the importance of applying new safety knowledge to existing power reactors throughout their lifetimes.[99]

### 3.3.3 Ageing of staff and atrophy of knowledge

The building of new nuclear reactors came to an almost complete halt for many years, beginning in the 1980s. The nuclear sector became less important, the need for personnel declined, and career prospects in the industry deteriorated. Young professionals began to be in short supply. However, the safe operation of nuclear power plants relies on experienced employees in the plants themselves and in the supply chain. Irreplaceable and undocumented knowledge can be lost when older personnel leaves. In the near future, first-hand knowledge from the construction phase will no longer be available – a phenomenon that we can already see today. Adverse effects on the safety performance of ageing reactors due to the atrophy of the knowledge base may be expected.

Another aspect of ageing is that in a declining market the number of manufacturers and service providers working exclusively or predominantly in the nuclear field has diminished over time. Specific experience has been lost and cannot be maintained on an equivalent level, especially where the delivery of technology only used in older plants is required. It has become apparent that the extraordinary high quality standards required for nuclear power plants will no longer be met with the same reliability as before. Manufacturers and subcontractors with insufficient experience in the nuclear field have become a significant factor in the decrease of quality and the increase in failures.

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[98] IAEA. 1992. Methodology for the management of ageing of nuclear power plant components important to safety. IAEA Technical Reports Series No. 338. IAEA, Vienna.

[99] IAEA. 2013. Nuclear Safety Review 2013. July 2013.

A basic safety principle is that safety-related equipment must be proven in use. However, the development of technology means that technology originally used in a power plant design will become obsolete. Identical parts for repair and replacement are available only for a limited time. A change of equipment involves inherent risks, because an equivalent proof of satisfactory performance in service is not available.

> **EXAMPLE:** the replacement of hard-wired control devices by digital control technology has triggered controversial discussions about how to guarantee the required reliability of safety-related control functions. Failure mechanisms and procedures for inspection and quality assurance are not transferable from one technology to the other. Susceptibility to faults may increase, and interaction between old and new control technology may cause additional problems. As a result the German regulator RSK has found it necessary to issue specific recommendations on this topic.[100]

Even components which comply with the required specification can deviate in details. Over the time, new manufacturing processes and changes of subcontractor can cause small differences with unexpected functional impacts. Despite conscientious quality control, such failures may remain undetected if it is recognised that the quality assurance procedure and criteria need to be adapted.

However, it is recognised that there is an increasing trend for components to be delivered and installed without adequate quality certification.

As a result, retrofitting or refurbishment of equipment carries a risk of introducing new defects into the plant.

> **EXAMPLE:** in the course of a retrofit required for seismic protection, thousands of anchor bolts were wrongly installed in several plants in Germany and had to be replaced.

Some manufacturers and suppliers intentionally offer substandard components to increase profitability. Naturally, such components cannot guarantee the required reliability and effectiveness.

> **EXAMPLES:** In Japan between 2003 and 2012, several thousand electrical parts and fittings were delivered with faked certificates. Most of them were at the timeof discovery installed in operational nuclear power plants. A significant proportion were used in components with safety-related functions. It has been suggested that around 100 employees of operators and of several suppliers were involved.[101]

In 2000 it was reported that fuel elements manufactured by BNFL were delivered to Japanese nuclear power plants with manipulated technical documents.[102]

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[100] RSK. 2011. RSK-Empfehlung: Rechnerbasierte Sicherheitsleittechnik für den Einsatz in der höchsten Sicherheitskategorie in deutschen Kernkraftwerken. 20 September 2011.

[101] Ingenieur.de. 2002. Japanische Atombranche unter Druck. 27 September 2002; http://www.ingenieur.de/Fachbereiche/Kernenergie/Japanische-Atombranche-unter-Druck

[102] Strom Magazin. 2000. Standpunkt: Deutsche Kraftwerke nicht von britischen Fälschungen betroffen. 20 February 2000.

# 4 Spent fuel storage

During operation of a nuclear reactor, a large inventory of radioactive fission products and actinides is produced in the reactor core. This radioactive inventory is concentrated in the nuclear fuel.

## 4.1 Spent fuel in nuclear reactors

After three to five years in the reactor core, the spent fuel is taken out of the RPV and replaced with new fuel. The spent fuel is then stored in spent fuel pools, to enable continuous cooling and the decay of the radioactive inventory.

Spent fuel pools are fundamentally large pools of water. The radioactivity of the spent fuel assemblies inside the pool is shielded by the water above the fuel. A pool cooling system is required to remove residual decay heat from the pool. Spent fuel pools are located either inside the containment within the reactor building (as in many PWRs), inside the reactor building but outside the actual containment (as in BWRs) or even in a separate spent fuel pool building (as in many older PWRs).

After approximately five years, when the heat generation has decreased sufficiently, it is in principle possible to reload the spent fuel elements into dry storage casks,[103] which can then be placed in an interim storage facility. At this stage heat removal from the spent fuel occurs passively via convection – active systems for heat removal are no longer needed.

As a nuclear power plant ages and spent fuel is added to the pool, the radioactive inventory stored there increases, thus increasing the potential level of radioactive contamination in the event of an accident involving the spent fuel pool.

Spent fuel storage policy varies between European countries. The spent fuel from the Spain's reactors is currently stored in the plants' own pools. The original storage racks have been progressively replaced with significantly more compact units, so expanding the storage capacity. This so-called re-racking is also practised at other countries' power plants, for example Bohunice in Slovakia. As a result of this approach, the radioactive inventory stored in the fuel pools is increased beyond the initial design values.

Slovakia, Finland, Spain, Sweden and Ukraine are the countries with the largest spent fuel inventory on their reactor sites, as Figure 1.10 shows. For comparison, the inventory of a nuclear reactor core generally consists of about 100 tonnes of heavy metal (tHM).

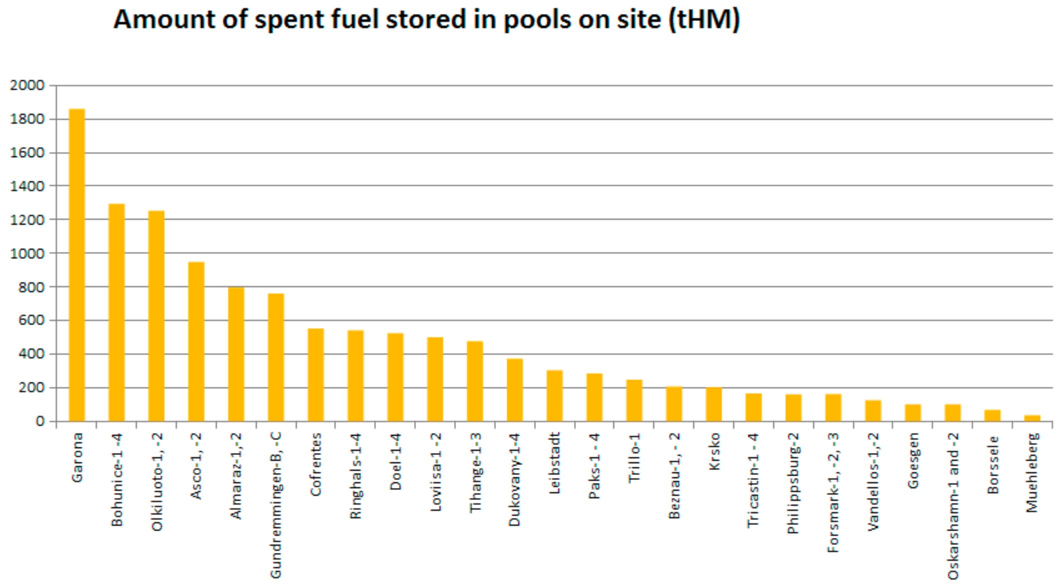

Figure 1.10 – Nuclear inventory of spent fuel pools in European nuclear power plants (where available).
Source: Nuclear Engineering International: 2012 Handbook; IAEA, Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management: 2012 country reports

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[103] Other options, such as storing spent fuel in an interim wet storage site or reprocessing it, and the associated ageing aspects, are not discussed here since this report's focus is on ageing aspects of nuclear power plants.

The cessation of reprocessing of spent fuel from Belgian reactors has led to stockpiling at the spent fuel pools at Tihange. The operator, Electrabel GDF Suez, has stated that by 2020 the on-site storage capacity for spent fuel will be full.

## 4.2 Risks of spent fuel storage

A loss of cooling to a spent fuel pool while there is spent fuel in the pool will lead to heating of the pool water and increased evaporation. The rate of heating of the pool water will depend primarily on the heat load in the fuel pool. Most heat will be contributed by the youngest spent fuel elements in the pool. The heat emitted by a fuel element depends on various factors such as the fuel type, the burnup and the time since shutdown of the critical reaction. Thus, the time taken for the pool to heat by a given amount is not directly related to the quantity of spent fuel in the pool as given in Figure 1.9.

Given sufficient evaporation of the water in the pool, the spent fuel elements will become uncovered and there is then a risk of them overheating and becoming damaged – in an extreme case a situation similar to a meltdown of the reactor core can develop, associated with the risk of hydrogen production and explosions. Physical damage to the spent fuel pool could also lead to water being lost, with the spent fuel elements potentially being uncovered rapidly, again leading to fuel damage and a release of radioactivity.

The risks associated with spent fuel storage were initially perceived to be low in comparison to the risks associated with the nuclear reactor core. Reasons for this were the much lower power density of the spent fuel (compared with that of the fuel in the reactor core, and the much lower risk of a critical reaction in the spent fuel pool. Because of the low power density and the large amount of water in a s spent fuel pool, considerable grace time is available in the event of a loss of spent fuel pool cooling, as long as the integrity of the fuel pool remains unchallenged.

This perception of low risk led to weaknesses in the safety of spent fuel pools especially in older power plants, as follows:

- Due to the perceived long grace time in the event of a loss of spent fool pool cooling, cooling systems tend to have a poor level of redundancy in comparison with the emergency cooling systems for the reactor core.
- As events involving a loss of external electricity were perceived to be likely to be of only short duration, spent fuel cooling systems are often not supported by emergency power supply systems.
- Spent fuel pools and their cooling systems are often not specifically protected against external hazards, especially in the case of older BWRs and VVER-440 reactors.
- The fuel pool is sometimes placed outside the containment (BWRs, some older PWRs and VVER-440), thus making release of radioactivity to the environment possible in the event of fuel damage.

## 4.3 Changed perceptions of risk

Following the 9/11 terrorist attacks in the USA, a renewed discussion of the safety of spent fuel storage took place. It was acknowledged that spent fuel pools located outside the reactor building in dedicated spent fuel pool buildings have a considerably lower degree of protection against terrorist attacks such as a deliberate aircraft impact. Such attacks could lead to a long-term loss of cooling or the immediate destruction of the pool structure itself, thus resulting in fuel damage and consequent large-scale releases of radioactivity to the environment.

The 2011 Fukushima disaster demonstrated powerfully the risks associated with other external hazards to spent fuel storage. Cooling of the spent fuel pools was lost after the earthquake, when external power to the site was lost. In addition, the essential service water systems were destroyed by the subsequent tsunami. When the hydrogen explosions in Unit 1, Unit 3 and Unit 4 destroyed the upper parts of the reactor buildings, the spent fuel pools were uncovered and came into direct contact with the environment.

Furthermore, the integrity of the reactor buildings was compromised as a consequence of the earthquake and the explosions. It was consequently feared that the buildings could at least partly collapse, in which case the integrity of the spent fuel pools would also be lost and cooling of the fuel would no longer be possible. Moreover, large amounts of debris from the heavily damaged reactor buildings – including the heavy structures of the fuel handling crane – had fallen into the spent fuel pools, with the risk that it had destroyed fuel assemblies (see Figure 1.11).

Staff had to attempt to ensure sufficient cooling of both the three reactor cores and the spent fuel pools simultaneously, which complicated matters further. For several days, the necessary cooling of the spent fuel remained a serious emergency challenge. First attempts were conducted with helicopters and water cannon, while later special truck mounted concrete pumps were used. At the end of 2013, nearly three years after the event, the spent fuel pools, especially that of the badly damaged unit 4, pose a severe danger to the site and surrounding environment. Full recovery of the spent fuel from all fuel pools is expected to take around another decade.

Figure 1.11 – Debris in the spent fuel pool of Fukushima-Daiichi 4 after the hydrogen explosion, with steam rising. Source: TEPCO.

In the aftermath of the Fukushima disaster, the safety of spent fuel storage has again been keenly debated in many countries in the EU and worldwide.[104]

For example, the Swiss nuclear regulator ENSI ordered directly after the Fukushima catastrophe in 2011 a design reassessment of spent fuel storage with regard to risks from earthquake, external flooding or a combination of the two. One outcome was that retrofitting of the spent fuel pool cooling system was required at the Mühleberg plant. However, the spent fuel pool itself has not been given improved protection against terrorist attacks such as a deliberate aircraft impact.[105]

Improvements to the safety of spent fuel storage discussed in the EU amount to additional instrumentation to monitor the spent fuel pool temperature and water level, retrofitting of water feed systems to enable refilling the spent fuel pool from external sources in the event of a loss of cooling, and the need for measures to protect against hydrogen explosions in the area of the spent fuel pool.

While these measures are important first steps to enhance the safety of spent fuel storage, other major shortcomings have not yet been addressed. No fundamental improvement of the physical protection of spent fuel pools that are not located inside well-protected reactor buildings has so far been discussed. Neither is the problem of containing possible releases of radioactivity from damaged spent fuel addressed by the improvements mentioned above. While freshly unloaded spent fuel requires several years of cooling in a spent fuel pool, another important step to enhance the safety of spent fuel storage would be the unloading of the older spent fuel from fuel pools into dry cask storage in physically well protected interim storage facilities.

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[104] See for example IAEA. 2012. International Experts Meeting. Reactor and spent fuel safety in the light of the accident at the Fukushima Daiichi Nuclear Power Plant. Vienna, 19–22 March 2012.

[105] ENSI, 2012, EU stress test Swiss national report - ENSI review of the operators' reports. Zürich.

# 5 External hazards and siting issues

Several of the lessons of the Fukushima disaster relate to the insufficient consideration of external hazards in the design and siting of the power plant. Furthermore it has become evident that additional problems arise from a severe accident happening in several units on one site at the same time.

A fundamental recommendation of the European Nuclear Safety Regulators Group (ENSREG) peer peview process to the European regulators has therefore been to develop harmonised guidance on how to assess natural hazards. The peer review also commented that:

> A good practice adopted by IAEA member states and used by the peer review is that external events should be addressed by designing to the hazard level consistent with a 10,000 year return period, i.e. a frequency equivalent to $10^{-4}$ per annum. Many countries adopt this level for new designs, while a large number of countries adopt it for re-evaluation of older designs. However a small number have not adopted this level for re-evaluation/back-fitting, in some cases since they judge that it is not feasible to define the characteristics of the earthquake at such remote frequencies. [106]

In November 2013 WENRA published a draft review of its Safety Reference Levels, including a new reference level T relating to natural hazards. This requires that:

> A common target value of frequency, not higher than $10^{-4}$ per annum, shall be used for each design basis event. [107]

Country-specific regulatory requirements may also change considerably due to new operational experience. For example, France is changing its regulatory requirements with respect to the assessment of flooding risks in response to a severe event happening at the Blayais power plant.[108]

Loss of key external infrastructure as a result of a natural disaster is another important factor. Natural disasters with extensive and long-lasting effects were usually not taken into account as an explicit design basis condition. Today, a more robust degree of plant autonomy is required to cope with situations beyond the original design basis.[109] Unfortunately, some measures to cope with emergency situations are based on conventional installations and infrastructure (external non-nuclear power plants, transportation routes, alternative cooling water resources) which are not as well protected as nuclear installations. This also holds true for some of the emergency preparedness measures for severe accidents that have been specifically introduced in response to the lessons learnt from the Three Mile Island and Chernobyl disasters.[110]

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[106] ENSREG. 2012. Peer review report: Stress Test Peer Review Board stress tests performed on European nuclear power plants. 25 April 2012.

[107] WENRA. 2013. WENRA safety reference levels for existing reactors: update in relation to lessons learned from Tepco Fukushima Dai-Ichi accident. 27 November 2013. http://www.wenra.org/media/filer_public/2013/11/21/updated_reference_levels_for_existing_npp_-_november_2013.pdf

[108] ASN. 2010. Protection des installations nucléaires de base contre les inondations externes. Projet de guide de l'ASN N° 13.

[109] WENRA Reactor Harmonisation Working Group. 2013. Updating WENRA Reference Levels for existing reactors in the light of TEPCO Fukushima Dai-ichi accident lessons learned. November 2013.

[110] ENSREG. 2012. Peer review report: Stress Test Peer Review Board stress tests performed on European nuclear power plants. 25 April 2012.

## 5.1 Seismic hazards

Older nuclear power plants were often originally designed to resist a lower magnitude of earthquake than has to be taken into account today.[111] Moreover, in the case of some sites with low seismicity, earthquakes were not considered at all in the original design, or only a very low level of resistance was requested. Today, even for sites with low seismicity, a minimum level of earthquake resistance is required.[112] For several European power plants, this requirement remains to be fulfilled.[113] In addition, new scientific findings require that seismic risk levels of existing plants are redetermined in accordance with the latest methods and data. In several cases, a recalculation of the robustness of existing plants to show consistency with the new standards has been accepted instead of the implementation of expensive retrofit s. Re-evaluation of earthquake resistance is conducted using the original margins, which were implemented in the original design of the reactor. If higher loads arising from new design basis earthquake assumptions are accepted without improvements to the installation, existing safety margins are thereby reduced. This approach may prove problematic due to the high uncertainty associated with hazard assessment. However, the alternative, the retrofitting of existing facilities, is expensive and sometimes difficult to achieve.

> **EXAMPLE:** for Switzerland's reactors, three of which are among the oldest in Europe, a probabilistic reassessment of seismic hazard at the end of the 1970s resulted in a hazard level which exceeded the original design level. The operators claimed to fulfil these requirements without further adjustments and the regulator ENSI retrospectively confirmed that the design of the reactors offered an adequate defence against earthquakes. At the end of the 1990s the seismic hazard was calculated again in the context of the Pegasos Project'[114] conducted by four independent expert groups. This reassessment resulted in an even higher seismic hazard level for each site. Some of the older reactors, especially Mühleberg (see Figure 1.12), were incapable of meeting the resultant strengthened requirements. ENSI therefore allowed a 20 percent decrease in the seismic hazard level for Mühleberg.[115] Meanwhile a new study had been started, the follow-up Pegasos Refinement Project. The results are currently being reviewed by ENSI, which intends to present more precise and less conservative hazard assumptions based on the new analysis.

As a result of the European Stress Test, in which Switzerland participated voluntarily, it was reported that the present seismic design basis for the spent fuel pool cooling systems at Beznau and Mühleberg appears inadequate. ENSI has requested retrofitting of the spent fuel pool cooling systems. Regarding the integrity of the containment, ENSI concluded that a more detailed examination of its earthquake resistance is needed.[116]

Figure 1.12 – Mühleberg nuclear power plant. Source: Fokus Antiatom

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[111] European Commission Staff Working Document: Technical summary on the implementation of comprehensive risk and safety assessments of nuclear power plants in the European Union. Brussels, 4 October 2012. SWD(2012) 287 final.

[112] IAEA. 2010. Seismic hazards in site evaluation for nuclear installations. IAEA Specific Safety Guide No. SSG-9. IAEA, Vienna.

[113] European Commission Staff Working Document: Technical summary on the implementation of comprehensive risk and safety assessments of nuclear power plants in the European Union. Brussels, 4 October 2012. SWD(2012) 287 final.

[114] Nagra & Pegasos. 2004. Probabilistic seismic hazard analysis for Swiss nuclear power plant sites. Pegasos Project Final Report. Nagra, Wettingen. July 2004.

[115] HSK. 2007. Neubestimmung der Erdbebengefährdung an den Kernkraftwerkstandorten in der Schweiz (Projekt Pegasos). HSK, Würenlingen. June 2007.

[116] ENSI, 2012, EU stress test swiss national report - ensi review of the operators' reports. Zürich.

**EXAMPLES:** in reaction to new findings on the seismic hazard level of the Biblis power plant in Germany, the regulatory authority of the state of Hessen published a list of requirements for earthquake protection retrofitting on 27 March 1991. But by December 2010, nearly 20 years after the requirements were published, not all of them had been implemented.[117] In September 2006 it was recognised that anchor bolts installed in the course of retrofitting to enhance earthquake protection had not been fitted in accordance with the required quality specifications.[118] After a systematic assessment of the other plants in Germany it became obvious that the problem of insufficient quality assurance when installing anchor bolts was of relevance to several plants. Following this finding, thousands of anchor bolts had to be repaired.

Another case at the Krško plant in Slovenia indicates the problems involved in bringing older plants into line with new scientific findings concerning earthquake risks. Seismic reassessment of the Krško site became necessary in the context of the planned new reactor Krško-2. Statements on the website of the Slovenian regulator, the SNSA, raise questions about the potential impact of a fault known as Libna on the seismic hazard at Krško as well as the need to update the seismic hazard assessment of Krško 1. The French national expert organisation the Radioprotection and Nuclear Safety Institute (IRSN), one of the institutes to bring forward this issue, urged in an open letter to the operator GEN Energija d.o.o. and the SNSA to seek further clarification.[119] In opposition to the operator and regulator, the IRSN confirmed the need to reassess the seismic data used in the design of Krško 1. The IRSN suggested to the operator that it should assure sufficient local data input of a study concerning Libna fault in order to minimise the identified uncertainties.[120]

## 5.2 Extreme weather conditions and climate change

The development of the risk posed by extreme weather conditions and the associated changes in risk perception are an important example of conceptual ageing.

Like conventional buildings, nuclear power plants are designed to withstand natural hazards, but with a lower acceptance level for certain events such as earthquakes or flooding (typically in the range of $10^{-4}$ per annum). For other external events, especially those related to other types of extreme weather event, much less strict acceptance levels are used. When assessing the robustness of European nuclear power plants, the ENSREG Peer Review Group commented:

> The situation with regard to extreme weather is even less satisfactory. Some countries demonstrated a capability based on recent historic data, which is less demanding than good practice would dictate. In general there was little evidence of assessing margins BDB [beyond design basis]. [121]

In general it is expected that normally occurring extreme weather conditions can be withstood by solidly constructed buildings, especially those designed to withstand extreme external events such as earthquakes, aircraft impacts or chemical explosions. However, the more frequent occurrence of extreme weather events over recent years and the debate on the possible effects of climate change have stimulated discussion of the issue.

Scientific research has shown that an increasing intensity and frequency of extreme weather events must be expected. The possibility of nuclear emergencies due to extreme precipitation (including snowfall), sudden icing, storms and tornadoes, heat waves and droughts has therefore to be considered. The effects of these extreme weather conditions, such as flooding, landslides, cooling water inlet or drainage clogging, forest fires or water shortages can directly compromise a power plant and can cause wide-ranging as well as long-lasting impairment of vital infrastructure. External infrastructure such as electricity and feedwater supplies and access roads are most threatened by natural impacts. It has to be assumed that in the event of an extreme weather event the site will become inaccessible. The effectiveness of fire-fighting and other external assistance and the delivery of external auxiliary emergency equipment and support, can thus be substantially affected.

Weak protection against natural hazards is a typical problem of ageing power plants, if the design is not adapted to cope with changing risk levels and new scientific findings. Nevertheless, in the context of the European stress test some operators refused a re-evaluation of external hazards. Conversely, some countries such as the Czech Republic admitted that they had underestimated extreme weather conditions up to now.[122]

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[117] Hessischer Landtag, Drucks. 18/2420, Kleine Anfrage der Abg. Ursula Hammann (BÜNDNIS 90/DIE GRÜNEN) vom 11.05.2010 betreffend Atomkraftwerk Biblis, Block A, Umsetzung der sogenannten „Weimar-Auflagen“ und Antwort der Ministerin für Umwelt, Energie, Landwirtschaft und Verbraucherschutz. 28 September 2010.

[118] German Reactor Safety Commission. 2010. Anforderungen an Dübelverbindungen in Kernkraftwerken. 20 May 2010.

[119] Repussard, J, 2013. Letter IRSN/DIR/2013-00525 from IRSN to SNSA. IRSN, Fontenay aux roses, 9 August 2013. http://www.ursjv.gov.si/fileadmin/ujv.gov.si/pageuploads/si/medijsko-sredisce/dopisGen/DopisIRSN.pdf

[120] Scotti, O, 2013. Presentation of IRSN report on possible NPP Krsko II site.What are the implications of this report?. IRSN, 2 December 2013. http://www.ursjv.gov.si/fileadmin/ujv.gov.si/pageuploads/si/medijsko-sredisce/dopisGen/IRSNpredstavitevNaKonferenciFocusa2013vLjubljani.pdf

[121] ENSREG. 2012. Peer review report: Stress Test Peer Review Board stress tests performed on European nuclear power plants. 25 April 2012. Page 16.

[122] State Office for Nuclear Safety. 2011. National report on ‘Stress Tests’ NPP Dukovany and NPP Temelín: evaluation of safety and safety margins in the light of the accident of the NPP Fukushima. December 2011.

The analysis of possible hazards due to extreme weather conditions is not a trivial undertaking, as the Swiss reassessments show. The nuclear regulator ENSI requested hazard analysis and safety cases for all Swiss nuclear power plants at the end of 2011. Although the operators commissioned acknowledged experts, an extension until mid-2014 was requested by the operators to finish the assessments. The increased expense of new methods and data collection had been underestimated.[123]

As reactors need large amounts of cooling water, they are usually located on lakes or rivers or by the sea. Consequently, the risk of flooding of the site has to be taken into account. New assessments according to the state-of-the-art of science and technology often reveal insufficient flood protection missed by previous assessments. Changes of land use in the surrounding area (land sealing, water management, embankment) may influence the flooding risk. These changes may happen over a much shorter timescale than climatic changes and thus have to be taken into re-assessed on a regular basis. As a rule public flood protection is designed for less significant and more frequent flooding events than nuclear power plants need to be protected against, for example events with return periods of 100 years rather than 10,000 years. Unforeseen combinations of natural hazards including extreme weather (storm and precipitation, sudden icing, land slides) as well as insufficient plant protection (undersized drainage systems, missing sealing, water ingress through underground channels) can exacerbate the consequences of an extreme weather event. Some sites are forced to rely on temporary measures which are not as reliable as permanent flood protection measures, or indeed a location above the level of a design basis flood.

**EXAMPLES:** in December 2009, as a result of prolonged and heavy rainfall, large quantities of vegetation were washed into the river Rhône. Subsequently, the feedwater intake of the Cruas 4 reactor was blocked, leading to a shutdown of the reactor. After a shutdown, residual heat removal is still required to avoid overheating of the reactor. However, the residual heat removal system was dependent on the functioning of the same cooling water intake. The operator was forced to take emergency action: it took over five and a half hours to unblock the water intake.[124]

In 2011 a flood had a serious impact on the Fort Calhoun power plant in Nebraska, even though it was less serious than the design basis flood.[125] The site was flooded to a depth of 60cm (see Figure 1.13). A rubber barrier installed as a temporary flood protection measure burst. Simultaneously a fire broke out in the control room. The electricity supply and some of the emergency diesel generators failed due to the flooding. The spent fuel pool cooling system was interrupted until the back-up emergency power supply started successfully. The entire site was inaccessible and some installations could not be reached for needed action. Staff had to remain on site for a prolonged period. Additional fuel had to be delivered rapidly and under difficult conditions to enable the emergency diesel generators to operate for a prolonged time.

Figure 1.13 – 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

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[123] http://www.ensi.ch/de/2012/07/06/extreme-wetterbedingungen-nachweise-der-kernkraftwerke-bis-ende-2013/

[124] http://www.world-nuclear-news.org/RS_Storm_shudown_at_Cruas_0212091.html

[125] http://www.nytimes.com/imagepages/2011/06/21/us/FLOOD.html

Possible effects of climate change are insufficiently addressed, for example, in the safety design of older UK power plants such as Wylfa, Hunterston B and Hinkley Point B. Hunterston B and Hinkley Point B may not tolerate wave overtopping of protection dykes in the event of an extreme storm surge exacerbated by climate change. Flooding of installations may result, especially if the drain water discharge is not as effective as assumed in the safety design, for example due to unforeseen clogging. In this event, the power plants would have to rely on provisional measures, such as the use of fire hydrants to ensure cooling water supply at Hinkley Point, or temporary dams to protect against flooding. Climate change is predicted to result in sea level rise and higher intensity and frequency of extreme storm surge events, as well as increased maximum wave heights. Furthermore it must be acknowledged that dams or dykes do not completely guarantee flood protection. Ageing mechanisms reducing their reliability and efficiency are a common problem. In certain cases it has been shown that these installations are of inadequate size due to incorrect design assumptions and failure to adapt to changing standards. The European stress test report on Hinkley Point B summarised the potential impact of sea level rise there:

> However, work subsequent to the second periodic safety review indicated a sea level rise due to climate change of approximately 0.88 m at Hinkley Point B over the current century. This indicated that sea level rise will be 9.18 m AOD [above Ordnance Datum] by 2016. This depth is still not adequate to threaten the main Hinkley Point B nuclear island at 10.21m AOD. However the cooling water pumphouse at 8.08m AOD would be flooded with consequential loss of the systems inside. The increased flood levels due to climate change do not change the nuclear safety arguments as the flooding is infrequent and therefore loss of cooling water systems remains tolerable given that the fire hydrant remains available. [126]

According to the findings of the ENSREG peer review to the Belgian stress test report, the Tihange nuclear power plant would be unable to withstand an external flooding event with a return period of 10,000 years:

> The results for Tihange NPP show that there are weak margins for floods exceeding those with 400 years return period. Significant damage to equipment would be caused already by floods with return periods of 600 to 1,000 years, worsening the consequences with increasing return periods (higher river flow rates). [127]

The Borssele power plant site in the Netherlands relies on the flood protection provided by the network of dykes in Zeeland. The operator has been required to improve the flood protection to withstand a flooding of 4,000 year return period, in order to comply with Dutch legal requirements.[128] Even then, however, the site would not be protected against a flood with a 10,000 year return period, as required by the new draft WENRA reference level.[129]

## 5.3 Sites with multiple nuclear power plants and twin units

Until the Fukushima disaster, it had usually been assumed that it was an advantage to have several reactors at one site, as they could support each other with shared equipment, personnel or emergency power supply in the event of an emergency affecting one reactor. The negative impacts on a site's other reactors of a severe accident in one reactor were not appropriately taken into account.

In practice, safety-related systems which are connected to multiple units or designed for alternating operation may give rise to adverse interactions. In many cases the shared usage of components and systems such as water reservoirs, pipelines and pumps is intended to compensate for an inadequate capacity of subsystems and/or insufficient redundancies. Multiple units are also often meshed by using cooling water inlets and pumping stations jointly. If a system's function is requested for one unit its availability for the other unit or units may become insufficient. Switching operations and modifications affecting one unit may also result in unexpected effects on the other unit(s).

Moreover, external hazards have the potential to cause simultaneous failures of identical components of several reactors on one site.

> **EXAMPLES:** At Fukushima Daiichi, the site's external power supply was lost as a consequence of the earthquake. The pumping stations of the cooling systems and most of the emergency diesel generators on site were destroyed by the tsunami. The four oldest reactors at Fukushima suffered the greatest destruction. The oldest unit – Fukushima Daiichi 1 – was the first of three units to suffer a core meltdown, leading to a hydrogen explosion that partly destroyed the reactor building. The reactor cores of units 5 and 6, the newest units at the site and located on higher ground, remained undamaged.[130]

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[126] EDF Energy. 2012. EU Stress Test – Hinkley Point B Rev 001. January 2012.

[127] ENSREG. 2012. Peer review country report Belgium: stress tests performed on European nuclear power plants. 26 April 2012.

[128] ENSREG Stress Test Peer Review Board. 2012. Peer review country report Netherlands: stress tests performed on European nuclear power plants.

[129] WENRA, 2013. WENRA safety reference levels for existing reactors - update in relation to lessons learned from TEPCO Fukushima Dai-ichi accident; http://www.wenra.org/media/filer_public/2013/11/21/updated_reference_levels_for_existing_npp_-_november_2013.pdf

[130] Gesellschaft für Anlagen- und Reaktorsicherheit mbH. 2013. Fukushima Daiichi – Unfallablauf, radiologische Folgen. March 2013.
Tokyo Electric Power Company. 2012. Fukushima nuclear accident analysis report. June 2012.

> Fukushima Daiichi units 3 and 4 used a shared chimney as part of the venting system for severe accidents. Hydrogen gas produced by the overheating of fuel in unit 3 – was released during venting operations and spread over piping to the common chimney into the reactor building of unit 4, leading to a severe hydrogen explosion.

Twin units dependent on shared support and safety systems entail especially high levels of risk. All interfaces between reactors make them more vulnerable to internal incidents.

It should be emphasised that the European Stress Test specification did not take specific account of issues facing multi-unit plants, and assessment of the risks due to common-cause failures or consequential failures between units was seldom addressed in the Stress Test reports. The operators of multi-unit power plants often describe only a single reactor as a reference for all units and their reports hardly touch on possible interactions between or simultaneous problems of several units.

Considering the impact of the July 2007 Chuetsu earthquake off the coast of Japan's Niigata Prefecture on the Kashiwazaki-Kariwa multi-unit power plant,[131] as well as the impacts of the March 2011 earthquake and tsunami on the Fukushima-Daiichi site, the IAEA decided in October 2012 to focus on the problem,[132] admitting that it had hitherto been neglected:

> The number of sites housing multi-unit nuclear power plants (NPPs) and other co-located nuclear installations is increasing. An external event may generate one or more correlated hazards, or a combination of non-co-related hazards arising from different originating events, that can threaten the safety of NPPs and other nuclear installations. The safety assessment of a site with a single-unit NPP for external hazards is challenging enough, but the task becomes even more complex when the safety evaluation of a multi-unit site is to be carried out with respect to multiple hazards… The currently available guidance material for the safety assessment of NPP sites in relation to external events is not comprehensive. The IAEA has not published safety standards in all the areas of this subject.

## 5.4 Development of infrastructure and population

Nuclear power plants are often built near areas of high population density to ensure proximity between power production and consumption, and because they require well-developed road and power supply infrastructure. Moreover, the extension of existing sites has often been given preference since decisions in favour of new sites became more difficult to secure.

Of course, the already high population density surrounding sites may increase with time. In the meantime, increasing knowledge about the possible consequences of accidents and radioactive releases shows the need for new assessments of the risks to the public.

The more people are liable to be affected by emergency civil protection measures in the event of a nuclear accident, the more difficult such measures will become to implement. Information provision, monitoring, decontamination, traffic management and medical care, as well as the process of evacuation, will present severe organisational challenges for the civil protection authorities.

Most European countries have evacuation plans covering a radius of less than 10 km around their nuclear power plants. No harmonisation of national regulations has yet been achieved. The experiences of Chernobyl and Fukushima, as well as modern computer simulations, show that external emergency plans for nuclear power plants should be extended.[133] Calculations by the Öko-Institut show that an area as large as 10,000 km$^2$ could be affected by evacuation and relocation after a severe nuclear power plant accident involving a large and early release of radioactivity. A radius of more than 50 km around the plant may thus be affected.[134]

Figure 1.14 shows the areal distribution of radioactivity around the site of Fukushima-Daiichi in April 2011. It can be seen that large area dose rate values occurred even outside a 30km zone around the plant.

> **EXAMPLE:** in Germany there has been discussion as to whether the radius of the inner evacuation zone (to be evacuated within six hours) should be expanded from 2 km to 5 km or more, and the 12 sectors of the middle zone (the downwind sector to be evacuated within 24 hours) should be expanded from 10 km to 20 km or more. The internationally used so-called intervention level for evacuation is 100 millisieverts (mSv) effective dose per seven days.

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[131] Tokyo Electric Power Company. 2010. Experience of NCO Earthquake and Restart of Kashiwazaki-Kariwa NPP. 25 November 25 2010.

[132] IAEA. 2012. International Workshop on the Safety of Multi-Unit Nuclear Power Plant Sites against External Natural Hazards, Anushakti Nagar, Mumbai, India, 17–19 October 2012.

[133] Gering, F., Gerich, B., Wirth, E. & Kirchner, G. 2012. Analyse der Vorkehrungen für den anlagenexternen Notfallschutz für deutsche Kernkraftwerke basierend auf den Erfahrungen aus dem Unfall in Fukushima. Bundesamt für Strahlenschutz (BfS). 19 April 2012. http://nbn-resolving.de/urn:nbn:de:0221-201204128010

[134] Öko-Institut. 2007. Analyse des Bedrohungspotenzials „gezielter Flugzeugabsturz“ am Beispiel der Anlage Biblis-A Im Auftrag der EUROSOLAR, Europäische Vereinigung für Erneuerbare Energien e.V., Dr. Hermann Scheer, MdB. July 2007.

In the event of a serious accident, permanent relocation could be necessary for areas around the nuclear power plant that receive more than 50mSv effective dose per year. Around Fukushima areas receiving 20mSv per year are subject to temporary relocation.

Table 1.4 gives examples of older reactors close to the larger cities of Europe. Notably, all the main cities in Switzerland are in the neighbourhood of ageing nuclear power plants and might be subject to evacuation in the event of a major accident. It should be emphasised that the region of Basel is the seismically most active region in Western Europe besides Italy and Greece (neither of which has any operational nuclear power plants) and also has six of the oldest active reactors in existence. In the area of Fukushima approximately 150,000 people had to leave their homes; while around Chernobyl 116,000 people from the 30km area, and subsequently another 240,000 people, were permanently relocated.

| Older reactor | Country | Affected cities | Population in the area of the cities |
|---|---|---|---|
| Doel 1–4 | Belgium | Antwerp | 5,000,000 |
| Tihange 1–3 | Belgium | Liège, Namur | 860,000 |
| Dukovany 1–4 | Czech Republic | Brno | 800,000 |
| Mühleberg | Switzerland | Bern | 500,000 |
| Beznau 1–2 | Switzerland | Zürich, Basel | 2,000,000 |
| Leibstadt | Switzerland | Zürich, Basel | 2,000,000 |
| Gösgen | Switzerland | Zürich, Basel | 2,000,000 |
| Fessenheim 1–2 | France | Mulhouse, Basel, Freiburg | 1,500,000 |
| Gravelines 1–6 | France | Calais, Dunkirk | 300,000 |
| Bugey 2–5 | France | Lyon | 1,300,000 |
| Blayais 1–4 | France | Bordeaux | 720,000 |
| Dungeness B 1–2 | United Kingdom | London | 14,000,000 |
| Borssele | Netherlands | Ghent | 600,000 |

Table 1.4 – European urban populations potentially affected by a major nuclear incident involving an older reactor

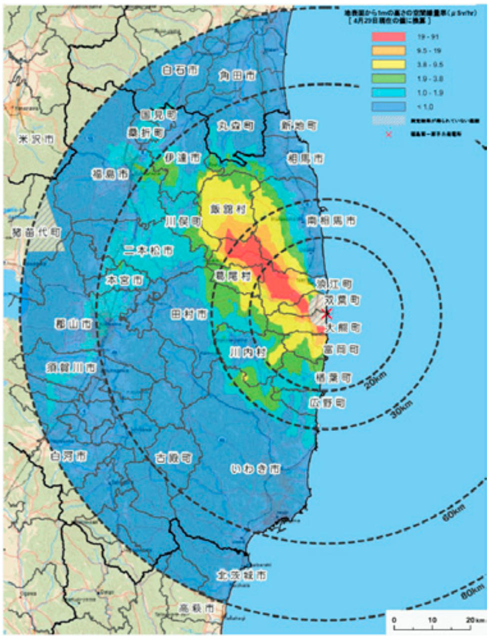

Figure 1.14 – Areal distribution of radioactivity around Fukushima in April 2011.
Source: MEXT

# 6 Lessons (to be) learnt from Fukushima – the EU Stress Test

On 11 March 2011, an earthquake and a resulting tsunami impacted several nuclear power plants on the east cost of Japan. As a consequence of this event, three units at the site of the Fukushima-Daiichi nuclear power plant faced an (at least partial) core meltdown, and several hydrogen explosions partly destroyed the reactor buildings of units 1, 3 and 4 (the last of which had not even been operating at the time). Approximately 150,000 people had to be evacuated from the surrounding area, most of whom have still not been able to return home.

An immediate lesson to be learnt from this event was that natural external hazards occur and can be far more serious than expected.

The deterministic safety requirements in place at the Fukushima site were not sufficient to ensure plant safety; the methodology for the plant's probabilistic safety assessments also failed to take account of the true full extent of external threats to the site.[135]

As a result it became evident that external hazards can cause widespread and lasting destruction of a nuclear power plant's infrastructure, including parts of the safety system, auxiliary systems such as the emergency power supply and the external power supply to the site.

## 6.1 Origin and timeline of the EU Stress Test

In the aftermath of the Fukushima event, the European Council concluded that 'the safety of all EU nuclear plants should be reviewed, on the basis of a comprehensive and transparent risk and safety assessment ("stress tests")'.[136]

The European Commission in close cooperation with ENSREG were assigned to perform the nuclear safety part of the so-called European Stress Test. and on 31 May 2011 ENSREG issued the EU Stress Test specifications, according to which all EU Member States with nuclear power plants then performed their investigations.[137] In addition to the countries of the EU, neighbouring countries such as Switzerland, Turkey and Ukraine took part in the Stress Test, while other countries worldwide also performed comparable safety assessments.

Within the framework of the EU Stress Test, the operators had to deliver reports on their facilities. These were evaluated by the national regulatory authorities, which in turn delivered national reports at the end of 2011. These national reports were then subject to peer reviews by experts assigned by fellow-regulators. Finally ENSREG, together with the European Commission, published a joint statement on 26 April 2012, and the European Commission reported the results of the EU Stress Test to the European Council and the European Parliament in October 2012.[138]

As a follow-up to these activities, the national regulators published national action plans summarising their conclusions from the EU Stress Test and the planned enhancements in the safety of nuclear power plants in their respective countries.

While this process was definitely very valuable for the harmonisation and enhancement of reactor safety in Europe, it did also exhibit some major shortcomings, which are discussed in the following sections. Further critical reviews of the EU Stress Test already exist, which could be used for in-depth evaluation of the results of the Stress Test.[139]

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[135] The National Diet of Japan. 2012. The official report of The Fukushima Nuclear Accident Independent Investigation Commission.

[136] European Council, 2011. Conclusions of the European Council 24/25 March 2011, EUCO 10/11. Brussels. Paragraph 31

[137] ENSREG, 2011. EU Stress Test Specifications. http://www.ensreg.eu/node/289/

[138] Communication from the Commission to the Council and the European Parliament on the comprehensive risk and safety assessments („stress tests") of nuclear power plants in the European Union and related activities. Brussels, 4 October 2012.

[139] See for example Makhijani, A. & Marignac, Y. 2012. Sûreté nucléaire en France post-Fukushima: analyse critique des évaluations complémentaires de sûreté (ECS) menées sur les installations nucléaires françaises après Fukushima. IEER, WISE, Paris. February 2012.
Wenisch, A. & Becker, O. 2012. Critical review of the EU Stress Test performed on nuclear power plants. Study commissioned by Greenpeace. May 2012.
Majer, D. 2012. Abschlussbericht zum Stresstest für das Kernkraftwerk Cattenom. February 2012.
Öko-Institut & Physikerbüro Bremen. Analyse der Ergebnisse des EU-Stresstest der Kernkraftwerke Fessenheim und Beznau. October 2012.

## 6.2 Scope of the EU Stress Test

The European Stress Test focused on the ability of nuclear power plants to withstand events beyond the original design basis, sometimes referred to as robustness. To this end, severe events were defined whose consequences had to be investigated by the operators and the national regulators.[140]

In the light of the Fukushima disaster external hazard played a key role in the EU Stress Test, with earthquake, flooding and extreme weather conditions required to be evaluated.

Furthermore, as the earthquake and tsunami that caused the Fukushima disaster resulted in the total loss of important safety functions, an investigation of a postulated loss of electrical power and of the ultimate heat sink for the reactor core and the spent fuel pool, independent of the causing initiating event, was to be conducted.

The pre-planned measures to deal with a severe accident at the Fukushima site were not capable of preventing core meltdown and hydrogen explosions. Accordingly, the severe accident management measures in place in EU nuclear power plants, i.e. measures to secure the cooling of core and spent fuel pool and the integrity of the containment, and to restrict radioactive releases, were also to be investigated.

### 6.2.1 Shortcomings in the scope of the EU Stress Test

Besides the events mentioned above, the scope of the EU Stress Test did not include other significant events that could lead to a severe accident, consideration of which is necessary for any comprehensive assessment of the safety of nuclear power plants, such as:

- loss-of-coolant accidents;
- reactivity-initiated events or anticipated transients without scram;
- internal events such as fires or internal flooding; and
- anthropogenic events, including terrorist acts such as deliberate aircraft impacts.

The specific topic of the ageing of nuclear power plants was also outside the scope of the EU Stress Test. This is of special importance, as several aspects of ageing as discussed in section 3 will have an impact on either the probability of an initiating event or the possible consequences of such an event.

For example, the risk of a small break loss-of-coolant accident will be influenced by the quality of chosen materials, the manufacturing processes and frequency and efficacy of in-service inspections. Ageing mechanisms will enhance the risk of failures of piping. Moreover, issues of design ageing, such as absence or insufficient physical separation of redundancies in older reactors, will increase the risk of common cause failures in events such as internal fires or internal flooding, compared with the risk faced by a more modern reactor. Particularly with respect to malevolent events, the design requirements for older plants were much less demanding than those for more recent plants.

Thus, because of the restricted scope of the safety assessment and its failure to cover ageing as an important topic, the EU Stress Test cannot be seen as a comprehensive assessment of the safety of EU nuclear power plants as originally requested by the European Council.

## 6.3 Assessment criteria of the EU Stress Test

The results of the investigations by the operators and the national regulator were expected to cover:

- 'Provisions taken in the design basis of the plant and plant conformance to its design requirements
- Robustness of the plant beyond its design basis [...]
- any potential for modifications likely to improve the considered level of defence-in-depth, in terms of improving the resistance of components or of strengthening the independence with other levels of defence.'[141]

Furthermore, the operator was free if it wished to 'describe protective measures aimed at avoiding the extreme scenarios' defined by ENSREG.[142]

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[140] ENSREG, 2011. EU Stress Test Specifications. http://www.ensreg.eu/node/289/

[141] ENSREG, 2011. EU Stress Test Specifications. http://www.ensreg.eu/node/289/

[142] ENSREG, 2011. EU Stress Test Specifications. http://www.ensreg.eu/node/289/

### 6.3.1 Shortcomings in the evaluation procedure

The evaluations of the EU Stress Test focused strongly on the robustness of plants beyond their initial design basis. This was a new and therefore important field of analysis, which is usually not covered in detail in the safety analyses of nuclear power plants. As a result valuable information was obtained.

At the same time, however, the procedrure clearly did not focus on important shortcomings in the original design basis of European nuclear power plants, nor on significant differences in the design bases of plants either within one country or in different countries. While the operator and national regulator had to discuss the conformance of the plant with its design basis, they were not required to consider the design's compliance with modern standards such as the WENRA Safety Objectives for New Power Plants[143] or even with safety standards for existing nuclear power plants such as the WENRA Reference Levels.[144]

As a result, the design deficiencies of older plants were not fully covered by the results of the EU Stress Test. For example, for a loss of electrical power, important factors such as the physical separation or protection of the emergency power supply system were not analysed in detail, even though the Fukushima disaster clearly showed that design flaws such as placing all emergency diesel generators and switchyards in the basement of the building without protection against flooding of the site can have a severe impact on the safety of a plant.

A full consideration of this problem would in particular have to take into account that some older plants have already received major retrofits to compensate for deficiencies or a lack of robustness in the original design (such as the installation of an additional emergency power supply or independent emergency core cooling systems). If the original design deficiencies that necessitated the retrofits are not fully taken into account in a safety assessment, the existence of additional equipment will give a false impression of safety in comparison with newer plants that have not needed such retrofits.

Particularly as regards external events such as earthquakes and floods, the original design basis of older power plants was determined according to the science and technology current at the time they were designed. In some cases, either the return periods for individual external hazards were set at less than 10,000 years, or no probabilistic assessment of the risk was available at all. While the methods and results underlying the current, updated, design basis of the nuclear power plants had to be described and conclusions as to the adequacy of that design basis were to be drawn, no up-to-date evaluation of the hazard was requested as part of the evaluation.

Again, with respect to the robustness of the nuclear power plant, possible cliff-edge effects were to be identified. But at the same time, no procedure was defined to assess the robustness of the plant with respect to those possible cliff-edge effects.

Possible improvements as suggested by the operator were to be taken into account in the regulator's assessment, making it difficult to judge the plant's actual status. Whether or not certain improvements will in the end be installed, and if so on what schedule, may vary considerably from plant to plant and from country to country. No common criteria were suggested by which to judge the effectiveness of proposed improvements, especially in relation to the robustness of the plant.

## 6.4 Implementation of the EU Stress Test

The operators had to provide their reports by 31 October 2011 and the national regulators had to provide theirs by 31 December 2011. The peer review process took another four months, until the end of April 2012. Fundamental sources for the entire assessment were documents provided by the operators, which could be either already validated in the course of the licensing process (by the national authority), qualified by the operator itself, or neither or both of the above. In addition to these reports, a (limited) number of actual plant visits were performed.[145]

### 6.4.1. Shortcomings in the implementation of the EU Stress Test

While the short timeframe over which the EU Stress Test was performed clearly shows the high urgency given to the assessment by all participants, at the same time it is evident that the depth and quality of the analyses was restricted by the time available.

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[143] WENRA Reactor Harmonization Working Group. 2009. Safety objectives for new power reactors. December 2009.

[144] WENRA Reactor Harmonization Working Group. 2008. WENRA reactor safety reference levels. January 2008.

[145] ENSREG, 2011. EU Stress Test Specifications. http://www.ensreg.eu/node/289/

The typical schedule for a comprehensive safety assessment such as those that are performed in many countries on a regular, typically ten-year basis, foresees a longer assessment period. Operators prepare their safety assessment documents over several years, and several years more are required by the authorities and their technical support organisations to evaluate the operator's reports and reach conclusions regarding necessary safety enhancements. Thus it is evident that, especially with respect to beyond design basis events, which have never before been analysed in detail, only a very limited quantity of validated or even qualified documents was available for the assessment. An important part of the results produced by the Stress Tests thus had to rely on expert judgement.

For older plants, the documentation produced during design and construction was not as comprehensive as is required today. Furthermore, first-hand knowledge of people who designed and constructed the plant is often no longer available, as noted in section 3.3. As a result, an in-depth assessment of older plants relying mostly on existing documentation will of necessity be limited in scope. As the number of site visits conducted in the course of the Stress Test was very limited, discrepancies between documentation and the actual status of individual plants could not be realistically assessed. No site visits were conducted for nearly two-thirds of reactors; for example only 3 out of 16 operational reactors in the UK and 12 out of 58 in France were visited. The oldest British reactors, at Wylfa, Hunterston and Hinkley, received no visits from reviewers.

## 6.5 Areas for improvement identified by the EU Stress Test

On the basis of the Final Report of the Peer Review Board,[146] ENSREG together with the European Commission identified four major areas for improvement:

1) 'Issuing WENRA guidance with the contribution of the best available EU expertise on assessment of natural hazards and margins taking account of the existing IAEA guidelines
2) Underlining the importance of Periodic Safety Review
3) Implementing the recognised measures to protect containment integrity
4) Minimising accidents resulting from natural hazards and limiting their consequences.'[147]

To achieve these potential improvements, the national regulators were asked to provide national action plans, with ENSREG and the European Commission recognising 'that the full implementation of the measures identified in the reports to improve safety will be a long-term process'.[148]

Further specific conclusions were compiled by the European Commission staff, identifying either safety issues or good practices noted in some but not all countries.[149]

Safety issues identified included: the definition of a design basis earthquake or flood with too low a return period, i.e. less than once in 10,000 years; a minimum earthquake peak ground acceleration of less than 0.1 g being used; absence of on-site seismic instrumentation; and inadequate protection of stored emergency equipment against external events.

Further safety issues relate to very short available reaction time (less than one hour) for the restoration of lost safety functions to prevent the onset of a severe accident, and missing emergency procedures for certain (shut down) plant states.

With respect to severe accidents, important measures developed as early as the aftermath of the Three Mile Island accident in 1979 and further promoted in the aftermath of the Chernobyl disaster in 1986 (such as filtered venting systems, passive means to prevent hydrogen explosions, and severe accident management guidelines covering all plant states) have still not been implemented in every EU nuclear power plant.

Good practices identified by the European Commission as being implemented in some plants included the existence of an alternative and fully independent back-up heat sink; an additional layer of safety systems independent of normal safety systems and well protected against external events; independent station blackout diesel generators; mobile equipment (like pumps and generators) for severe accidents; and a well-protected emergency control centre.

As an important means of enhancing nuclear safety in Europe, the principle of European peer reviews was identified as a good practice and may possibly be introduced permanently by ENSREG.150

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[146] ENSREG Stress Test Peer Review Board. 2012 Peer review report: stress tests performed on European nuclear power plants. 25 April 2012.

[147] ENSREG & European Commission. 2012. Stress tests and peer review process. Joint statement of ENSREG and the European Commission. 26 April 2012.

[148] ENSREG & European Commission. 2012. Stress tests and peer review process. Joint statement of ENSREG and the European Commission. 26 April 2012. p.2.

[149] Commission Staff Working Document: Technical summary on the implementation of comprehensive risk and safety assessments of nuclear power plants in the European Union. SWD(2012) 287 final. Brussels, 4 October 2012.

[150] ENSREG. 2012. Nuclear Safety in Europe. Second Regulatory Conference. Brussels, 11–12 June 2013.

### 6.5.1 Shortcomings in the implementation of improvements recommended by the EU Stress Test

Although a significant number of possible improvements was identified, not a single plant in the EU faced an unplanned shutdown or was permanently shut down as a direct result of the EU Stress Test.

While a broad range of safety issues and good practices was identified in the framework of the Stress Test, there is still no unified or harmonised set of minimum requirements at an EU level. The actual level of improvements implemented is decided on a national basis.

Although a WENRA guidance document on external hazards is currently under development, its effectiveness is likely to be constricted by methodological limitations to establish a sound design basis for some external hazards of very high severity but very low probability, such as some extreme weather events.

TEPCO identified insufficient preparation for severe accidents as an important underlying contributor to the Fukushima disaster, and said that this situation had arisen because:

- it was assumed that severe accidents had too low a probability of occurrence to be worth preparing for;
- there were concerns about liability issues and public anxiety if severe accident prevention and response preparation measures were implemented; and
- there was a fear that, once severe accident response measures had been identified, the plant might be forced to shut down until those measures had been put in place.[151]

Despite these insights in the root causes of the Fukushima disaster, important severe accident response measures (such as hardened filtered vents) that had been developed and promoted well before the Fukushima disaster have still not been implemented in all EU nuclear power plants, and there is still no EU-wide mandatory requirement to implement them.

Even in those plants where severe accident measures, like hardened filtered vents have been implemented, they are sometimes not fully protected against external events such as earthquakes.

While important safety improvements such as the installation of a diverse and fully independent secondary heat sink and an emergency control building, are identified by the Stress Test as good practices, there is no general consensus in favour of such retrofits.

Some countries already have an additional layer of safety systems to ensure fundamental safety functions, including auxiliary systems (such as emergency diesel supply) in physically separated and/or specially protected buildings. Some countries such as France are preparing requirements to install a so-called ‘hardened core’ of equipment.

Such a hardened core should safeguard all fundamental safety functions including auxiliary systems, even against external hazards of a much higher impact than has been allowed for by design basis assumptions up until now. A hardened core of this kind would be a very valuable retrofit for all EU nuclear power plants. At the same time, it has to be recognised that the implementation of such a core will take a number of years, even in France where it is already under discussion for a longer time.

Finally, while the introduction on a regular basis by ENSREG of a peer review process like the one implemented during the EU Stress Test would provide a very valuable means of discussing and harmonising some safety issues of EU nuclear power plants, the effect on actual safety enhancements would be limited as long as the scope of such peer reviews remained limited to certain special topics and their results were not made binding in any way. After all, some underlying root causes of the Fukushima accident had previously been addressed by IAEA’s peer review missions to Japan, but this did not result in the necessary safety enhancements due to the non-binding nature of the recommendations.

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[151] Tokyo Electric Power Company Nuclear Reform Special Task Force. 2012. Fundamental policy for the reform of TEPCO nuclear power organization. 12 October 2012.

# 7 Summary of major risk arguments

Important aspects of risk with respect to ageing reactors are:

- physical ageing;
- conceptual and technological ageing;
- ageing of staff and atrophy of knowledge;

As of 2014, the average age of European reactors has risen to 29 years. As the number of new-build reactors in the EU has been very limited since the 1990s, European nuclear power plant operators have followed two strategic routes, lifetime extension and power uprating.

These two strategies have serious implications for the safety of nuclear power plants, especially with respect to the following aspects:

1) Physical ageing of components in nuclear power plants leads to degradation of material properties. The effects of ageing mechanisms such as crack propagation, corrosion and embrittlement have to be countered by continuous monitoring and timely replacement of components. Nevertheless, an increasing level of material degradation cannot be completely avoided and is accepted to a certain degree, therefore lowering the original safety margins. Particularly under accident conditions that cannot be precisely predicted, an abrupt failure of already weakened components cannot be fully excluded.
2) Power uprating imposes significant additional stresses on nuclear power plant components due to an increase in flow rates, temperatures and pressures. Ageing mechanisms can be exacerbated by these additional stresses. Modifications necessitated by power uprating may additionally introduce new potential sources of failure due to adverse interactions between new and old equipment.
3) Reactor lifetime extension and power uprating therefore decrease originally designed safety margins and increase the risk of failures.
4) Serious problems related to ageing effects have already been encountered in nuclear power plants worldwide, even though they have not yet exceeded their design lifetimes. Typical ageing problems are:
    - embrittlement, cracks or leaks in the RPV or primary circuit components;
    - damage to RPV internals such as core shrouds;
    - degradation of older concrete containment and reactor buildings; and
    - degradation of electrical cables and transformers.
5) The fundamental design of a nuclear power plant is determined at the time of planning and construction. The science and technology of nuclear reactor safety is continually developing. Subsequent adaptation of a plant's design to new safety requirements is possible only to a limited degree. Thus, during the lifetime of a facility, the gap between the technology employed and state-of-the-art technology is constantly increasing.
6) To enable lifetime extensions of existing plants, operators must implement enhanced ageing management. Nevertheless, general acceptance criteria for the maximum permitted extent of ageing effects are not defined. Besides technical aspects of ageing, ageing management has to consider loss of experienced staff both in the plant's workforce and in the supply chain, as well as problems of quality assurance under changing external supply conditions.
7) With increasing lifetime, the radioactive inventory stored in a reactor's spent fuel pool and, where present, dry storage increases. As the risk associated with the spent fuel pools and dry storage was initially perceived as low, design requirements with respect to cooling and physical protection were weak. New risk perceptions after the 9/11 terrorist attacks and the Fukushima disaster necessitate a considerable improvement in the safety of spent fuel storage.
8) The site specific design basis of older nuclear power plants was usually rather weak concerning external hazards such as earthquakes, flooding and extreme weather. Site-specific reassessments of plants usually result in stricter hazard assumptions due to better knowledge and higher standards. However, comprehensive retrofitting is difficult to implement in older power plants, especially in terms of protection against earthquakes or even terrorist acts such as deliberate aircraft impacts. In the case of multiple-unit sites, the possibility of emergency situations occurring simultaneously in different units had been largely overlooked until the Fukushima disaster.
9) Until now, most evacuation plans for nuclear power plants have covered radii of less than 10 km. No harmonisation of country-specific regulations in the EU has yet been achieved. The Chernobyl and Fukushima disasters show that external emergency plans for plants need to include larger evacuation areas.
10) The European Stress Test provided valuable insights into the safety level of European nuclear power plants. Nevertheless, important aspects of ageing were not explicitly addressed and evaluated. ENSREG created a list of good practices and recommended possible safety enhancements. But neither the good practices nor the identified safety enhancements are obligatory for EU nuclear power plants.

While all the above aspects can be dealt with individually, the complex interactions between all of them have the potential fundamentally to undermine the safety level of ageing nuclear power plants.

# The economics of nuclear power plant lifetime extension

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## Content

# 1 Introduction

The nuclear power plants that came on line in the 1970s, and which make up a significant proportion of the world's nuclear generating stock, are now coming to the end of their expected operating life, typically 30–40 years. The replacement of these reactors with new nuclear capacity is highly problematic, for example in terms of cost, finance and siting, so utilities are increasingly looking to extend the lifetime of their existing nuclear power plants as the easiest way to maintain their nuclear capacity. If the cost of modifications were to prove relatively low, life-extended plants could be highly profitable to their owners because the capital cost (which makes up the majority of the cost of a unit of nuclear electricity) will already have been paid off, leaving only the operating and maintenance (O&M) costs to be paid.

This report examines the evidence on the economics of lifetime extension for nuclear power plants, paying attention to the standards required by safety regulators for plants whose lifetime is being significantly extended. The report looks at lifetime extensions of 10 years or more, as opposed to shorter extensions which are often granted on a more ad hoc basis. It focuses on pressurised water reactors (PWRs) and boiling water reactors (BWRs), which accounted for 271 and 84 respectively of the 435 reactors in operation worldwide in November 2013, and which encompass the majority of reactors being considered for lifetime extension. In a number of countries, only one or two reactors are coming up for retirement and the authorities' approach to lifetime extension may be tailored to specific conditions at these reactors. The report therefore focuses on the two countries, the USA and France, which, because they have a significant numbers of reactors nearing their original licensed lifetime, might be expected to have developed a more systematic process for authorising lifetime extension.

## 1.1 The case for lifetime extension

The advantages to nuclear power plant owners of lifetime extension are as follows:

- The cost is expected to be much lower than that of new-build nuclear or other electricity generation capacity.
- Maintaining capacity on an existing site is much less likely to cause public opposition than new-build, even on an existing site.
- Upgrading an existing plant represents a low economic risk because it is expected to be much less likely to lead to cost escalation and time overruns than new-build.
- Unexpected technical problems are much less likely with a long-established design than with a new, relatively untested design.
- If a plant's capacity represents a large proportion of the country's nuclear capacity, extending its lifetime will help maintain nuclear skills, which may be lost if the reactor(s) involved are closed.
- It may allow upgrades to be carried out to improve the plant's profitability, for example raising the output by installing a more efficient turbine generator.
- It delays the start of decommissioning and reduces the annual provisions needed to fund this process. Decommissioning is technologically largely unproven, raises issues of waste disposal and is expected to be an expensive, challenging and controversial process.

However, the process of lifetime extension is dependent on convincing national nuclear safety regulatory authorities that the reactor's design is safe enough to allow it to be re-licenced for a period of time that represents a significant fraction (up to half) of its original expected lifetime. It is clear that none of the designs that are currently reaching the end of their lifetime could be licensed as new-builds, and even if major safety upgrades are made the plants in question will still fall short of the standards expected of a new plant. However, while the quality of these designs falls short of current requirements, the plants are much more a known quality; any major design flaws or construction errors are likely to have emerged after more than 30 years of operation, and the operating workforces are well-established and ought to be competent.

While lifetime extension is clearly an expedient option in many cases, it does raise serious questions. These include the following:

- How appropriate is it to re-licence facilities that inevitably fall well short of the design standards required for new plants?
- How far can regulators be sure that all significant plant deterioration can be identified, especially in parts of the plant that are effectively inaccessible?
- How far can regulators be sure that significant construction quality issues, which would be picked up now because of improved quality control technology or more rigorous procedures, do not exist?

# 2 Concepts of power plant lifetime

While regulatory approval is a necessary condition for continued operation, it is far from being a sufficient condition. There are at least six different concepts of the lifetime of a power plant, in particular, a nuclear power plant, which are relevant. These include:

- design lifetime;
- accounting lifetime;
- economic lifetime;
- political lifetime;
- physical lifetime; and
- regulatory lifetime.

## 2.1 Nuclear economics

Prior to discussing these concepts, it is useful to outline briefly the main determinants of the economics of nuclear power. A detailed discussion of the subject is beyond the scope of this report, but some basic information is useful.[1] The major element in the cost of a unit of nuclear-generated electricity is the fixed cost, mostly comprising the construction cost. This fixed cost is determined by the construction cost itself and the cost of capital. There is no consensus on the construction cost of a nuclear power plant, and there has been a strong upward trend in real construction costs throughout the history of nuclear power. The cost of capital is highly variable and depends entirely on the circumstances of the plant, specifically the perceived risk of the project to its financiers.

The O&M costs represent the main element of the rest of the cost of a unit of nuclear-generated electricity besides the fixed cost. However, only for the USA -there are reliable data on O&M costs in the public domain. This is available because the US economic regulatory system will only allow properly audited costs to be recovered from consumers. Even this source of data is becoming less extensive as more US plants recover their costs from a non-regulated, competitive market and are not required to publish accurate costs. In other countries, there is no incentive for utilities to publish O&M costs. Utilities regard this information as commercially confidential and also have good reason to present their investments in nuclear power in a good light, so data from other countries have to be treated with scepticism.

In 2009, the most recent year for which data are available, the average US O&M costs were $21.78/MWh, made up of $6/MWh for fuel and the rest for non-fuel costs.[2] However, the fuel cost represents an underestimate of the likely actual cost. The US Government assumes responsibility for disposal of spent fuel in return for a flat fee of $1/MWh. This is an arbitrary price set more than two decades ago and is not based on actual experience.

O&M costs are relatively insensitive to plant output and costs per MWh are therefore heavily dependent on the reliability of the plant. If a plant has poor reliability, its O&M costs could easily be 50 per cent higher than the average.

## 2.2 Design lifetime

The plant's design lifetime is set by the specifications of the materials used and equipment installed, and how long these are expected to remain serviceable. The design lifetime is not a precise measure of how long a power plant will last, because this will depend on a number of factors, in particular the O&M regime. For example, if any thermal power plant is shut down and started up more often than expected, this will impose thermal stresses likely to shorten the life of the plant. If the plant is not maintained as well as expected, its life will be shortened. In the case of nuclear power plants, there is still limited experience of how long materials will last when exposed to radioactive bombardment. In practice, plants are retired not on the basis of the design lifetime but according to other factors, and design lifetime is not considered further in this chapter.

## 2.3 Accounting lifetime

Any capital asset is given an accounting lifetime when it enters service: this represents the period over which the construction cost is to be recovered. Once the initial capital cost has been recovered, the plant is said to be 'amortised', and the output can be profitably sold at marginal cost plus a profit margin. In the case of a nuclear power plant, for which the operating costs are expected to be a relatively low proportion, perhaps 30 per cent, of the overall cost of a unit of electricity, once the initial costs have been recovered the plant may be seen as a cheap source of electricity. However, this is not invariably the case: for example, in 2013 the retirement of five US nuclear power plants was announced because the costs of operating them and keeping them in service were too high for them to be profitable.

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[1] For a more detailed analysis of nuclear economics, see Thomas, S. 2010. The economics of nuclear power: an update. Heinrich-Böll-Stiftung, Berlin. http://boell.org/downloads/Thomas_UK_-_web.pdf

[2] Nucleonics Week. 2011. US nuclear operating and maintenance costs increased in 2009. 25 August 2011.

In theory, whether a plant is amortised or not should not influence decisions on retirement – the initial costs have to be repaid whether or not the plant is operating. The operating costs should be the sole determinant of whether or not to retire a plant. However, whether or not plants are amortised may influence political decisions about their future. In Germany, the utilities are demanding compensation for the government's phase-out policy because closing the plants at about year 30 will prevent the utilities earning large profits from their continued operation.[3] In Belgium, the government was demanding the payment of windfall taxes on the profits made by the utilities as a condition for allowing their plants to be life-extended.[4] Unsurprisingly, the German utilities who filed for compensation for not being allowed to life-extend their plants, claimed that their foregone profits would have been high so as to ensure that their compensation will be high, while the Belgian utilities claimed that the profits of their life-extended plants would be lower than the Belgian electricity regulator's estimate so as to minimise the windfall taxes payable. However, like design lifetime, accounting lifetime is an ex ante measure and not generally speaking a determinant of decisions on lifetime extension, and is therefore not considered further in this report.

## 2.4 Economic lifetime

Any piece of industrial plant is generally only kept in service as long as it is profitable. Once a piece of industrial plant such as a power plant is no longer profitable and there is little realistic prospect of it becoming profitable again, it will be retired. This is particularly relevant in the case of technologies in which progress is rapid, or when the costs of the existing technology or its potential replacements changes. For it to be economic to replace a piece of plant, the cost of building and operating its intended replacement must be less than the cost of continuing to operate the existing plant. For example, in the past, old coal-fired power plants were often retired because new coal-fired designs were available that were so much more thermally efficient than their predecessors that the cost savings from lower coal consumption would more than pay for the capital cost of the replacement. Changes in environmental regulations, may also help to justify the retirement and replacement of existing capacity. For example, in the 1990s combined cycle gas turbines had such low overall costs, because of low construction costs, low world gas market prices and high thermal efficiencies, that in some cases they were able economically to replace existing coal-fired capacity, helped by the fact that the cost of retrofitting environmental controls to the coal-fired plants was avoided (the environmental performance of the gas-fired plants being intrinsically superior). It should not be overlooked, however, that any unamortised capital costs of a plant that is retired and replaced will have to be met from the revenues of the replacement plant, in addition to its own capital costs.

## 2.5 Political lifetime

Major pieces of industrial plant may also be subject to considerations of political acceptability: if a process or product is no longer politically acceptable, the plant must be retired. This is clearly illustrated by countries with nuclear 'phase-out' policies where plants are retired because they no longer command public acceptance, even if the regulator is prepared to continue to license the plant. In some cases, the political forces are external; this was the case for Eastern European and former Soviet Union countries including Bulgaria, Lithuania, Slovakia and Ukraine, on which the West placed pressure to retire designs of nuclear power plant that it categorised as unsafe.

## 2.6 Physical lifetime

Many components in power plants are readily and quite cheaply replaceable, and plants all of whose major components can readily be replaced can be seen as effectively having an indefinite life-time. In practice, the lifetime of such plants will be determined by economic or regulatory factors. A simple analogy is 'your grandfather's axe', which had had three blades and four handles but was still the same axe. However, where there are components that it would clearly not be economically viable to replace – so-called life-limiting components – the plant's lifetime will be determined by the lifetime of those components. A simple analogy is a bicycle: failure of the frame means bicycle has to be scrapped. The older a plant gets, the lower its value tends to become once repaired, and the more likely it is that the replacement of a given component will turn out to be prohibitively expensive. For nuclear power plants, the most commonly quoted life-limiting component is the reactor vessel. If the integrity of the vessel can no longer be guaranteed, there is a risk of the core being exposed to the environment and the plant has to be retired.

This raises the issue of the consequences of failure of life-limiting components. If these are relatively small in terms of safety and environmental damage, it may be acceptable to run a plant until component failure, or at least to retire it only when the risk of failure becomes relatively high. However, if the consequences of component failure are serious, the plant will have to be retired as soon as there are significant doubts about the integrity of the component. For example, if there are any significant doubts about the integrity of a reactor pressure vessel, the plant will have to be retired. In practice, this means that the physical lifetime of a nuclear power plant is effectively equivalent the regulatory lifetime: if the regulator believes the risk of failure of a life-limiting safety-sensitive component is unacceptably high, the plant must be retired.

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[3] Deutsche Welle. 2012 German utilities demand compensation for nuclear exit. 13 June 2012.

[4] Nucleonics Week. 2011. In Belgian nuclear tax debate, PM hints at full life extension. 10 March 2011.

## 2.7 Regulatory lifetime

All major pieces of industrial plant are subject to health and safety regulation. Before a plant is commissioned the design should be approved by the regulatory authority to ensure that the basic design meets the required standard and construction has met the required quality control standards. Plants must also be regularly reviewed by the regulatory authorities to ensure that they are consistent with current regulations and that their physical condition is acceptable. Experience and changes in knowledge may mean that standards have to revised, almost invariably upwards, so that a design that was acceptable in the past may no longer be acceptable now. It is often said that regulatory standards for nuclear power plants have been raised, but this is misleading. The standards have remained largely constant, but what has changed is the knowledge of feasible events, such that designs that were thought to meet the required standards have been shown not to do so. For example, before the accident at the Three Mile Island power plant in Pennsylvania, USA, it was assumed that the simultaneous failure of two independent safety systems was so unlikely as to be effectively impossible. Three Mile Island proved that this was not the case, [5] so additional safety requirements had to be introduced.

There is variation between countries on the duration of the nuclear power plant licences. In the USA, nuclear plants were given a lifetime of 40 years by the Nuclear Regulatory Commission (NRC), at the end of which the licence must be renewed or the plant shut. At the other end of the spectrum, in the UK, once a nuclear plant has been licensed for operation, that licence remains in force only until the next major maintenance shutdown, usually about a year ahead, after which the regulator (the Office of Nuclear Regulation (ONR)[6]) must approve the restart. In France, nuclear power plants are subject to a 10-yearly review by the Autorité de Sûreté Nucléaire (ASN). In practice, the difference between these regimes is less than it appears at first glance. In the USA, the 40-year licence does not give the operator carte blanche to run the plant for 40 years, as it can be withdrawn at any time. For example, in 1987, the NRC found evidence of poor operating practice at the two-unit Peach Bottom site in Pennsylvania.[7] As a result the two reactors were closed for more than two years until the NRC was satisfied that the issues had been resolved. Severe reactor head degradation was found at the Davis-Besse power plant in Ohio and the plant was kept off-line for two years until repairs had been carried out to the NRC's satisfaction.[8]

The UK's 14 Advanced Gas-cooled Reactors (AGRs) were given a 20-year design lifetime. In 1996, when they approached the end of that period (the first two were commissioned in 1976), a review (the Periodic Safety Review (PSR)) of each plant was carried out in which the operator[9] had to convince the Nuclear Installations Inspectorate (NII, the predecessor to ONR) that, in principle, the plants would be able to be licensed for a further five years. That process of review had to be repeated every five years. In 2004, cracking in the graphite moderator core was identified. This was reported as serious enough to hand out a warning that the next PSR in 2006 might prevent the oldest plants reaching a 35 year lifetime.[10] However, the issue was resolved to the satisfaction of the NII and all 14 AGR reactors remained in service in 2013.

In 2012, the two oldest AGR plants had been given approval in principle to operate until 2016. However, the owner and operator, EDF, began discussions with the ONR about obtaining approval in principle to operate these plants until 2026, meaning that they would remain in operation for more than twice their original design lifetime.[11] The other five newer plants were all licensed until 2023, their 35th birthday. This date is often quoted as being the date when these plants will go off line. This is premature, however; the owners of British nuclear power plants have generally not sought lifetime extension until perhaps three to four years before the existing licensed lifetime expires, so there may well be an application for a further extension.

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[5] In fact what happened was that a safety system failure was not detected and became apparent only when a second failure occurred.

[6] Previously known as the Nuclear Installations Inspectorate (NII).

[7] The operators were found to have been routinely sleeping during their shift.

[8] Inside NRC. 2005. Seeking balance, NRC proposes $5.45-million fine for Davis-Besse. 2 May 2005.

[9] Then British Energy, since 2009 EdF

[10] Utility Week. 2004. British Energy warns of threat to asset life. 10 December 2004.

[11] Nucleonics Week. 2012. Hunterston B, Hinkley Point B in UK due safety review in 2015: ONR. 13 September 2012.

# 3 Experience of nuclear plant lifetimes

Some of the nuclear power plants that have so far been retired around the world were early designs that had been shown to have design problems. For example, four out of six of the first generation BWRs were retired around 1980 because their steam generators were causing serious problems. Experience of nuclear technology and of regulatory approval of new designs should mean that serious design errors are less likely now. However, such errors are still possible, particularly in the case of more radical new designs. For example, the N4 design developed by Framatome (predecessor of Areva, the French public-owned nuclear power corporation) for four reactors built in the 1990s in France contained a number of significant design errors that delayed commercial operation and necessitated significant design changes.

In practice, nuclear power plants may be retired for a combination of reasons; in the following tables the reason for retirement listed is the major one. For example, when a plant requires replacement of a major part that is not normally seen as life-limiting, the cost may nevertheless be such that the value of the repaired plant if it is near retirement would be less than the cost of the part replacement. Nuclear power plant retirements to date have been dominated by the USA, Germany, Eastern Europe and the countries of the former Soviet Union. By comparison, there have been relatively few retirements in the rest of the world. Some countries have adopted nuclear phase-out policies that were originally expected to lead to early retirement of some reactors, or at least to life-times not being extended beyond their original expected span. In practice, with the exception of Austria, phase-out policies have been subject to revision by later governments and have often been made less rigorous or even abandoned altogether (see Annex 2 for more details).

## 3.1 USA

In the USA (see Table 2.1), the dominant reason for plant retirement has been economic, particularly in the 1990s and again in 2013 – both times when the natural gas price was low, and nuclear power plants could be economically replaced by gas-fired plants. The NRC had actually given approval in principle for two of the five plants whose retirement was announced in 2013 to continue to operate for a total of 60 years. One study identifies 38 US reactors as being under threat of closure on economic grounds, with 12 under particular threat (see Annex 1).[12] This shows how quickly the outlook for an operating nuclear power plant can alter with changes in fossil fuel prices, the need for significant repairs and the need for significant safety upgrades. The larger the extent that nuclear plants are exposed to unpredictable wholesale electricity markets, the more economically vulnerable they become. The five plants whose retirement was announced in 2013 deserve further discussion as, while the fundamental issue was cost, there were important differences between them that illustrate the issues involved in lifetime extension.

| Reactor | Retirement date /Years in service | Unit size (MW) /Technology | Retirement reason |
|---|---|---|---|
| Dresden 1 | 1978/18 | 208/BWR | Design |
| Crystal River 3 | 2013/26 | 890/BWR | Economic/repair |
| Haddam Neck | 1996/28 | 603/PWR | Economic |
| Indian Point 1 | 1974/12 | 277/PWR | Design |
| Kewaunee | 2013/39 | 595/PWR | Economic |
| Maine Yankee | 1997/25 | 900/PWR | Economic |
| Millstone 1 | 1997/27 | 684/BWR | Economic |
| Rancho Seco | 1989/14 | 917/PWR | Economic |
| San Onofre 1 | 1992/24 | 436/PWR | Economic |
| San Onofre 2 | 2013/30 | 1,127/PWR | Economic/repair |
| San Onofre 3 | 2013/29 | 1,127/PWR | Economic/repair |
| Shoreham | 1986/0 | 849/BWR | Regulatory |
| Three Mile Island 2 | 1979/0 | 959/PWR | Accident |
| Trojan | 1992/16 | 1,155/PWR | Economic |
| Vermont Yankee | 2014/41 | 635/BWR | Economic |
| Yankee | 1991/30 | 180/PWR | Economic |
| Zion 1 | 1998/25 | 1,085/PWR | Economic |
| Zion 2 | 1998/24 | 1,085/PWR | Economic |

**Table 2.1** – Nuclear power plant retirements in the USA. Source: http://www.iaea.org/PRIS/

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[12] Cooper, M. 2013. Renaissance in reverse: competition pushes aging US nuclear reactors to the brink of economic abandonment. http://will.illinois.edu/nfs/RenaissanceinReverse7.18.2013.pdf

### 3.1.1 Crystal River 3

The Crystal River 3 plant was built by a Florida utility, Progressive Energy Florida (PEF), which was acquired by the much larger Duke Energy company in 2012.[13] The plant was commissioned in 1987 and was closed in 2009 for refuelling and maintenance, including replacement of the steam generators. Steam generator replacement is a major and costly operation expected to be carried out perhaps once or twice during the lifetime of a plant. However, during the replacement process, damage was done to the concrete walls of the containment building. Repairs were nearly complete in 2011 when further damage occurred, preventing the reactor's return to service. PEF announced three months later that it wanted to rebuild the containment building by 2014 at a cost of up to $1.3bn. However, the new owner, Duke Energy, took a different view and in February 2013 announced the retirement of the plant. The credit rating agency Fitch cited 'rising repair cost estimates, construction risks and the low gas price environment'[14] as justifying the decision. In short the plant was at risk both from uncertainty about its own costs and from the low cost of alternatives, especially natural gas. Crystal River is sited in a state where power prices are still regulated and a particular uncertainty concerned how far regulators would be prepared to allow Duke to recover the repair costs from consumers.

### 3.1.2 Kewaunee

The Kewaunee plant in Wisconsin was commissioned in 1974 and its present owners Dominion Power bought it in 2005. The reason for its closure was much more straightforwardly its operating costs, with no major issues of repairs or plant condition involved.[15] When Dominion bought the plant, wholesale electricity prices in the region were about $40–50/MWh, but by 2013 the low price of gas meant that this price had fallen to only $30/MWh. Kewaunee was a so-called 'merchant plant' – in other words, it had to compete to sell its power; and with gas prices as low as they were in 2013, this was no longer possible.

### 3.1.3 San Onofre 2 and 3

Units 2 and 3 of the San Onofre plant in California were completed in 1983 and 1984 respectively. They were built and are owned by Southern California Edison (SCE). The retirement of the San Onofre units was related to the cost of replacing the steam generators.[16] The plants had been closed in January 2012 after the discovery of tube wear in the steam generators, which had been replaced as recently as 2010 (Unit 2) and 2011 (Unit 3) at a cost of $602m. SCE claimed in November 2012 that it was safe to continue to operate the units at 70 per cent capacity, but by May 2013 it had been unable to convince the NRC of its case and the plant was shut down. SCE is now trying to recover the cost of the apparently inadequate replacement steam generators from the supplier, Mitsubishi and from its insurer, and also wants to pass any unrecovered costs on to consumers. The issue facing SCE is how far it will be able to recover both these costs and the replacement power costs from its consumers. California has a regulated energy market, and as of September 2013 there were doubts as to whether the regulator, the California Public Utilities Commission (CPUC), would allow these costs to be recovered.[17] By November 2013, it seemed likely that CPUC would rule that already calculated replacement power costs would have to be refunded to consumers.[18] The closure of the plant therefore seems to have been related more to concerns about the safety of the steam generators and the consecutive need to have them replaced, uncertainties about recovery of the repair costs and related future costs than to the cost of gas-fired alternatives.

### 3.1.4 Vermont Yankee

Vermont Yankee is one of the USA's oldest operating reactors, having entered service in 1972. In August 2013, its owner and operator Entergy announced that Vermont Yankee would close in the third quarter of 2014.[19] As discussed below, the company's application to life-extend the plant had been problematic, with permission being granted in 2011 after five years instead of the expected two. However, opposition to its operation at state level meant its future was in doubt even after the NRC had approved the lifetime extension, and especially in the wake of the Fukushima disaster, given that the oldest Fukushima reactor was of a similar design to Vermont Yankee's. Nevertheless, Entergy cited low natural gas prices, the high costs of operating a single-unit nuclear plant, and low wholesale electricity prices as the reasons for the closure.

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[13] For more details of the plant's retirement, see Nucleonics Week. 2013. Duke decision to retire Crystal River-3 positive, financial analysts say. 7 February 2013.

[14] Nucleonics Week. 2013. Duke decision to retire Crystal River-3 positive, financial analysts say. 7 February 2013.

[15] For more details of the plant's retirement, see Nucleonics Week. 2013. Dominion's Kewaunee nuclear plant shuts permanently. 9 May 2013.

[16] Nuclear Fuel. 2013. SCE decision to retire San Onofre came after delays in NRC action on restart. 10 June 2013.

[17] Nucleonics Week. 2013. Proposed CPUC decision would deny San Onofre cost recovery. 26 September 2013.

[18] Orange County Register. 2013. Edison to fight decision to refund $94 million in San Onofre costs. 23 November 2013.

[19] Nucleonics Week. 2013. Vermont Yankee closure seen boosting New England gas demand. 29 August 2013.

## 3.2 Germany

In Germany (see Table 2.2), the dominant reason for plant retirements has been the political decision to phase out nuclear power, first taken in 2002 (as a result of which two reactors were retired) and then reconfirmed in 2011 after the Fukushima disaster, whereupon a further eight reactors were retired. The remaining nine reactors will be progressively retired over the period from 2015 to 2022.

| Reactor | Retirement date /Years in service | Unit size (MW) /Technology | Retirement reason |
|---|---|---|---|
| Biblis A | 2011/36 | 1,225/PWR | Political |
| Biblis B | 2011/34 | 1,300/PWR | Political |
| Brunsbüttel | 2011/34 | 806/BWR | Political |
| Gundremmingen A | 1977/10 | 250/BWR | Design |
| Lingen | 1977/9 | 268/BWR | Design |
| Isar 1 | 2011/32 | 912/BWR | Political |
| Krümmel | 2011/27 | 1,402/BWR | Political |
| Mülheim-Kärlich | 1988/1 | 1,302/PWR | Regulatory |
| Neckarwestheim 1 | 2011/35 | 840/PWR | Political |
| Obrigheim | 2005/36 | 357/PWR | Political |
| Philippsburg 1 | 2011/31 | 926/BWR | Political |
| Stade | 2002/31 | 672/PWR | Political |
| Unterweser | 2011/32 | 1,410/PWR | Political |
| Würgassen | 1994/19 | 670/BWR | Design |

**Table 2.2** – Nuclear power plant retirements in Germany. Source: http://www.iaea.org/PRIS/

## 3.3 Eastern Europe and the former Soviet Union

In Eastern Europe and the former Soviet Union (Table 2.3), the dominant reason for plant retirement has been concerns about the safety of some Soviet technologies – especially the RBMK design used at the Chernobyl site, but also the first generation Soviet PWR, the VVER. A condition for entry into the European Union for Bulgaria, Slovakia and Lithuania was that plants using these suspect designs be retired. Russia's own regulatory process is not open and the reasons for retirement of plants are not publicly disclosed. The RBMK design uses graphite as a moderator, and if the integrity of the moderator cannot be assumed, safety issues emerge. During the 1990s Russia essentially rebuilt four reactors of the RBMK design at the Leningradskaya site near St. Petersburg, with shutdowns of about two years.[20] The plants were also upgraded to take account of the lessons from the Chernobyl disaster, and after a further 18 month shutdown to repair the graphite, the first unit at the site was returned to service in November 2013. The other three units are now expected to undergo similar repairs.[21] It has not been reported how long these reactors are expected to continue to operate. The six RBMKs built outside Russia, in Lithuania and at Chernobyl, have all been retired. Including the four at Leningradskaya, eleven RBMKs remain in service in Russia but these will not be considered further because the determinants of their lifetime are very different to those of PWRs and BWRs and because there is no reliable information on the standards the Russian authorities require these plants to meet.

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[20] Eastern European Energy Report. 1996. 'RBMKs produce the goods when it counts. April 1996.

[21] World Nuclear News. 2013. Restored RBMK back on line. 2 December 2013. http://www.world-nuclear-news.org/RS-Restored-RBMK-back-on-line-0212137.html

| Country | Reactor | Retirement date /Years in service | Unit size (MW) /Technology | Retirement reason |
|---|---|---|---|---|
| Armenia | Armenia 1 | 1989/12 | 408/PWR | Regulatory |
| Bulgaria | Kozloduy 1 | 2002/28 | 440/PWR | Political / design |
| Bulgaria | Kozloduy 2 | 2002/27 | 440/PWR | Political / design |
| Bulgaria | Kozloduy 3 | 2006/15 | 440/PWR | Political / design |
| Bulgaria | Kozloduy 4 | 2006/14 | 440/PWR | Political / design |
| E Germany | Greifswald 1 | 1990/16 | 440/PWR | Political / design |
| E Germany | Greifswald 2 | 1990/15 | 440/PWR | Political / design |
| E Germany | Greifswald 3 | 1990/12 | 440/PWR | Political / design |
| E Germany | Greifswald 4 | 1990/11 | 440/PWR | Political / design |
| E Germany | Greifswald 5 | 1990/0 | 440/PWR | Political / design |
| Lithuania | Ignalina 1 | 2004/19 | 1,500/RBMK | Political / design |
| Lithuania | Ignalina 2 | 2009/12 | 1,500/RBMK | Political / design |
| Russia | Novovoronezh 1 | 1988/24 | 210/PWR | ? |
| Russia | Novovoronezh 1 | 1990/20 | 365/PWR | ? |
| Slovakia | Bohunice 1 | 2006/26 | 440/PWR | Political / design |
| Slovakia | Bohunice 2 | 2008/27 | 440/PWR | Political / design |
| Ukraine | Chernobyl 1 | 1998/17 | 1,000/RBMK | Political / design |
| Ukraine | Chernobyl 2 | 1991/12 | 1,000/RBMK | Political / design |
| Ukraine | Chernobyl 3 | 2000/18 | 1,000/RBMK | Political / design |
| Ukraine | Chernobyl 4 | 1986/12 | 1,000/RBMK | Accident |

**Table 2.3** – Nuclear power plant retirements in the Eastern Europe and the former Soviet Union. Source: http://www.iaea.org/PRIS/

## 3.4 Rest of the world

In the rest of the world (Table 2.4), there has been a mixture of reasons for retirement. The gas-cooled reactors (GCRs) using carbon dioxide as a coolant and graphite as a moderator (installed in the UK, France, Italy, Spain[22] and Japan) were very expensive to operate and all except those in the UK have now been retired. In the UK, all reactors of the first-generation Magnox design have been closed except for one, expected to close in 2015; but all seven plants using the second-generation UK design, the Advanced Gas-cooled Reactor (AGR), remained in service in 2013. For graphite moderated reactors, the main life-limiting component is the graphite moderator framework which thins and distorts with exposure to heat and radiation. The GCRs are not considered further in this report because the determinants of their lifetime are different to those for PWRs and BWRs.

In the Canadian-designed Pressurised Heavy Water Reactors (CANDUs), the fuel is contained in a large number of pressure tubes rather than in a single pressure vessel. Up until 1987, it was assumed that these pressure tubes would leak before breaking so that there would be ample warning of a pressure tube rupture, and tube failure was therefore not seen as a serious safety issue. This assumption was then proved false when it was discovered that rupture could occur unpredictably. Since then, once the integrity of these pressure tubes can no longer be assumed (expected to be after 20–25 years), they must be replaced in a major repair. For three reactors, the cost of this was seen as unjustifiable and they were therefore retired. The special issue of the integrity of the pressure tubes means that the decision-making for CANDUs is somewhat different to that for PWRs and BWRs, and accordingly CANDUs are not considered further in this report.

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[22] The Spanish GCR had to be retired partly because its fuel was reprocessed in France and France was closing the reprocessing plant.

| Country | Unit | Retirement date /Years in service | Unit or plant Size (MW) /Technology | Retirement reason |
|---|---|---|---|---|
| Canada | Gentilly 2 | 2012/29 | 675/PHWR | Technical/economic |
| Canada | Pickering 2 | 1997/26 | 542/PHWR | Technical/economic |
| Canada | Pickering 3 | 1997/26 | 542/PHWR | Technical/economic |
| France | Bugey 1 | 1994/22 | 555/GCR | Economic |
| France | Chinon A2 | 1985/20 | 240/GCR | Economic |
| France | Chinon A3 | 1990/24 | 480/GCR | Economic |
| France | Chooz A | 1991/24 | 320/PWR | Economic |
| France | St Laurent A1 | 1990/21 | 500/GCR | Economic |
| France | St Laurent A2 | 1992/21 | 530/GCR | Economic |
| Italy | Caorso | 1987/6 | 882/BWR | Political |
| Italy | Garigliano | 1978/15 | 160/BWR | Technical |
| Italy | Latina | 1987/24 | 160/GCR | Political |
| Italy | Trino Vercellese | 1987/22 | 270/PWR | Political |
| Japan | Fukushima Daiichi 1 | 2011/41 | 460/BWR | Accident |
| Japan | Fukushima Daiichi 2 | 2011/38 | 784/BWR | Accident |
| Japan | Fukushima Daiichi 3 | 2011/37 | 784/BWR | Accident |
| Japan | Fukushima Daiichi 4 | 2011/33 | 784/BWR | Accident |
| Japan | Hamaoka 1 | 2009/35 | 540/BWR | Design |
| Japan | Hamaoka 2 | 2009/31 | 840/BWR | Design |
| Japan | Tokai 1 | 1998/32 | 166/GCR | Lifetime |
| Spain | Jose Cabrera | 2006/37 | 150/PWR | Lifetime |
| Spain | Vandellos | 1990/18 | 500/GCR | Technical/economic |
| Sweden | Barsebaeck 1 | 1999/24 | 615/BWR | Political |
| Sweden | Barsebaeck 2 | 2005/28 | 615/BWR | Political |
| UK | Berkeley | 1989/27 | 332/GCR | Technical/economic |
| UK | Bradwell | 2002/40 | 292/GCR | Technical/economic |
| UK | Dungeness A | 2006/40 | 460/GCR | Technical/economic |
| UK | Hinkley Point A | 2000/35 | 534/GCR | Technical/economic |
| UK | Hunterston A | 1990/26 | 346/GCR | Technical/economic |
| UK | Oldbury | 2012/45 | 460/GCR | Technical/economic |
| UK | Sizewell A | 2006/40 | 490/GCR | Technical/economic |
| UK | Wylfa | 2012/40 | 545/GCR | Technical/economic |

**Table 2.4** – Nuclear power plant retirements in the rest of the world. Source: http://www.iaea.org/PRIS/

Note: The UK plants are all made up of pairs of interdependent reactors. The Wylfa plant still had one of its two reactors operational at the end of 2013.

Following a 1987 referendum Italy took the decision to close its nuclear plants, and although there were attempts by Prime Minister Silvio Berlusconi to reverse this decision, it was confirmed by a second referendum in 2011. A phase-out decision taken in 1980 in Sweden under a referendum led to only two out of 12 of the country's reactors being shut down before the policy was abandoned in 2010. Similarly, a phase-out promise made in 2004 by the Spanish government has led to the closure of only one of the remaining nine units, a very small, old reactor.

In Japan, there is considerable uncertainty about how many reactors will restart after the Fukushima disaster. Two units (Hamaoka) had been closed in 2009 as a result of concerns about their ability to withstand earthquakes, following damage to plants at another site as a result of a magnitude 6.6 earthquake in 2007. Only the four reactors at the Fukushima Daiichi site catastrophically damaged by the 2011 earthquake and tsunami have been definitively retired since the disaster. However, in September 2013, only one of the 50 reactors nominally in service was actually operating and it is unclear how many of these 50 will be returned to long-term service.[23]

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[23] Nucleonics Week. 2013. Ohi-3 shuts for outage; unit 4 Japan's only reactor online. 5 September 2013.

## 4 The impetus for lifetime extension programmes

Until the last decade, nuclear power plants had an expected lifetime of 40 years or less. As the first wave of commercial nuclear power plants did not enter service until the mid-1960s, plant retirements were few and generally driven by either economic factors, design issues or political factors. Table 2.5 shows that for most countries dealing with retirement is still not a major issue. Nearly half (14) of the 31 countries operating nuclear power plants have no reactors aged 35 or older.

| Country | Number 35 years or older | Technologies | Total number in service (under construction) |
|---|---|---|---|
| Argentina | 1 | PHWR | 2 (1) |
| Armenia | | | 1 |
| Belgium | 3 | PWR | 7 |
| Brazil | | | 2 (1) |
| Bulgaria | | | 2 |
| Canada | 6 | PHWR | 19 |
| China | | | 18 (30) |
| Czech Republic | | | 6 |
| Finland | 2 | PWR, BWR | 4 (1) |
| France | 4 | PWR | 58 (1) |
| Germany | | | 9 |
| Hungary | | | 4 |
| India | 3 | BWR (2), PHWR | 21 (6) |
| Iran | | | 1 |
| Japan | 12 | BWR (4), PWR (8) | 50 (2) |
| South Korea | 1 | PWR | 23 (5) |
| Mexico | | | |
| Netherlands | 1 | PWR | 1 |
| Pakistan | 1 | PHWR | 3 (2) |
| Romania | | | 2 |
| Russia | 7 | PWR (4), RBMK (3) | 28 (6) |
| Slovakia | | | 4 (2) |
| Slovenia | | | 1 |
| South Africa | | | 2 |
| Spain | 1 | BWR | 8 |
| Sweden | 4 | BWR (3), PWR (1) | 10 |
| Switzerland | 3 | BWR (1), PWR (2) | 5 |
| Taiwan | 2 | BWR | 6 (2) |
| Ukraine | | | 15 (2) |
| UK | 2 | GCR | 8 |
| USA | 52 | BWR (20), PWR (32) | 100 (3) |

**Table 2.5** – Reactor stock worldwide in 2013. Source: http://www.iaea.org/PRIS/

Countries with more than 40 per cent of their reactors in service or under construction aged 35 or older, that use PWRs or BWRs and that have three or more reactors aged over 35 (see Table 2.5) include Belgium, Sweden, Switzerland and the USA. The first three of these countries have or have had nuclear phase-out policies, which if carried through would mean that the issue of lifetime extension would have limited relevance.

The USA is by far the most advanced country in terms of its progress towards lifetime extension: the majority of its reactors have been given approval by the NRC to operate for at least 60 years as opposed to the 40-year life for which they were originally licensed. However, this was done before the Fukushima disaster and, as has been demonstrated by the retirements in 2013, the existence of permission to extend a reactor's lifetime to 60 years is far from a guarantee that it will actually operate for this long.

While France appears to have less need to consider lifetime extension as yet, the scale and speed of the French nuclear power programme from 1977 to 1992 means that the issue is already of importance for planning. Of the 58 reactors in service in 2013, 23 were commissioned in the period 1977–82 (see Table 2.6), representing more than 20GW of capacity. If France was to replace all this capacity with the latest French design, the European Pressurised Water Reactor (EPR), this would require at least 13 new reactors. If we assume that the cost per reactor would be the same as that agreed by the UK government for its Hinkley Point B EPR, €9.5bn[24], and the existing reactors were replaced at age 40, the investment needed before 2022 would be in excess of €120bn in present-day terms, a sum that would be difficult for France to finance. To put this figure in perspective, it represents about double the annual turnover of the entire global EDF group.

However, President François Hollande was elected on a promise to reduce the nuclear contribution to France's electricity from 75 per cent to 50 per cent, and has promised to close the two oldest reactors, at Fessenheim, by the end of 2016. Moreover, the ASN is requiring an expensive range of upgrades to take account of the lessons from the Fukushima disaster, making lifetime extension less attractive. The French case is therefore complex and highly uncertain.

| Period | Reactors entering service |
|---|---|
| 1977–82 | 23 |
| 1983–87 | 23 |
| 1988–92 | 7 |
| 1993–99 | 5 |

**Table 2.6** – Service entry dates for France's reactors. Source: http://www.iaea.org/PRIS/

## 5 Regulatory objectives

There are two regulatory standards of relevance to nuclear power: the principle that risk should be 'as low as reasonably achievable' (ALARA) and the principle that the 'best available technology/technique(s)' (BAT) should be used. The NRC defines ALARA as making every reasonable effort to maintain exposures to ionizing radiation as far below the dose limits as practical, consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest.[25]

In general terms, BAT is seen as the means of achieving the ALARA standard. EC Directive 96/61[26] defines it as the most effective and advanced stage in the development of activities and their methods of operation which indicates the practicable suitability of particular techniques for providing the basis for emission limit values designed to prevent, and where that is not practicable, generally to reduce the emissions and the impact on the environment as a whole.

Other related concepts include 'best practicable means' (BPM) and 'best practicable environmental option' (BPEO). The issue of cost and proportionality is covered by the related concept of 'best available technology/technique not entailing excessive cost' (BATNEEC).

There can be semantic discussions about the definitions of 'best', 'practicable', 'available' and 'excessive'. In practice, however, it does not seem plausible that for a technology as complex and as yet still not fully proven as nuclear power a 'best' option can be identified with confidence.

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[24] Financial Times, 2013, UK agrees nuclear power deal with EDF, 21 October, 2013

[25] http://www.nrc.gov/reading-rm/basic-ref/glossary/alara.html

[26] http://adlib.everysite.co.uk/adlib/defra/content.aspx?id=000HK277ZW.0A5QFJHNYYMI5Z

For the purposes of lifetime extension, it is clear that the technologies under consideration are far short of the standards that would be required for a reactor planned today. By definition, all were designed before the Browns Ferry accident of 1975 and can take only limited account of the lessons learnt there, much less the lessons from the Three Mile Island (1979) accident and the Chernobyl (1986) and Fukushima (2011) disasters. The Browns Ferry accident occurred when a fire in a cable tray disabled the control systems for all three reactors on the site and led to the recognition of the need for a much greater degree of independence of the reactors on a multi-unit site. The first reactors designed post-Chernobyl have yet to enter service, while it is clear that the lessons to be learnt from Fukushima are only now beginning to emerge and that it will be decades before they are fully embodied in the available reactor designs.

Many of these design lessons cannot be applied to existing reactors. For example, the Chernobyl disaster led to a requirement in some jurisdictions that 'core-catchers' be installed to prevent the core burning down into the environment in the event of a reactor vessel failure. Similarly the 9/11 terrorist attack led to a requirement that reactor containments should be able to stand up to impact from a full size civil aircraft. It is clear that neither of these requirements could be met in existing reactors, and that the BAT standard cannot therefore be met. So the decision to life-extend inevitably means giving what is essentially a new life of perhaps 20 years to a facility that falls far short of current best practice. Regulators must therefore judge how far short of current standards it is acceptable for facilities to fall.

## 6 Lifetime extension in France

The French licensing process is based on unlimited-time licences with reviews typically every 10 years, so the process of lifetime extension differs from that applied in the USA, where there are time-limited licences. However, the ASN[27] has said that it can give an indicative permission for 20-year operation extension based on a strong safety case. The ASN is advised in these matters by the Institut de Radioprotection et de Sûreté Nucléaire (IRSN).

| Site and reactors | Unit size (MW) | First grid connection |
|---|---|---|
| Fessenheim 1, 2 | 2×920 | 4/77, 10/77 |
| Bugey 2, 3, 4, 5 | 2×945, 2×917 | 5/78, 9/78, 3/79, 7/79 |
| Gravelines 1, 2, 3, 4, 5, 6 | 5×951, 1×937 | 3/80, 8/80, 2/81, 6/81, 8/84, 8/85 |
| Dampierre 1, 2, 3, 4 | 4×937 | 3/80, 12/80, 1/81, 8/81 |
| Tricastin 1, 2, 3, 4 | 4×955 | 5/80, 8/80, 2/81, 6/81 |
| St Laurent B 1, 2 | 2×956 | 1/81, 6/81 |
| Blayais 1, 2, 3, 4 | 4×951 | 6/81, 7/82, 8/83, 5/83 |
| Chinon B 1, 2, 3, 4 | 4×954 | 11/82, 11/83, 10/86, 11/87 |
| Cruas 1, 2, 3, 4 | 4×956 | 4/83, 9/84, 5/84, 10/84 |
| Paluel 1, 2, 3, 4 | 4×1,382 | 6/84, 9/84, 9/85, 4/86 |
| St Alban 1, 2 | 2×1,381 | 8/85, 7/86 |
| Flamanville 1, 2 | 2×1,382 | 12/85, 7/86 |
| Cattenom 1, 2, 3, 4 | 4×1,362 | 11/86, 9/87, 7/90, 5/91 |
| Belleville 1, 2 | 2×1,363 | 10/87, 7/88 |
| Nogent 1, 2 | 2 x 1,363 | 10/87, 12/88 |
| Penly 1, 2 | 2 x 1,382 | 5/90,2/92 |
| Golfech 1, 2 | 2×1,363 | 6/90, 6/93 |
| Chooz B 1, 2 | 2×1,560 | 8/96, 4/97 |
| Civaux 1, 2 | 2×1,561 | 12/97, 12/99 |

**Table 2.7** – France's operating nuclear reactors. Source: http://www.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=FR

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[27] The French nuclear safety regulator Autorité de Sûreté Nucléaire (ASN) was previously known as the Service Central de Sûreté des Installations Nucléaires (SCSIN) until 1991, the Direction de la Sûreté des Installations Nucléaires (DSIN) until 2002, then the Direction Générale de la Sûreté Nucléaire et de la Radioprotection (DGSNR) until 2006, when it became the ASN.

The ASN carries out reviews of each reactor in France (see Table 2.7) at the tenth maintenance outage (usually after about 10 years) to determine in principle what measures are needed for the plant to to be allowed to operate for a further 10 years. This review is known as the Periodic Safety Review (PSR). The outage is typically extended while the studies required are carried out. Because of the high level of standardisation of the French reactors, the process is in theory more easily manageable than it would be in, say, the USA, where there are a large number of different designs. Many of the issues identified are ‘generic’ to a whole class of reactors.

The first 10 year safety reviews for the 900 MW class reactors were completed only in 2002, 15 years after the last reactor of this type entered service. (There were three generations of 900 MW reactor designs, the six first reactors being designated CP0 and the other 28 being divided between the CP1 and CP2 designs.)

The safety regulator identified a number of areas where the reactors fell short of their design bases. For example, an error in the original calculations of the seismic resistance of boric acid tanks was discovered, requiring the retrofitting of a metallic belt around each tank that holds it to the floor with 80 tie-rods. Improvements were also made, including the qualification of plant equipment to lower temperatures than the -15°C for which the CP0 units were originally designed. Additional heat sources were installed and changes made to buildings so that the plants could resist temperatures down to -38°C for six hours, and -29°C for seven days. The whole process took much longer than expected and was thus completed five years after the next round of 10 year inspections of the CP0 reactors was due to start.[28]

For the 20th-year PSRs for the twenty 1,300 MW reactors and the 30th year PSRs for the 900 MW reactors, the regulator required that the calculations of the nuclear plants’ seismic resistance be redone, potentially leading to the need for further retrofits in some cases.[29] It is not clear how many reactors were retrofitted but the total cost was estimated to be €1.9bn, of which €1.2bn was accounted for by the six CP0 units.[30] By 2006, the two Fessenheim CP0 units were being identified as ‘lagging behind’ the other French reactors in the field of ‘operational discipline’.[31] Despite this, in 2011 Fessenheim received approval to operate up to 40 years, taking it to 2019.[32]

In 2010, Tricastin 1 was the first 900 MW reactor to receive clearance to operate up to 40 years. This process required rigorous checks on its reactor pressure vessel, which was known to have been affected by cracking that had earlier led to suggestions that its lifetime would be extended only to 35 years instead of 40 years.[33] Generic approval for the 900 MW reactors to operate up to 40 years had already been given that year, although each reactor had to be given specific approval to continue to operate.

The Fukushima disaster led to a major re-evaluation of the safety of reactors in Europe under the auspices of the European Union ‘stress tests’. These appear to have been more rigorously carried out in France than in most other countries.[34] The ASN suspended the process of reviewing reactors for operation past 40 years while this re-evaluation was ongoing. The IRSN reported in its November 2011 recommendations to the ASN that several reactors had departures from their design bases that needed immediate action. The Bugey, Civaux and Fessenheim sites were identified as having inadequate seismic protection, while Fessenheim, Tricastin, Cruas, Chinon and Saint Laurent needed flood protection upgrades.[35]

In January 2012, the ASN submitted its report on the stress tests to the French energy minister. This called for a range of upgrades at French nuclear sites, expected to take until beyond 2020 to implement. These included bunkered diesel generators and control rooms expected to cost many billions of euros, according to ASN Chairman André-Claude Lacoste. However, EDF CEO Henri Proglio was less pessimistic on cost, claiming that the modifications required in the light of Fukushima could be done for less than €10bn over 10 years, bringing the utility’s total planned investment in its operating fleet over the next 30 years to about €50bn.[36]

In November 2012, President Hollande confirmed the closure of Fessenheim in 2016, three years before its approval to operate up to 40 years runs out.[37] Despite this, EDF has been carrying out lifetime extension modifications and improvements to allow the plant to operate up to 40 years.[38]

As of December 2013, the current status of the PSR process, particularly the earlier mentioned review to tentatively extend the lifetime of plants by up to 20 years, was unclear.

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[28] Inside NRC. 2002. Conformance checks on French reactors seen as key to improvement. 15 July 2002.

[29] Inside NRC. 2003. DGSNR’S judgment on seismic issues sends EDF back to drawing board. 16 June 2003.

[30] Nucleonics Week. 2007. French critics raise quake fears, but rules said already tightened. 19 July 2007

[31] Inside NRC. 2007. NEA regulators challenged to devise shutdown criteria for old plants. 25 June 2007.

[32] Nucleonics Week. 2011. Fessenheim-1 safe for 40 years, with conditions, ASN says. 7 July 2011.

[33] Inside NRC. 2010. French regulator approves 40-year operation for Tricastin-1. 6 December 2010.

[34] Peer reviews of the stress test under the auspices of the European Nuclear Safety Regulators Group ranked France’s stress tests as one of the best five in Europe. Inside NRC. 2012. European reactors need tougher rules, Ensreg reviewers say. 7 May 2012.

[35] Inside *NRC*. 2011. French nuclear sites ‘not dangerous’ but need safety fixes: IRSN. 21 November 2011.

[36] Nucleonics Week. 2012. Government, industry to determine schedule of French safety upgrades. 5 January 2012.

[37] Nuclear News. 2012. Hollande: Fessenheim plant to close by end of 2016. November 2012.

[38] Nucleonics Week. 2013. EDF will make Fessenheim-2 modifications. 2 May 2013.

# 7 Lifetime extension in the USA[39]

The USA has both the largest and the oldest stock of reactors in the world. It also has a more open safety regulatory process than elsewhere, with much more information being publicly available. It is therefore not surprising that consideration of lifetime extension began there long before it did in other countries. The diversity of the reactor stock, with four reactor vendors each with several different basic reactor designs, often customised for a particular site, means that the review process is much more complex than in, say, France where there are essentially only three designs, all PWRs, only one of which (the 900 MW design) has reactors which are within 10 years of their 40th birthday.

The NRC makes clear that the decision to grant nuclear power plants a 40-year lifetime was based not on any assessment of the likely operating life of reactors, but on economic and anti-trust considerations. NRC dates its work on lifetime extension to a 1982 workshop it ran which concluded that extension was likely to be feasible. After consultations and pilot projects, a new regulation was introduced in 1995 allowing nuclear plant licences to be renewed for up to 20 years on top of the original 40 years.

The main features of the renewal procedure are as follows:

- The process from application to decision is expected to take 30 months.
- Applications can be made any time up to 20 years before the expiry of the existing licence.
- A plant for which a renewal application has been made more than five years before expiry of the existing licence can continue in operation until a decision is made, if a decision has not yet been made at time of licence expiry.
- A plant for which a renewal application has been made less than five years before expiry of the existing licence cannot continue in operation if a decision has not been made at time of license expiry.

The process involves two parallel review streams: one reviewing safety issues and one environmental issues. The standard the plant must achieve is the ‘licensing basis’, consisting of a set of standards that evolves as experience and knowledge grow. This suggests that an ALARA approach is being followed. Lifetime extension does not therefore preclude the plant owner being required to carry out safety upgrades after an extension has been given. In addition, the NRC carries out inspections to verify the information in applications, and schedules public meetings where the application can be questioned.

Tables 2.8 and 2.9 show progress to date. With one exception (Arkansas) multi-unit sites are dealt with under one application even where different designs are involved and, in one case (Millstone) where more than one vendor is involved. By December 2013, only one plant (Oyster Creek) had submitted a lifetime extension application within five years of expiry of its existing licence and a significant number had been operating for less than 25 years when they applied for a lifetime extension. None of those plants which have not yet applied for a lifetime extension has been operating for more than 30 years.

Of the 45 lifetime extensions granted by December 2013, only seven were granted after the Fukushima disaster and none since May 2012. It is unclear how far this reflects more stringent reviews post-Fukushima and how far it reflects the fact that relatively few applications remain to be made, and that some of these were seen as problematic before Fukushima. There has been no specific statement from NRC that it is reviewing its requirements and making them more stringent.

Up to mid-2005, nearly all extension applications were decided successfully within, or within a few months of, the target of 30 months. Since then, seven applications have taken more than a year longer than the target time: Diablo Canyon (49 months), Oyster Creek (45 months), Pilgrim (76 months), Vermont Yankee (65 months), Indian Point (incomplete in December 2013 after 80 months), Crystal River (closed on economic grounds before the application was decided) and Seabrook (incomplete in December 2013 after 42 months). With exception of Diablo Canyon (California), all these plants are sited in the north-east of USA.

Oyster Creek’s application was particularly contentious because it was, by then, the oldest operating reactor in the USA, and indeed the first commercial (unsubsidised) nuclear power plant ordered in the USA.[40] Despite the granting of an extension until 2030, its owners announced in 2010 that the plant would close no later than 2019 due to low electricity market prices and high operating costs. To maintain the reactor in service beyond 2019 would have required new cooling towers at an estimated cost of $800m.[41]

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[39] Unless otherwise stated, this material is drawn from http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-reactor-license-renewal.html

[40] Inside NRC. 2009. Oyster Creek receives renewed license. 13 April 2009.

[41] Nuclear Engineering International. 2012. Editor’s view – Comment – A write-off. December 2012.

The extension process for the Pilgrim plant, of a very similar design to that at Oyster Creek (Mark 1 BWR), was even lengthier; as with Oyster Creek, NRC Chair Gregory Jaczko expressed dissatisfaction with the application, in this case voting against it. Vermont Yankee, also a Mark 1 BWR, saw a lengthy and strongly contested application process before it was given a lifetime extension in March 2011.[42] Vermont is the only US state that claims the right to overrule nuclear licensing decisions of the Federal authorities, and there was speculation that the plant would be closed on those grounds at its 40th birthday in 2012. However, while this did not happen, its closure was announced in 2013 on economic grounds.[43]

Indian Point involves a completely different design to Oyster Creek (both its reactors being large Westinghouse PWRs), but the reactors have often been problematic: they are unreliable (lifetime load factor about 70 per cent) and have given rise to regulatory issues. As with Vermont Yankee, the state authorities (New York) oppose its continued operation. The plant can continue in operation even though the first unit has passed its 40th birthday because its still unresolved extension application was made while there was still five years of operating licence left. For Seabrook, extension is not expected to be granted before September 2014.[44]

In August 2012, the NRC voted to impose a moratorium on new and extended operating licences until there was a new decision on siting of a high-level waste repository, following the Obama administration's decision to abandon the Yucca Mountain site in Nevada. However, the review process is continuing.[45]

## 7.1 Impact of Fukushima

The French requirement to upgrade plants in response to Fukushima does not appear to have been matched by the level of upgrades called for in the USA. A Platts' survey of the cost of upgrades found that US utilities expected to spend about $3.6bn over the next three to five years on mandated upgrades for the in June 2013 103 operating reactors.[46] This compares to a cost of about €10bn for France's 58 operating reactors, none of which are BWRs, the design installed at Fukushima. Because of the diversity of the siting situations and the variety of designs in the USA, the requirements are difficult to summarise, but they include upgrades to spent fuel pools, seismic and flooding re-evaluations and improvements of regional emergency response centres. In the case of BWRs, the costs of required upgrading of containment vent systems are included as well.

## 7.2 Costs of lifetime extension in the USA

Despite the greater openness of the US regulatory process, as with France published data on the costs of lifetime extension in the USA are sparse. One additional cost must be enhanced maintenance. If a piece of equipment is being maintained for a short period, the maintenance required will tend to be less extensive than if a much longer life is expected. There is also the cost of pursuing the application. However, the most uncertain cost and potentially the largest is the cost of any upgrades, replacements or repairs required. At the same time, plant upgrades undertaken on economic grounds, such as upgrades to the turbine boosting output, will be much more likely to be justifiable if the remaining life of the plant is decades rather than just a few years. So the cost of upgrades required purely to satisfy regulatory needs can be very difficult to separate from other concurrent upgrade costs.

In 1999, when the US lifetime extension process was only in its early years, a survey by the Nuclear Energy Institute revealed that utilities expected to pay $10–50/kW for lifetime-extension provided that no major capital expenditure was required. In other words, this represented the cost of the analyses provided to the NRC and the cost of consultations with the NRC and the public. Even at a time when the nuclear industry was claiming that new nuclear capacity could be built for only $1,000/kW (compared with estimates in 2013 of about six to eight times that much), this still appeared a remarkably cheap option.[47] With natural gas prices high enough not to represent an economic threat to existing nuclear power plants – the figure of $1,000/kW for a new nuclear power plant was said to mean that new nuclear plants would be competitive with new gas-fired plants – lifetime extension was expected to be the rule. In 2007 Entergy claimed that lifetime extension costs, implicitly the costs of the process excluding upgrades, were about $10-20m.[48]

Few utilities have published the costs of the repairs and upgrades required for lifetime extension, but those that have done so have revealed costs far higher than these estimates. The Omaha Public Power District published costs of a major maintenance and repair outage connected with the lifetime extension of its Fort Calhoun reactor. This outage included the replacement of the steam generators, the vessel head, the pressuriser, the low-pressure turbines, and the main output transformer at a cost of $417m or about $850/kW.[49]

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[42] Inside NRC. 2011. Vermont Yankee receives 20-year license renewal. 28 March 2011.

[43] Nucleonics Week. 2013. Financial issues prompted Entergy to shut Vermont Yankee: executive. 29 August 2013.

[44] Inside NRC. 2013. NRC issues draft EIS for Seabrook license renewal. 20 May 2013.

[45] Nucleonics Week. 2012. No final licensing votes until waste rule resolved: commissioners. 9 August 2012.

[46] Nucleonics Week. 2013. Post-Fukushima modifications could cost US nuclear operators $3.6 billion. 6 June 2013.

[47] Nuclear Engineering International. 1999. US nuclear power: can competition give it a renewed life? June 1999.

[48] Nucleonics Week. 2007. Experts say planning, care needed for long nuclear unit lives. 25 October 2007.

[49] Nuclear News. 2007. Fort Calhoun's 'big outage'. April 2007.

| Plant | First grid connection | Lifetime extension applied for | Lifetime extension granted |
|---|---|---|---|
| Calvert Cliffs 1, 2 | 1/75, 12/75 | 4/98 | 3/00 |
| Oconee 1, 2, 3 | 5/73, 12/73, 9/74 | 7/98 | 5/00 |
| Arkansas 1 | 8/74 | 2/00 | 6/01 |
| Hatch 1, 2 | 11/74, 9/78 | 3/00 | 1/02 |
| Turkey Point 3, 4 | 11/72, 6/73 | 9/00 | 6/02 |
| Surry 1, 2 | 7/72, 3/73 | 5/01 | 3/03 |
| North Anna 1, 2 | 4/78, 8/80 | 5/01 | 3/03 |
| McGuire 1, 2 | 9/81, 5/83 | 6/01 | 12/03 |
| Catawba 1, 2 | 1/85, 5/86 | 6/01 | 12/03 |
| Peach Bottom 2, 3 | 2/74, 9/74 | 7/01 | 5/03 |
| St Lucie 1, 2 | 5/76, 6/83 | 11/01 | 10/03 |
| Fort Calhoun | 8/73 | 1/02 | 11/03 |
| Robinson 2 | 9/70 | 6/02 | 4/04 |
| Ginna | 12/69 | 8/02 | 5/04 |
| Summer | 11/82 | 8/02 | 4/04 |
| Dresden 2, 3 | 4/70, 7/71 | 1/03 | 10/04 |
| Quad Cities 1, 2 | 4/72, 5/73 | 1/03 | 10/04 |
| Farley 1, 2 | 8/77, 5/81 | 9/03 | 5/05 |
| Arkansas 2 | 12/78 | 10/03 | 6/05 |
| Cook 1, 2 | 2/75, 3/78 | 11/03 | 8/05 |
| Browns Ferry 1, 2, 3 | 10/73, 8/74, 9/76 | 1/04 | 5/05 |
| Millstone 2, 3† | 11/75, 2/86 | 1/04 | 11/05 |
| Point Beach 1, 2 | 11/70, 8/72 | 2/04 | 12/05 |
| Nine Mile Point 1, 2† | 11/69, 8/87 | 5/04 | 10/06 |
| Brunswick 1, 2 | 12/76, 4/75 | 10/04 | 6/06 |
| Monticello | 3/71 | 3/05 | 11/06 |
| Palisades | 12/71 | 3/05 | 1/07 |
| Oyster Creek | 9/69 | 7/05 | 4/09 |
| Pilgrim | 7/72 | 1/06 | 5/12 |
| Vermont Yankee* | 9/72 | 1/06 | 6/11 |
| Fitzpatrick | 2/75 | 8/06 | 9/08 |
| Susquehanna 1, 2 | 11/82, 7/84 | 9/06 | 11/09 |
| Wolf Creek | 6/85 | 10/06 | 11/08 |
| Shearon Harris | 1/87 | 11/06 | 12/08 |
| Indian Point 2, 3 | 6/73, 4/76 | 4/07 | - |
| Vogtle 1, 2 | 3/87, 4/89 | 6/07 | 6/09 |
| Beaver Valley 1, 2 | 6/76, 8/87 | 8/07 | 11/09 |
| Three Mile Island 1 | 6/74 | 1/08 | 10/09 |

| | | | |
|---|---|---|---|
| Prairie Island 1, 2 | 12/73, 12/74 | 4/08 | 6/11 |
| Kewaunee* | 4/74 | 8/08 | 2/11 |
| Cooper | 5/74 | 9/08 | 11/10 |
| Duane Arnold | 5/74 | 10/08 | 12/10 |
| Palo Verde 1, 2, 3 | 6/85, 5/86, 11/87 | 12/08 | 4/11 |
| Crystal River 3* | 1/77 | 12/08 | - |
| Hope Creek | 8/86 | 8/09 | 7/11 |
| Salem 1, 2 | 12/76, 6/81 | 8/09 | 6/11 |
| Diablo Canyon 1, 2 | 11/84, 10/85 | 11/09 | - |
| Columbia | 5/84 | 1/10 | 5/12 |
| Seabrook | 5/90 | 6/10 | - |
| Davis Besse | 8/77 | 8/10 | - |
| South Texas 1, 2 | 3/88, 4/89 | 10/10 | - |
| Limerick 1, 2 | 4/84, 5/89 | 6/11 | - |
| Grand Gulf | 10/84 | 11/11 | - |
| Callaway | 10/84 | 12/11 | - |
| Sequoyah 1, 2 | 7/80, 12/81 | 2/13 | - |

**Table 2.8** – Lifetime extension of US nuclear power plants.
Sources: For grid connection http://www.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=US and for lifetime extension dates http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-reactor-license-renewal.html. For Sequoyah, see Inside NRC. 2013. TVA applies for license renewal for Sequoyah-1 and -2. 11 February 2013.

**Notes:**
1. Reactors marked * have been permanently closed.
2. Pairs of reactors marked † have significantly different designs.
3. The owner of Nine Mile Point 2 applied for and received a license extension before its 20th birthday.

| Plant | First grid connection | Expected life extension application |
|---|---|---|
| Braidwood 1, 2 | 7/87, 5/88 | |
| Byron 1, 2 | 3/85, 2/87 | |
| Clinton | 4/87 | 1–3/17 |
| Comanche Peak 1, 2 | 4/90, 4/93 | 7–9/16, 10–12/18 |
| Fermi 2 | 9/86 | 4–6/14 |
| Lasalle 1, 2 | 9/82, 4/84 | 1–3/15 |
| Perry | 12/86 | 9/15 |
| River Bend | 12/85 | 1–3/16 |
| Waterford 3 | 3/85 | 1–3/15 |
| Watts Bar | 2/96 | |

**Table 2.9** – US nuclear power plants yet to apply for lifetime extension.
Sources: For grid connection http://www.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=US and for lifetime extension dates http://www.nrc.gov/reactors/operating/licensing/renewal/applications.html.

Note: The STARS Alliance of nuclear power plant owners has informed the NRC that it will submit applications for lifetime extensions for two unnamed units in 2016 and 2018. The Comanche Peak reactors are the only ones owned by STARS members that have not already had lifetime extension applications made or granted so it is assumed that the application refers to these two units.

In 2008 SCE estimated that lifetime extension of its reactors would cost about 10 per cent of the cost of a new plant. However, this was in advance of an application to life-extend its two reactors at San Onofre – an application that was ultimately not made, with the two reactors being closed in 2013 on the grounds that the repairs required were not economically justified.[50] The value of this estimate is therefore questionable.

In 2012, the owner of the Cook plant (Indiana Michigan Power, a subsidiary of American Electric Power), which was granted a lifetime extension in 2005, began a programme of upgrades expected to cost $1.17bn (about $500/kW) to allow the plant's two reactors to continue to operate until 2035 and 2037 respectively. The work to be carried out includes upgrading the plant's instrumentation and control systems, and replacing the transformers and turbines.[51]

In 2013, the owner of the Monticello plant (Northern States Power-Minnesota, a subsidiary of Xcel Energy Inc.) announced that the cost of lifetime extension and an uprating of 71 MW had doubled compared with the original 2008 estimate ($320m), to $655m (about $1,000/kW).[52] At the time of writing, it was not clear whether the state economic regulatory authorities would allow Northern States Power-Minnesota to recover the whole of this cost from consumers. If they do not, this will send a strong signal to utilities, their owners and the financial community that lifetime extension can be an economically risky business. Northern States Power-Minnesota claims that the costs it incurred are consistent with those incurred by other utilities carrying out upgrades and lifetime extensions.[53]

## 8 Lifetime extension decisions in the rest of the world

### 8.1 Belgium

Belgium has seven operating reactors (all PWRs), three of which had been in service for more than 35 years by the end of 2013: Doel 1 & 2 (454 MW each, in service since 1974 and 1975 respectively) and Tihange 1 (1,009 MW, 1975). The Belgian phase-out law was confirmed in November 2013 in the lower house of the country's legislature, with the following dates: Doel 1: closure 2015 (40 years of operation); Tihange 1: closure 2025 (50 years, due to a 10 year life-time extension); Doel 2: closure 2015 (40 years), Doel 3: closure 2022 (40 years), Tihange 2: closure 2023 (40 years), Doel 4: closure 2025 (40 years), Tihange 3: closure 2025 (40 years). This phase-out law now awaits approval in the Senate.[54]

After proposals were considered in 2009 for life-time extensions for all reactors, the debate had been complicated by the suggestion to tax 'windfall profits' that would be earned by the plants' owner, Electrabel GDF Suez. It had finally been agreed that from 2011 to 2015 Electrabel GDF Suez, would pay an annual tax of between €215m and €245m on the projected additional revenue from the extension of the reactors' operation past 40 years.[55] The new phase-out law on nuclear reactor life-time replaces these taxes with one payable only when a certain minimum market price is exceeded, so heavily reducing the burden on Electrabel GDF Suez. See Annex 2 for more background.

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[50] Nuclear News. 2008. Challenges of life beyond 40 (and 60): a utility perspective. October 2008.

[51] The Herald-Palladium. 2012. Pay as you go for Cook nuke. 4 May 2012.

[52] Nucleonics Week. 2013. Xcel Energy utility says Minnesota nuclear project cost has doubled. 25 July 2013 and Nucleonics Week. 2013. Minnesota PUC investigating Monticello uprate, life extension costs. 15 August 2013.

[53] FierceEnergy. 2013. Xcel CNO: Monticello cost overage not unique. 23 October 2013.

[54] http://www.dekamer.be/FLWB/pdf/53/3087/53K3087006.pdf

[55] Nucleonics Week. 2011. In Belgian nuclear tax debate, PM hints at full life extension. 10 March 2011.

## 8.2 Hungary

Hungary operates four 500 MW reactors of Russian design at the Paks site, installed during 1982–87. Despite being relatively new reactors, lifetime extension has been under consideration for some time because they had only a 30-year design lifetime. In 2003, serious consideration began of extending their lifetime for a further 20 years. This was despite a serious incident that year at the plant, rated 3 on the International Atomic Energy Agency's International Nuclear and Radiological Event Scale of severity (the INES scale running from 0 to 7), when spent fuel was left inadequately cooled and sustained serious damage. A parliamentary committee voted to approve the lifetime extension in 2004. However, no detailed lifetime extension plan was submitted to the Hungarian nuclear safety authority (OAH) at that stage. A plan was submitted by the end of 2008 so that the first unit could continue to operate beyond its 30th birthday in 2012, and lifetime extension was approved in 2011. The work involved in the lifetime extension included a power uprating of 8 per cent of all four reactors. On the safety side, it was based on enhanced in-service inspection, particularly of the reactor pressure vessels. The cost of the lifetime extension has been estimated at €118m for the four units.[56] A 2004 estimate of €573m was said to include costs on non-safety related works and costs to incur between lifetime extension and ultimate plant closure.

## 8.3 The Netherlands

The Netherlands' only reactor, Borssele, a 515 MW PWR, entered service in 1973. In the past, Dutch governments have had differing attitudes to lifetime extension, with some wanting to close the plant in 2013 and others wanting to extend its lifetime to 2033. In 2013 the government continued procedures to allow lifetime extension, and a 2006 decision to allow the plant to operate until 2033 still stands.[57] The coalition government in power in December 2013 consists of the conservative People's Party for Freedom and Democracy (which wants new reactors and lifetime extension) and the centre-left Labour Party (which opposes new reactors and does not favour lifetime extension, although it is not vocal in its opposition). No details have been published of the cost of the proposed lifetime extension.

## 8.4 Spain

The only plant whose lifetime-extension is under consideration is the one at Santa María de Garoña, with a single 466 MW Mark 1 BWR that entered service in 1971. In 2009, the Spanish safety authority (Consejo de Seguridad Nuclear, CSN) determined that the plant was safe to operate for a further 10 years. However, in December 2012 the owner, Nuclenor, decided not to seek to renew its licence when it expired in July 2013, and the plant was shut in December 2012 and the fuel unloaded. Nuclenor claimed that the decision had been precipitated by new taxes on spent nuclear fuel and electricity production, estimated by the company to cost €16/MWh, in addition to safety upgrades required by the CSN in the wake of the Fukushima disaster (the oldest unit at Fukushima is of a similar design to that at Santa María de Garoña).[58] No estimate has been published of the cost of these upgrades. By December 2013, no decision had been taken on the future of Santa María de Garoña.

## 8.5 Sweden

As of 2013 Sweden had four reactors (out of ten) in service that had operated for more than 35 years: one PWR (Ringhals 2 (917 MW, in service since 1974)) and three BWRs (Oskarshamn 1 (492 MW, 1971), Oskarshamn 2, (661 MW, 1974) and Ringhals 1 (917 MW, 1974)). Despite the existence of a national phase-out policy until 2009, the owners of the two plants have long planned to operate their reactors for at least 60 years and have been investing in upgrades and repairs accordingly.[59] In 2014 all four of the oldest reactors will have passed 40 years of operation. Currently the Swedish Radiation Safety Authority is carrying out a PSR for Oskarshamn 1 and 2 and will decide on lifetime extension for the two reactors during 2014.

## 8.6 Switzerland

As of the end of 2013, Switzerland had five operating reactors, three of which had already passed 40 years of operation. Two are small PWRs (Beznau 1 and 2 (380 MW each, in service since 1969 and 1971)) and one is a small BWR (Mühleberg (390 MW, 1971)). A third plant, (Gösgen (PWR, 1035 MW)) entered service in 1979. It now appears unlikely, on political grounds, that the lifetime of Switzerland's plants will be extended. However, in 2010 the owner of the Beznau plant estimated that lifetime extension to 60 years would require investment of $860m, about $1,100/kW.[60]

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[56] http://energiakontrollprogram.hu/sites/energiakontrollprogram.hu/files/paks_plex.pdf

[57] European Power Daily. 2011. Netherlands to fund new nuclear license. 20 September 2011.

[58] Nuclear News. 2013. Nuclenor reconsiders shutdown of Garona plant. July 2013.

[59] Nuclear Engineering International. 2009. Plant life management – the Oskarshamn extra. April 2009.

[60] Nucleonics Week. 2010 Sixty-year lifetime for Beznau PWRs will cost $860 million, manager says. 27 May 2010.

# 9 Conclusions

Very few nuclear reactors have been retired because they have reached the end of their licensed lifetime. Much likelier life-determining factors are: the economics of the plant; the existence of national phase-out policies; serious and unexpected equipment failures; and, for older designs in particular, existence of design issues that makes their continued operation unacceptable in terms of current standards. There seems to be a consensus among regulators that most existing reactors can be safely operated in principle for 60 years, and there are even investigations in the USA into extending lives to 80 years.[61]

However, in the 15 years since lifetime extension began to be adopted, the perception of the risk attached to assuming a significantly longer life has increased. In the USA, the process of obtaining the first lifetime extensions went smoothly, without major plant modifications being required. However, as more problematic plants came up for consideration and safety-related incidents (initially the 9/11 attack) began to play a role in official thinking, the process became more difficult and expensive. It also became clearer, especially after the Fukushima disaster, that in-principle approval for a reactor to operate for 60 years was far from being a guarantee that it actually would complete a 60-year operational life.

The collapse of natural gas prices in the USA also emphasised that there are economic risks to lifetime extension, with two of the four plants retired in the USA in 2013 being closed purely on the grounds that they were expected to become loss-makers.

A longer lifetime gave utilities the opportunity to justify upgrades aimed at improving the economics of a plant, such as power upgrades. However, as the risks and costs of lifetime extension became clearer, the case for this additional discretionary investment was weakened.

There is a significant variation in the length of operating licences awarded by different countries' regulators. In the USA, nuclear power plants are licensed for 40 years and the current process is aimed at extending this by 20 years. In other countries, such as France, there is no specific duration to an operating license. In practice, however, the difference between these regimes is less than might appear at first sight. The US authorities, like any credible safety authority, must have the power to close down any plant at any time if they believe it does not meet the required safety standards. As experience accumulates, more knowledge of the failures that can occur emerges and the requirements imposed by the specified safety standard will inevitably become more onerous.[62] Equally, while the French, and most other authorities, do not set a specific life-time, they carry out periodic safety reviews, mosty on a 10-yearly basis, to determine whether a plant is safe enough to be allowed in principle to operate for another decade.

There are two elements to the cost of lifetime extension: the cost of providing the evidence to the national safety authority that the plant is safe enough to operate for an extended period, and the cost of carrying out any modifications necessary. The first cost is much more predictable and likely to be low (of the order of €10-20m) in relation to the replacement cost of the plant (several billion euros). For utilities, applying for lifetime extension is therefore a low-cost step that potentially opens the way to considerable profits. If it turns out that the cost of modifications is prohibitively high, the loss of the application fee can easily be borne. As a result, most utilities are looking to open the option of lifetime extension. Nearly all US utilities have already applied, and most have already received approval to operate their reactors for up to 60 years. In many cases US utilities have applied for lifetime extension 15 years or more before the end of their licences.

It is clear that the cost of lifetime extension is heavily dependent on the specific circumstances of a plant: its basic design, its operating and maintenance history, and the particular requirements of the safety regulator. However, cost data are very sparse. Lifetime extension may make economic upgrades to a plant, such as upgrading the turbine generator, viable and disentangling these discretionary costs from the required cost of life extension is generally impossible.

Regulators face the difficult task of determining how safe is safe enough. It is clear that the designs of plants now reaching the point where lifetime extension will be considered fall far short of the requirements for a new plant, and that retrofitting to bring them up to today's new-build standards would be technically and economically infeasible. As a result the required standard for the upgraded technology of a life-extended plant tends to be merely that the risk should be as low as reasonably achievable (ALARA), with the 'best available technology' (BAT) standard being unattainable.

There appears to be a significant difference between the requirements of the US regulator NRC, and those of the French regulator ASN, particularly post-Fukushima. The ASN is now requiring an extensive range of upgrades, for example improved seismic resistance and flood protection of back-up power and control rooms. The NRC does not appear to have modified its requirements significantly in the light of Fukushima, and the cost of related modifications appears to be much lower than in France, despite the fact that some US reactors are of comparable type and vintage to Fukushima's, whereas the French reactors are of a very different design.

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[61] Nucleonics Week. 2008 NRC, DOE, industry to investigate LWR life extension beyond 60 years. 21 February 2008.

[62] This is not a matter of the safety standard itself changing, but rather of changes in what is believed to be necessary to meet that standard.

## Annex 1 US nuclear plants at risk of closure on economic grounds

A 2013 study identifies 38 US reactors as under threat of closure on economic grounds, with 12 of them under particular threat (see Table 2.10).[63] It argues that no US reactor has ever been retired on grounds of reaching the end of its licence period and that other factors will determine future retirements. The study identifies four economic factors as putting reactors at risk of closure:

- size: small reactors may be less economic than large ones;
- age: older reactors may have higher running costs;
- competition: reactors exposed to competitive power markets are more at risk; and
- remaining licence life: reactors with a short remaining licence life are more at risk.

It further identifies two operational factors (poor reliability and need for significant repairs) and two safety factors (need for general safety upgrades and need for specific Fukushima upgrades) that may precipitate closure.

The study lists five nuclear power stations where economic upgrades have been cancelled because of uncertainties about their future viability. In 2008, the owners of the Prairie Island plant agreed with the state economic regulator to uprate the plant by 146 MW (11 per cent) at a cost of about $1,800/kW. The uprating was later cut to 116 MW and in March 2012 was abandoned altogether.[64] Plans to uprate the output of the two reactors at each of Exelon’s Limerick and Lasalle plants, which would have seen an addition of 423 MW at a cost of about $1,500/MW, were abandoned in June 2013. Uprating of the Monticello and St Lucie reactors has seen large cost overruns.

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[63] Cooper, M. 2013. Renaissance in reverse: competition pushes aging US nuclear reactors to the brink of economic abandonment. http://will.illinois.edu/nfs/RenaissanceinReverse7.18.2013.pdf

[64] Nucleonics Week. 2013. Outlook for uprates downbeat, analysts say. 11 July 2013.

| Plant/reactors | Grid connection | Unit size (MW)/Technology | Extension applied for | Risk factor |
|---|---|---|---|---|
| Browns Ferry 1, 2, 3 | 10/73, 8/74, 9/76 | 1,155/BWR | 5/05 | |
| Diablo Canyon 1, 2 | 11/84, 10/85 | 1,197/PWR | 11/09 | |
| Millstone 2, 3 | 11/76, 2/86 | 918, 1,280/PWR | 1/04 | Tax issues |
| Turkey Point 3, 4 | 11/72, 6/73 | 829, 729/PWR | 9/00 | |
| Clinton | 4/87 | 1,098/BWR | - | Selling into tough market |
| Dresden 2, 3 | 4/70, 7/71 | 926, 829/BWR | 10/04 | |
| Quad Cities 1, 2 | 4/72, 5/73 | 940/PWR | 10/04 | |
| Lasalle 1, 2 | 0/82, 4/84 | 1,207/BWR | - | |
| Duane Arnold | 5/74 | 624/BWR | 10/08 | |
| Wolf Creek | 6/85 | 1,280/PWR | 10/06 | |
| Calvert Cliffs 1, 2 | 1/75, 12/75 | 918, 911/PWR | 4/98 | |
| Pilgrim | 7/72 | 711/BWR | 1/06 | Local opposition, large number of risk factors |
| Cook 1, 2 | 2/75, 3/78 | 1,100, 1,151/PWR | 11/03 | |
| Fermi | 9/86 | 1,100/PWR | - | |
| Palisades | 12/71 | 845/PWR | 3/05 | Repair costs |
| Monticello | 3/71 | 613/PWR | 3/05 | |
| Prairie Island 1, 2 | 12/73, 12/74 | 566, 560/PWR | 4/08 | |
| Callaway | 12/11 | 1,275/PWR | 10/84 | |
| Cooper | 5/74 | 801/BWR | 9/08 | |
| Fort Calhoun | 8/73 | 512/PWR | 1/02 | Poor performance |
| Seabrook | 5/90 | 1,296/PWR | 6/10 | |
| Hope Creek | 8/86 | 1,240/BWR | 8/09 | |
| Oyster Creek | 9/69 | 652/BWR | 7/05 | Expected to retire |
| Fitzpatrick | 2/75 | 849/BWR | 8/06 | High cost |
| Ginna | 12/69 | 608/PWR | 8/02 | Poor economics |
| Indian Point 2, 3 | 6/73, 4/76 | 1,067, 1,085/PWR | 4/07 | State opposition, lifetime extension pending |
| Nine Mile Point 1, 2 | 11/69, 8/87 | 640, 1,320/BWR | 10/06 | Poor contract |
| Davis Besse | 8/77 | 925/PWR | 8/10 | Large number of factors |
| Perry | 12/86 | 1,303/BWR | - | |
| Limerick 1, 2 | 4/84, 5/89 | 1,194/BWR | 6/11 | |
| Susquehanna 1, 2 | 11/82, 7/84 | 1,330/BWR | 9/06 | |
| Three Mile Island | 6/74 | 880/PWR | 10/09 | |
| Robinson | 9/70 | 780/PWR | 6/02 | |
| Sequoyah 1, 2 | 7/80, 12/81 | 1,220, 1,201/PWR | 2/13 | |
| Comanche Peak 1, 2 | 4/90, 4/93 | 1,259, 1,250/PWR | - | |
| South Texas 1, 2 | 3/88, 4/89 | 1,354/PWR | 10/10 | |
| Vermont Yankee | 9/72 | 635/BWR | 1/06 | Tax issues, state opposition |
| Point Beach 1, 2 | 11/70, 8/72 | 640/PWR | 2/04 | |

**Table 2.10** – US nuclear power plants at risk of closure on economic grounds. Sources: For grid connection www.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=US, for lifetime extension dates www.nrc.gov/reading-rm/doc-collections/fact-sheets/fs-reactor-license-renewal.html and for risk factors Cooper, M. 2013. Renaissance in reverse: competition pushes aging US nuclear reactors to the brink of economic abandonment, http://will.illinois.edu/nfs/RenaissanceinReverse7.18.2013.pdf

# Annex 2 Nuclear phase-out programmes

A number of countries, including Austria, Belgium, Germany, Italy, Spain, Sweden and Switzerland, have taken political decisions to phase out nuclear power. In the case of Austria, the decision was clear-cut, and in 1978, following a referendum, a complete but not yet operational nuclear power plant was closed.

In some other cases, the outcome of a referendum has not been decisive, sometimes because the referendum question was too complex, for example specifying that the existing reactors be shut and presenting a time-table for their closure. In still other cases, a government's decision to phase out nuclear power has been part of the electoral platform for a party that became part of the following government. In these cases, successor governments have often altered these decisions.

## Italy

In Italy in November 1987, shortly after the Chernobyl disaster, a referendum produced a vote against nuclear power, although the questions were not easily comprehensible and were framed in such a way as not to require immediate action. Only one of the three reactors then nominally in service had produced any power in 1987 and none was operating at the time of the referendum, although the decision to retire them was only definitively taken in 1990. Around 2008 an attempt was made to restart the nuclear power programme and there was even some unrealistic talk of re-opening the closed reactors. Some political agreements were reached on the building of new plants, but a second referendum shortly after the Fukushima disaster came out against nuclear power and there are now no realistic prospects of a nuclear power revival in Italy.

## Belgium

In January 2003 the Belgian Parliament passed a law requiring the phase-out of the country's seven nuclear reactors when they reached 40 years of operation, meaning that the three oldest plants would be closed in 2014-15, with two of the remaining plants closing in 2022 and the other two in 2025.[65] In 2009, the government agreed that the oldest three plants could operate for a further 10 years beyond 2014/15, provided that the windfall profits arising from their continued operation were taxed.[66] The government fell before the agreement could be formalised and the law of 2003 survived, although there have been various initiatives to try to extend the lives of the newer plants. The only provision is that lifetimes can be extended if security of supply would be endangered by reactor closure.

An added complication was the discovery of the possibility of cracks in the pressure vessels of two of the newer reactors. There appeared to be a risk that this could lead to the early closure of these two reactors, but the Belgian safety regulator allowed them to return to service in May/June 2013, after a year-long shutdown.

On 28 November 2013, the Belgian Chamber of Representatives accepted a new law confirming the phase-out at 40 years reactor lifetime, with the exception of the Tihange 1 reactor, which received a 10 year extension. The windfall tax envisaged in 2009 will be greatly reduced. This new law is likely to be adopted in the Senate in the first months of 2014.

## Spain

In 1984 Spain's then Socialist government halted the development of new nuclear capacity, ending construction work on several plants. In 2008, another Socialist government was elected on a promise to phase out nuclear power. Whilst there has been talk of limiting life-times to 40 years, only one of Spain's nine operating reactors (the 466 MW Santa María de Garoña BWR) was approaching this age with the other plants reaching their 40th birthday after 2020. The Socialist government was replaced in 2011 and the Santa María de Garoña plant was given a license to 2019. This is therefore the only plant for which life-time extension is a pressing issue.

## Switzerland

In 2011, following the Fukushima disaster, the Swiss government banned the construction of new reactors and voted for the closure of existing ones after 50 years of operation, meaning that three reactors would be closed in 2019–21, one more in 2029 and the last in 2034.[67] By 2013, however, the law had still not been passed and the final decision on the future of the nuclear sector in Switzerland had yet to be taken. It remains to be seen whether lifetime extension will be undertaken in Switzerland.

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[65] Nucleonics Week. 2004. Minister says basis for Belgian phase-out should be reconsidered. 9 September 2004.

[66] Nucleonics Week. 2011. In Belgian nuclear tax debate, PM hints at full life extension. 10 March 2011.

[67] Nucleonics Week. 2011. Swiss vote leaves the door open for new reactors: lawmaker. 6 October 2011.

## Sweden

In 1980, in the wake of the Three Mile Island disaster, a referendum was held in Sweden on the future of nuclear power. The result was a decision to phase out nuclear power by 2010. Paradoxically, most of Sweden's nuclear capacity came on line in 1980 or later, the latest reactor becoming operational in 1985. There appears to have been little attempt to complete the phase-out, with only two small old reactors closed, one in 1999 and one in 2005. Not by coincidence these reactors were only 20km from the Danish capital Copenhagen: Denmark has consistently been anti-nuclear.

In 2009, the Swedish government announced that it would not after all be phasing out nuclear power and that it would seek to change the law banning construction of new nuclear power plants.[68] On 17 June 2010 the Swedish Parliament voted in favour of repealing a 1997 law on nuclear decommissioning and approval of the replacement of old reactors with new ones. Although in July 2012 the publicly owned power company Vattenfall took the first steps in the application process for one or two new reactors, the prospects for new nuclear build in Sweden appear distant. The owners of the oldest operating reactors, Oskarshamn 1 and 2, spent significant amounts of money on upgrades in the 1990s and are proposing to spend more.[69] Lifetime extension is therefore a significant issue for Sweden, as a sizeable proportion of its nuclear capacity will pass 40 years of operation by 2020.

## Germany

Germany's phase-out decision, taken originally in 2000, is the best-known phase-out decision worldwide. In 2000, the Chancellor Gerhard Schröder reached agreement with the utilities to close all nuclear power plants by 2020, giving the plants an average life of 32 years. There was some flexibility concerning lifetimes, and only two plants had been closed by 2009, even though four more had been operating for over 32 years. In 2009, Chancellor Angela Merkel's government introduced a law extending the lifetimes of the remaining plants by 8–14 years. The utilities also began to hope that new build would eventually become possible. However following the Fukushima disaster Merkel had a change of heart and the phase-out was firmly reimposed, with eight reactors closed immediately and completion of the phase-out set for 2022, at which point the remaining reactors will have operated for 33 to 37 years. There seems no prospect of a reversal of this decision, so lifetime extension is not an issue in Germany.

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[68] Nucleonics Week. 2009. Swedish government: nuclear power needed for 'foreseeable future'. 24 September 2009.

[69] Nucleonics Week. 2009. OKG options include modernizing Oskarshamn-1, building new unit. 25 June 2009.

# Nuclear Liability Of Ageing Nuclear Reactors[1]

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[1] This chapter is based on: Faure, M & Vanden Borre, T. 2013. Study on the influence of Plant Lifetime Extension (PLEX) on nuclear liability, Study commissioned for Greenpeace, Stockholm: http://www.greenpeace.org/france/PageFiles/300718/Study%20%20PLEX%20nuclear%20liability.pdf

# Content

# 1 Introduction

The relationship between reactor lifetime extension and nuclear liability is a key issue, which is the particular focus of this chapter. It analyses the possible impact of lifetime extension on nuclear liability and examines to what extent a nuclear operator would be liable for the costs of an incident affecting a life-extended reactor. It addresses the following questions:

- Does the current legal framework on nuclear liability address nuclear ageing and lifetime extension of reactors?
- Would it be a good idea to have a specific provision addressing nuclear ageing and lifetime extension of reactors ?
- What is the liability of suppliers of upgrades for life-extended reactors?

# 2 The international nuclear liability conventions

## 2.1 Overview of the international nuclear liability conventions

In the early years of the development of the commercial nuclear industry, two international treaty regimes were created to regulate the civil liability for damage caused by nuclear incidents, i.e. to create compensation mechanisms for nuclear damage.[2] The first treaty regime was established under the auspices of the OECD Nuclear Energy Agency (NEA) and consists of the Convention on Third Party Liability in the Field of Nuclear Energy of 29 July 1960 (hereinafter referred to as 'the Paris Convention')[3] and the Brussels Supplementary Convention to the Paris Convention on Third Party Liability in the Field of Nuclear Energy of 31 January 1963 (hereinafter referred to as 'the Brussels Supplementary Convention'). The Paris Convention introduces the five major principles of international nuclear liability conventions. The Brussels Supplementary Convention provides for additional compensation of damage in the event that the coverage of the operator under the Paris Convention is inadequate.

The second nuclear liability treaty regime was developed under the aegis of the International Atomic Energy Agency (IAEA): the Vienna Convention on Civil Liability for Nuclear Damage of 21 May 1963 (hereinafter referred to as "the Vienna Convention").[4] The Vienna Convention introduces, as does the Paris Convention, the five major principles of international nuclear liability law.

## 2.2 Five major principles of the international nuclear liability conventions

1. A victim of a nuclear incident wanting to introduce a claim against a nuclear operator does not have to prove a fault committed by the operator itself. This type of liability is generally known as strict liability. According to the Exposé des Motifs of the Paris Convention:

    > the absolute liability of the operator is not subject to the classic exonerations such as force majeure, Acts of God or intervening acts of third persons, whether or not such acts were reasonably foreseeable and avoidable. […] The only exonerations lie in the case of damage caused by a nuclear incident directly due to certain disturbances of an international character such as acts of armed conflict and hostilities, of a political nature such as civil war and insurrection, or grave natural disasters of an exceptional character, which are catastrophic and completely unforeseeable, on the grounds that all such matters are the responsibility of the nation as a whole.

    The nuclear operator is therefore even liable for damage caused by acts of terrorism, which are not part of a civil war or insurrection.[5]

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[2] For a useful overview, see, among others, OECD. 1994. Liability and compensation for nuclear damage: an international overview.

[3] The following countries in Europe are part to the Paris Convention: Belgium*, Denmark***, Finland***, France*, Germany***, Greece**, Italy***, Netherlands***, Norway***, Portugal, Slovenia**, Spain*, Sweden**, Switzerland, Turkey**, United Kingdom*, Those that also ratified the Brussels Protocol are marked with an *, those that also ratified the Joint Protocol with **, those that ratified both with ***.

[4] The following European countries are party to the Vienna Convention: Belarus*, Bosnia-Herzegovina, Bulgaria**, Croatia**, Czech Republic**, Estonia**, Hungary**, Latvia***, Lithuania**, Macedonia, Montenegro, Poland**, Romania***, Russian Federation, Serbia, Slovakia**, Ukraine**, Those that ratified the 1997 amendment are indicated with a *. Those that ratified the Joint Protocol with a **. Those that ratified both with ***. Also a number of countries outside Europe is party to the Vienna Convention.

[5] Horbach, N., Brown, O. F. II, and Vanden Borre, T., 2002. "Terrorism and Nuclear Damage Coverage", 20 J. Energy Nat. Resources & Envtl. L., 2002, 231-269, p. 231.

2. The second principle is the so-called legal channelling of all liability to the nuclear operator. This means that, under the conditions of the conventions, the right to compensation can only be exercised against the nuclear operator (or its insurer) . Second, no one besides the nuclear operator[6] is liable for damage caused by a nuclear incident. Finally, the conventions are the only legal basis for a liability claim against the nuclear operator in the event of a nuclear incident. Victims cannot call upon other legal provisions (especially those based on general tort law), either against the nuclear operator or against any one else (such as the plant's designer or a supplier of equipment).

3. The conventions also limit the liability of the nuclear operator, both in amount and in time (though the amounts have been increased and – in the case of the Vienna Convention – the time limit revised since the conventions were signed). According to Article 7 of the Paris Convention (as originally worded), the maximum liability of the operator in respect of damage caused by a nuclear incident was to be 15 million Special Drawing Rights (SDRs) (€17.09m or $22.91m as of November 2013).[7] According to Article V of the Vienna Convention (as originally worded) the liability of the operator was to be limited by the Installation State (the country in which the installation is located) to not less than $5m for any one nuclear incident.[8] This limitation of liability was considered to be necessary in order not to obstruct the development of the nuclear industry. Moreover, the right to claim compensation was to be extinguished if an action was not brought within 10 years of the date of the nuclear incident.

4. To cover its liability, the operator is required to have and maintain insurance or other financial security of the amount of its liability and of such type and terms as the competent public authority shall specify. In literature, reference is often made to the 'congruence principle'.[9] According to this principle, the operator's liability must in all times be covered by the given amount of financial cover (in practice mainly by insurance). The congruence principle applies in cases where the nuclear operator's liability is limited: the amount for which the operator must have a financial security will equal the liability cap established by law. The congruence principle does not apply where the liability of the operator is unlimited since there is no unlimited financial cover available (not in the nuclear insurance industry and not, to our knowledge, in any industrial activity). In such a case, the national law will require the operator to have a financial security at least equal to the minimum liability amounts required by the conventions.

5. The Vienna and Paris Conventions also concentrate, in principle, all jurisdiction over lawsuits for compensation caused by a nuclear incident in one court, which is a court in the state where the nuclear incident occurred. For example, according to Article 13(a) of the Paris Convention, jurisdiction over actions under Articles 3, 4, 6(a) and 6(e) shall lie only with the courts of the Contracting Party in whose territory the nuclear incident occurred.[10]

Note that two studies by the American nuclear industry have had a decisive influence on the principles of the nuclear liability conventions. The so called Preliminary Report on 'Financial protection against atomic hazards'[11] from the Columbia University concluded that the interests of both the industry and the public could be met by limiting the amount of liability of the nuclear operator to the amount available on the insurance market and by providing for public funds to be set aside for damage not covered for by the operator (or its insurer). The so called Harvard Report on 'International Problems of Financial Protection against Nuclear Risks'[12] introduced the idea of legally channelling all liability to the nuclear operator in order to prevent victims of a nuclear incident in Europe introducing a claim against American suppliers.

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[6] The operator is the legal person designated by the competent authorities as the operator of a nuclear installation. See Article 1(a) of the Paris Convention.

[7] The exact value of the SDR is determined by the International Monetary Fund (IMF) and is published on its website. For this study, we used the exchange rate of 11 November 2013: 1 SDR = €1.1395 = $1.5276.

[8] Both the Paris and Vienna Conventions stipulate a limitation per incident.

[9] Pelzer, N., 2000. "Focus on the Future of Nuclear Liability Law", in Reform of Civil Nuclear
Liability, OECD, 2000, 421-451, p. 433
and Vanden Borre, T., 2001. Efficiënte preventie en compensatie van catastroferisico's. Het voorbeeld van schade door kernongevallen, Antwerp, Intersentia, 2001, p. 357 ff.

[10] The competent court shall thus deal with all actions which might be brought against an operator, either directly by persons suffering damage (Article 3 of the Paris Convention) or by other persons who might be liable under international agreements in the field of transport or under the legislation of a non-contracting state (Article 6(d) and 6(e) of the Paris Convention). The forum for actions in recourse by an operator under Article 6(f) of the Paris Convention or for actions for contribution by an operator against other operators in the case of joint and several liability is not fixed in the Convention and will be decided upon by national law.

[11] Arthur W. Murphy, 1956. Preliminary report on financial protection against atomic hazards. Atomic Industrian Forum, Inc. New York

[12] Polach, J. G., 1960. International problems of financial protection against nuclear risks, a forum report. The American Journal of Comparative Law Vol. 9, No. 1 (Winter, 1960), pp. 130-133. American Society of Comparative Law.

## 2.3 Public funding

The NEA's 1963 Brussels Supplementary Convention adds two additional tiers in the form of public funds to the first layer (which is the insured liability under the Paris Convention). According to Article 3 of the Brussels Supplementary Convention, the Contracting Parties undertake that compensation in respect of damage caused by a nuclear accident shall be provided up to the amount of 300 million SDRs per incident (€341.85m or $458.29m as of November 2013). Such compensation shall be provided:

- up to an amount of at least 5 million SDRs (€5.70m or $7.64m), out of funds provided by the operator's insurance or other financial security, such amount to be established by the legislation of the Contracting Party in whose territory the nuclear installation of the operator liable is situated;
- a second tier consisting of the difference between 175 million SDRs and the amount required under the first tier (thus a maximum of 170 million SDRs or €193.72m or $259.70m) to be made available out of public funds by the Contracting Party in whose territory the nuclear installation of the operator liable is situated; and
- a third tier of 125 million SDRs (€142.44m or $190.96m), to be made available out of public funds by the Contracting Parties according to a formula for contributions based on each Party's GNP and the thermal capacity of the nuclear reactors.

## 2.4 Changes after Chernobyl

The Chernobyl disaster of 26 April 1986 triggered the revision of the international nuclear liability conventions. The first result of the revision exercise was the 1988 Joint Protocol which will not be further discussed here: it links the operator's funding under the Vienna Convention and the Paris Convention in such a way that the benefit of the special regime of civil liability is extended to all parties falling under either the Vienna or the Paris Convention. In fact, the Joint Protocol thereby creates a link between the territorial scope of the Paris and Vienna Conventions.[13]

In the IAEA regime, a Protocol to the Vienna Convention was adopted on 12 September 1997.[14] Article 7 of the Protocol amends Article V of the Vienna Convention with regard to the limited amount of liability. It states that the maximum liability of the operator may be limited by the Installation State for any one nuclear incident, either to not less than 300 million SDRs; or to not less than 150 million SDRs provided that in excess of that amount, and up to at least 300 million SDRs, public funds shall be made available by that state to compensate for nuclear damage.[15]

Furthermore a new Article VI of the Vienna Convention was introduced, according to which rights of compensation shall be extinguished if an action is not brought within 30 years from the date of the nuclear incident with respect to loss of life and personal injury and within 10 years from the date of the nuclear incident with respect to other damage.

In the NEA regime, the 2004 Protocol to the Paris Convention[16] introduces a new liability limit: according to the new Article 7 of the Convention, each Contracting Party shall provide under its legislation that the maximum liability of the operator in respect of nuclear damage caused by any one nuclear incident shall not be less than €700m. According to the related 2004 Protocol to the Brussels Supplementary Convention the Contracting Parties shall undertake that compensation in respect of nuclear damage shall be provided up to an amount of €1.5bn per nuclear incident. This will now be divided as follows:

- up to an amount of at least €700m: funds provided by insurance or other financial security or out of public funds provided pursuant to Article 10(c) of the Paris Convention;
- between this amount and €1.2bn: public funds to be made available by the Contracting Party in whose territory the nuclear installation of the operator liable is situated; and
- between €1.2bn and €1.5bn: public funds to be made available by all the Contracting Parties according to the formula for contributions.

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[13] For more details, see Von Busekist, O., "Le Protocole Commun relatif à l'application de la Convention de Vienne et de la Convention de Paris: Une passerelle entre les deux Conventions sur la responsabilité civile pour les dommages nucléaires", Bulletin de Droit nucléaire, nr. 43, June 1989, 10-45.

[14] The Protocol to the Vienna Convention has three goals: to provide for a broader scope of operator liability, an increased level of operator liability and enhanced means for securing adequate and equitable compensation. For the sake of the analysis we focus only on the issue of liability.

[15] The Protocol also provides for a so-called phase-in mechanism for a 15-year period. Indeed, for a maximum of 15 years from the date of entry into force of the Protocol, the Installation State can set its limit at a transitional amount of not less than 100 million SDRs in respect of a nuclear incident occurring within that period. An amount lower than 100 million SDRs may be established, provided that public funds shall be made available by that State to compensate nuclear damage between that lesser amount and 100 million SDRs (see Article 7 of the Protocol to the Vienna Convention, amending Article V of the Vienna Convention).

[16] Both the Paris and Brussels Supplementary Conventions have been supplemented by a few additional protocols. The Protocol to the Paris Convention of 16 November 1982 adjusts some of the definitions and imposes liability on the operator for damage to the means of transport; the Protocol to the Paris Convention of 16 November 1982 changes the unit of account into SDR and increases the liability amounts of the three tiers from the initial 120 million up to 300 million SDRs. Although the basic text is always that of the Paris Convention, when referred to the latter it will include the additional protocols as well. In this respect, see, inter alia, M. Lagorce (1993), at 24. In 2004 additional protocols to the Paris and Brussels Convention were signed, which also changed currency from SDR to Euro. The Paris 2004 protocol which is so far only ratified by Norway and Switzerland and the Brussels protocol additionally by Spain, but none of these are yet in force.

Finally, the Convention on Supplementary Compensation (CSC), adopted on 12 September 1997, but due to too little ratifications still not valid,[17] is a new and independent legal instrument, which means that a state does not need to be a party to the Vienna or Paris Conventions in order to become a party to the CSC. According to Article III.1.a of the CSC, the Installation State shall ensure the availability of at least 300 million SDRs ( €341.85m or $458.29m). This provision provides for an obliges the Installation State to ensure that 300 million SDRs are available; the Installation State is free to choose how this amount is funded (private insurance, regional agreement, etc.). A state meets its obligation under Art. III.1.a of the CSC when it imposes a liability on the nuclear operator for the entire amount. As such, this Article does not oblige a state to make public funds available. However, according to Art. II.1.B of the CSC, the Contracting Parties shall, beyond the amount available under the above mentioned first tier, make public funds available in the event of an incident[18] according to a formula that provides the basis for an international fund of approximately 300 million SDRs per unit if a large part of the countries having a nuclear power plant on their territory become parties to the Convention.[19]

## 2.5 Specific provisions with regard to nuclear reactor ageing

The international nuclear liability conventions do not specifically address the issue of ageing nuclear reactors. This is unsurprising inasmuch as the drafters of the Conventions did not and could not envisage the lifetime extension of nuclear reactors.  A nuclear reactor that has been granted a lifetime extension remains subject to the provisions of the nuclear liability conventions in just the same way as one that has not yet been granted such an extension. If one considers that ageing reactors represent a higher risk, the question arises of whether the Conventions allow for a higher maximum level of liability for such reactors.

The Paris Convention seems to recognise a link between the level of risk and the level of liability. Article 7 of the Paris Convention allows for any Contracting Party to establish by legislation a greater or lesser ceiling of liability, taking into account the opportunities for the operator to obtain insurance or other financial security. Any Contracting Party, having regard to the nature of the nuclear installation or the nuclear substances involved and to the likely consequences of an incident originating from them, may establish a lower ceiling, provided that in no event shall any amount so established be less than 5 million SDRs.

It seems clear that this stipulation does not prevent countries from setting a higher liability ceiling. First of all, the Steering Committee of the NEA has recommended Contracting Parties to adopt a higher ceiling than the one foreseen in the Conventions, subject to the availability of insurance cover.[20] Moreover, the Conventions establish a minimal framework. Countries wanting to offer more protection to their citizens by setting a higher ceiling of liability, for example for ageing reactors, seem to have a certain freedom to do so. These arguments have been used by Germany to justify introducing a system of unlimited liability, even though the Paris Convention advises setting a nuclear operator's maximum liability.

A specific issue arises with regard to ageing nuclear installations and concentrated liability (i.e. legal channelling of liability). Before an operator is permitted licence to extend the lifetime of a reactor, it will be required to invest in the safety of the reactor. This will require it to purchase goods and services from various suppliers. According to the principle of channelling of liability, these suppliers will remain immune from the claims of victims should there be an incident after the reactor has been life-extended. Suppliers will have little difficulty in establishing that only the operator can be held liable for the damage caused by a nuclear incident and that no other legal bases exist besides the special regime of the nuclear liability conventions. As explained above, the conventions continue to be applicable to life-extended reactors and hence so does the channelling inherent in the conventions.

The only exception to channelling foreseen by the conventions is a contractual right of recourse. Were it not for the conventions, a nuclear operator wanting to extend the lifetime of a nuclear reactor, would be in a strong bargaining position to demand such a contractual right of recourse from its supplier. However, the text of the conventions weakens the position of the nuclear operator since it can only exercise a right of recourse if expressly provided for by contract. There is very little chance of any operator being able to obtain such a clause in a contract.

Even if it were possible to hold contractors and suppliers liable, victims would still face serious difficulties in proving who caused an accident. Suppose for example that a contractor supplied and installed some replacement parts at a power plant and that two months later a nuclear accident occurred. The supplier would most likely claim that the accident was caused by companies involved in the initial design and construction of the plant and not by the maintenance work carried out on the plant.

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[17] The CSC has been ratified by Argentina, Morocco, Romania and the United States (status 3 December 2013).

[18] IAEA, 1998, Convention on Supplementary Compensation for Nuclear Damage. According art.IV 1(a) to the following formula:

- the amount which shall be the product of the installed nuclear capacity of that Contracting Party multiplied by 300 SDRs per unit of installed capacity; and
- the amount determined by applying the ratio between the United Nations rate of assessment for that Contracting Party as assessed for the year preceding the year in which the nuclear incident occurs, and the total of such rates for all Contracting Parties to 10 per cent of the sum of the amounts calculated for all Contracting Parties.

[19] McRae, B., "Overview of the Convention on Supplementary Compensation", Reform of Civil Nuclear Liability (OECD: 2000), 174-183, p. 176.

[20] Recommendation of the Steering Committee of 20 April 1990 (NE/M(90)1).

The occurrence of an accident after lifetime extension of a nuclear reactor also raises the question of on-site damage. It seems likely that the nuclear operator would have the right to sue its supplier for damage to the site. Of course this would, if successful, add to the operator's financial assets, which should in turn, at least in principle, benefit the victims of the accident to whom the operator is liable. However, it would not be easy for the operator  to prove the supplier's responsibility for the damage.

## 3 The US nuclear liability system

The originall US legislation, the Price-Anderson Nuclear Industries Indemnity Act of 1957, just like the international compensation regime, aimed to spread the risk of nuclear activities between private industry on the one hand and the nation that benefited from the development of nuclear energy on the other. The nuclear operator was obliged to buy all the insurance coverage then available, which at the time was $60m. On top of that amount, the government agreed to make available an amount of $500m in the event of an accident. Thus the major part of the compensation scheme provided for by the 1957 Price-Anderson Act consisted of public funds. Several authors agreed soon after the Price-Anderson Act became law that it created a favourable climate for the (American) nuclear industry.[21]

A special feature of the Price-Anderson Act is that it is revised every decade or so.[22] This opportunity inspired the US Federal administration to introduce in 1975 a new tier in the compensation scheme, the so-called retrospective premium. This was a premium to be financed by all American nuclear operators that had received a licence from the US Nuclear Regulatory Commission (NRC); in the event that the damage caused by an incident exceeded the amount of the nuclear operator's individual liability coverage of $60m, the retrospective premium was to come into play.

Since then, the levels of both the operator's liability insurance and the retrospective premium have increased. As of 10 September 2013, the following amounts apply: operator's liability coverage of $375m; and retrospective premium of $121.255m per reactor per incident, plus an additional 5 per cent for legal expenses. tFrom that date, therefore, the total amount of compensation available in the USA is $13,616.046m [375m + (104 x (121.255m+ 6,062,750))], with a maximum contribution to the damage caused by any reactor incident by other reactor operators of $18.963m per reactor per calender year.[23]

Under the 'omnibus' coverage feature of the Price-Anderson Act, the system covers 'anyone liable'[24] for 'public liability'. 'Public liability' is defined in the Act as 'any legal liability arising out of or resulting from a nuclear incident or precautionary evacuation...'.[25] Thus, unlike the international compensation regime, the Price-Anderson Act has a system of economic channelling as opposed to legal channelling.[26] It is interesting to note that while on the one hand the USA insisted on the introduction of legal channelling in the nuclear liability conventions, on the other hand US domestic nuclear liability law provides for a system of economic channelling.

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[21] Stason, E.B., Estep, S.D. and Pierce, W.J., Atoms and the Law, Ann Arbor, University of Michigan Law School, 1959, pp. 572 and 780.

[22] It was revised in 1966, 1975, 1988 and 2005.

[23] The calculation is based on the amount of 104 operating reactors in the USA at 1 January 2013.

[24] 42 US Code Section 2210(t) (defining 'person indemnified').

[25] 42 US Code Section 2210(w).

[26] Under a system of legal channelling of liability a claim against other legal persons is legally impossible, precisely because of the fact that liability is exclusively concentrated on one person. Economic channelling means that the rules of ordinary tort law remain applicable, but that the economic burden of such liability lies with one person only. Other persons than those to which liability is economically channelled can therefore be held legally liable, but can reclaim any amounts they may have to pay from the person who is economically liable. This is exactly the case under the Price-Anderson Act: suppliers can be held liable, but their liability is covered by the omnibus coverage of the nuclear operator.
For more details, see Vanden Borre, T., "Channelling of Liability: A Few Juridical and Economic Views on an Inadequate Legal Construction", Horbach, N.L.J.T., (ed.), Contemporary Developments in Nuclear Energy Law. Harmonizing Legislation in CEEC/NIS, The Hague, Kluwer Law International, 1999, 13-39..

## 4. Economic consequences

According to European Commission figures, the March 2011 Fukushima disaster caused €130bn of damage. The question now arises whether a nuclear incident in Europe would cause a similar amount of damage. A report by the French Institut de Radioprotection et de Sûreté Nucléaire (IRSN) has indicated that the damage caused by a serious nuclear incident in France would cost between €120bn and €300bn.[27]

The costs of the Fukushima disaster as well as the recent French study demonstrate once again that the amounts provided for under the nuclear liability conventions are absolutely too low. Even assuming that the 2004 Protocols to the Paris and Brussels Supplementary Convention was in force, this would mean that potentially only half of one per cent of the damage could be compensated for (€1.5bn available against damage of €300bn).

It should be clear from the foregoing sections that nuclear liability has a few particular features that differ to a significant extent from traditional liability provisions. In particular, the financial cap (the limit on liability) and the channelling of liability to the operator are important features, in addition to the additional funding provided by the state where the plant is located and by all contracting parties. Since operators do not have to pay for additional funding provided by the state, this additional funding can be considered as a subsidy.

### 4.1 Distortions created by the liability subsidy

As has often been stressed in the literature, the most problematic aspect of the international nuclear liability regime lies in the financial caps on liability. As just noted, limiting the liability of the operator is from an economic perspective equivalent to providing it with a financial subsidy. This subsidy has two linked aspects. First, there is the limitation of the operator's liability; second, there is the fact that the state and all signatory states take over the compensation (up to certain limits) when the damage is higher than the capped amount provided by the operator.

As the figures given above demonstrate, the liability limits set by the conventions do not at all relate to the possible magnitude of the damage caused by a nuclear incident. These limits work against the internalisation of risk costs by the operator, since it has to internalise such costs (and cover them) only up to the amount fixed by the conventions. It is implicitly admitted by the conventions that as soon as the cost of a nuclear incident exceeds the limit set by the conventions (which is more than probable), the nuclear operator will not provide complete compensation to the victims. This regime thus protects the nuclear operator and artificially decreases its risk costs. Furthermore, inasmuch as the state pays the compensation from which the nuclear operator is exempted by the conventions, it directly contributes to the lack of internalisation of the risk costs by the operator since it intervenes ex nihilo to cover the risk instead of the operator.

This liability subsidy can potentially create three unwelcome consequences:

1. it may artificially increase the competitiveness electricity produced by a nuclear operator (see section 4.2);
2. it may reduce an operator's incentive to prevent nuclear incidents (see section 4.3); and
3. it may result in inadequate compensation for victims (see section 4.4).

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[27] Les rejets radiologiques massifs diffèrent profondément des rejets contrôlés. See IRSN website: www.irsn.fr/FR/Actualites_presse/Actualites/Documents/FR_Eurosafe-2012_Rejets-radioactifs-massifs-vs-rejets-controles_Cout_IRSN-Momal.pdf

## 4.2 Artificial competitiveness

A first consequence of the liability subsidy is that nuclear operators may enjoy a preferential situation in the energy market compared with other producers that do not receive such a subsidy. Since operators of nuclear plants do not have to internalise the full social cost of their activity, the price of nuclear energy will be artificially lowered compared with energy from other sources, leading to a distortion of competition and reducing the incentive to build other types of power plant.

Moreover, the artificially lowered unit price of nuclear energy sends misleading signals to consumers and potential investors.

In this light, it is legitimate to ask what the impact would be of the complete internalisation of risk costs on an operator's profitability – or in other words, whether this internalisation would be financially sustainable for the operator or not. A recent study estimated the financial impact of the subsidy, taking the example of EDF, the monopoly operator of France's 59 nuclear reactors.[28] The study used as a financial benchmark the average of EDF's annual financial benefit from its financial reports from 2000 to 2006, that is €1.7bn.[29] It calculated various scenarios and analysed how the abolition of the liability cap would affect the price of nuclear energy compared with other energy sources. The study concluded that a removal of this subsidy would not substantially affect the competitiveness of the industry.

## 4.3 Reduced incentive to prevent nuclear incidents

As already noted, a nuclear operator's incentive to prevent nuclear incidents may also be affected by the limited internalisation of costs resulting from the liability subsidy. Since in financial terms the operator does not take into account all the risks it generates, its approach to risk may prove inadequate to prevent incidents. Rationally, the operator will seek to adopt a level of prevention corresponding to the risks it bears. If accordingly it takes as a reference an underestimated level of risk, its preventive actions will necessarily be inadequate and thus insufficient to prevent an incident. Or in other words, the optimality of his level of prevention is determined by the optimality of the level of the considered risks. As a result, a suboptimal estimation of risks leads to a suboptimal level of prevention.

In view of this, to guarantee an optimal level of risk prevention on the part of the nuclear operator, it would be desirable for the operator to be exposed to the whole risk cost engendered by its activities. However, in practice the role of national nuclear regulation and safety authorities is argued to make up the shortfall created by the liability subsidy's weakening of the operator's financial incentive to ensure safety. Incidents like the one in Fukushima, where shortcomings in the regulatory regime appeared to play a significant role, illustrate this might not be a sufficient substitution.

## 4.4 Reduced victim compensation

Another potential consequence of the nuclear liability subsidy relates to the compensation of victims in the event of a nuclear incident. The current international nuclear liability regime fails to provide adequate capacity for compensation. The 2004 Protocol to the Paris Convention, will raise the total amount available under the international regime to €1.2bn at a national level, and at €1.5bn at a transboundary level when it comes into force. However, in spite of this increase from the previous coverage of €700m, the operator's subsidy remains high and a large proportion of the risk costs are still neither internalised nor covered. The new levels of coverage are still too low to cover the potential cost of an incident, particularly a major one. As already demonstrated, in severe cases they would cover at most one per cent of the damage.

Of course, one could argue that insufficient compensation of victims is not an economic consequence, in the sense that whether or not a victim is compensated is primarily a distributional issue rather than an efficiency issue. However, particularly with the catastrophic losses potentially caused by nuclear incidents, that perspective is too simple. The consequences of such incidents can be so devastating for entire (groups of) countries that, for example, financial markets may be completely disrupted, if no guarantee can be given that funds will be available to compensate losses and assist in restoration.

Another consequence of inadequate victim compensation, is that it would be very hard to ensure equal treatment of victims. There is a significant risk that victims who have filed a claim first will be awarded compensation first, while, victims who are later in filing a claim (for example because effects on health become apparent only some time after the incident) face the risk of receiving less compensation or no compensation at all, especially when the compensation already awarded exceeds the limited liability amounts. This possibility raises important issues in terms of equal treatment of victims (guaranteed under Article 14 of the Paris Convention and Article XIII of the Vienna Convention), and also highlights the procedural difficulties likely in the wake of a nuclear incident.

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[28] Faure, M. & Fiore, K., "The Civil Liability of Nuclear Operators: which coverage for the new 2004 Protocols? Evidence from France", 8 International Environmental Agreements, 2008a, 227-248.

[29] The annual financial benefitswere: €1.141bn in 2000, €0.841bn in 2001, €0.481bn in 2002, €0.857bn in 2003, €1.3bn in 2004, €3.2bn in 2005 and €5.6bn in 2006.

# 5 Insurance of nuclear risk

Reactor ageing and lifetime extension may of course have important consequences for the demand for nuclear insurance and financial security and for the price of the cover provided. To the extent that the probability of a nuclear accident increases with ageing, there are consequences for the premiums charged; to the extent that chance (larger chance of failure) and the magnitude of the potential damage (because of a decreasing functionality of protection barriers) may increases, there may be consequences for the necessary scope of cover. This prospect threatens to exacerbate the tendency whereby debate on reform of nuclear liability (for example towards unlimited operators' liability) has always been obstructed by the argument that higher levels of liability than currently provided for by the conventions, and certainly unlimited liability, would be uninsurable. As we will argue below, this argument contains serious fallacies.

First, policymakers have been too much dependent on one-sided information provided by the nuclear industry as to what amounts would be insurable. More recent estimates, for example by nuclear reinsurers, hold that substantially larger amounts could be covered[30]; moreover, it is, as the examples of some EU Member States show, not necessary to link the level of nuclear liability to the available level of insurance coverage on the market. Liability could in principle be unlimited (as in Germany), but the required financial cover could be limited to the amount that could be provided by the market. Policymakers need to become much more critical and rather than relying on one-sided information provided by the nuclear lobby, conduct an objective analysis of cover available on the financial and insurance markets, taking into account information from relevant stakeholders such as large reinsurers.

The remainder of this section, reviews the current arrangements for covering nuclear risk and discusses some of the limits and the alternatives, as well as briefly considering the costs of nuclear insurance and the importance of mandatory financial security.

## 5.1 The nuclear insurance pools

Conventional insurance companies do not provide coverage for damage caused by a nuclear incident – their insurance policies exclude coverage for such damage. Instead, insurance for nuclear damage is generally provided by national nuclear insurance pools.[31] The insurance of nuclear risk by nuclear insurance pools involves a bundling of resources at a national level to meet the demand for insurance coverage.[32]

Most countries with nuclear power plants on their territory have their own national nuclear insurance pool; the effect is that, as far as third-party liability is concerned, a Belgian nuclear operator can buy insurance only from the Belgian pool, a German operator from the German pool, etc. Even if a nuclear operator invites tenders for the most favourable insurance offer, it will only receive offers from its national pool. The monopoly position of the nuclear insurers has been heavily criticised.[33]

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[30] Guy, J. 2011.Munich Re first to create potential pollution liability solution. Business Insurance (online), 20 July 2011. http://www.reinsurancemagazine.com/articles/munich-re-first-create-potential-pollution-liability-solution

[31] See, among others, Belser, W.E. "Über die Zweckmäßigkeit der Poolung von Atomrisiken", 1959 Versicherungswirtschaft, 18, 572 et seq;; Dow, J.C., Nuclear Energy and Insurance, Witherby & Co., 1989.; Nuclear Pools' Bulletin. 1992. Nuclear power: insurance and the pooling system, special edition; Reitsma, S.M.S., "Nuclear Insurance Pools: History and Development", in: Nuclear Accidents: Liability and Guarantees (OECD-IAEA: 1993), 341-347.

[32] Most pools provide coverage for third-party liability as well as damage to the operator itself. The operator's (mandatory) liability insurance generally covers the compensatory consequences of its extra-contractual liability for damage resulting from a nuclear incident, even if the incident was directly due to a serious natural disaster. This policy should be clearly separated from the policy covering potential damage to the operator itself.

[33] Faure, M.G. & Van den Bergh, R., „Restrictions of competition on insurance markets and the applicability of EC antitrust law", 48(1) Kyklos, 1995, 65-85. Faure, M., "Economic Models of Compensation for Damage caused by Nuclear Accidents: some lessons for the revision of the Paris and Vienna Conventions", 2 European Journal of Law & Economics, 1995, 21-43.

The national nuclear insurance pools generally provide not only cover for third-party liability but also first-party insurance for damage caused to a nuclear power plant itself by an incident. This is an aspect of considerable importance, since the amounts available for third-party liability insurance are limited by the amounts made available for first-party insurance. In other words, if the capacity of a nuclear insurance pool is partially used to cover damage to the nuclear power plant, there will be less capacity left to cover third-party liability. It has even been argued by some that the amounts available for coverage of the nuclear power plant should be much higher than the amounts to be made available for the operator's liability toward third parties.[34] One justification for this is that nuclear accidents will always affect the nuclear power plant, causing first-party damage, but will not always affect the surrounding area, which would be required to trigger third-party liability.[35]

Just as in Europe, US operators only can operate a nuclear power plant if they have a licence for that plant, and they can only have a licence if they are able to prove that they comply with the liability insurance provisions of the Price-Anderson Act. The NRC requires each operator to show proof that its liability insurance includes the $375m of primary insurance coverage required under the Price-Anderson Act. The NRC and the operator also sign an indemnity agreement requiring the latter to maintain an insurance policy in the same amount. However, the NRC relies on the US insurers pool American Nuclear Insurers (ANI) to send it an annual confirmation providing proof of insurance after the operators have paid their annual premiums.[36]

In addition to their primary insurance coverage, operators must also show the NRC proof of secondary insurance in the form of the retrospective premiums system. Although this is not a conventional insurance policy like the one in the primary coverage, it seems to be common practice for every nuclear operator to sign a bond for coverage of payment of retrospective premiums as proof of the secondary insurance; every operator needs to send a certified copy of this to NRC. This bond is a contractual arrangement between the operator and ANI that obliges the operator to pay ANI the retrospective premiums if necessary. If a nuclear incident in the US exceeds the operator's primary coverage of $375m, ANI will immediately collect the retrospective premiums from all operators. If an operator fails to pay its retrospective premiums, ANI has to advance up to $30m. In case if an operator fails to pay the deferred premiums for this ANI advance, the NRC reserves the right to pay those premiums on behalf of the operator and subsequently recover them from the operator.

ANI writes nuclear liability insurance for nuclear facilities in the USA, and assumes reinsurance shares on nuclear business written by other nuclear pools and mutual insurers throughout the world.[37] First party (property) insurance is dealt with by Nuclear Electric Insurance Limited (NEIL), a captive incorporated under the laws of Bermuda and based in Delaware, USA.[38] NEIL is one of the existing nuclear mutual insurance systems, the functioning of which will be discussed below.

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[34] Dow, J.C., "The Organisation and Development of International Liability Capacity and National Market Pools with Special Reference to New Nuclear Countries", in: Nuclear Third Party Liability and Insurance: Status and Prospects, München Symposium IAEA/NEA IAEA/OECD, 1985, 172-182.

[35] Müller, W., "The Role of the Insurance Industry in Covering Nuclear Third Party Liability Risks", in Nuclear Third Party Liability Insurance: Status And Prospects, Proceedings Of The Munich Symposium: 10-14th September 1984, 171 (NEA-IAEA, 1985), 166-171. Müller notes: In view of the rising cost of erecting nuclear energy plants, nuclear property insurance, which is likewise borne by the nuclear pools, is under considerable pressure and, in turn, represents an involvement by the insurance industry to the machinery insurance which, in the case of a nuclear power plant, also goes into the millions. Both forms of cover have priority over liability insurance, since a theoretical large scale nuclear occurrence would probably first affect the material assets within the plant, then the surrounding area. It is naive to consider only the third party suffering loss or damage - as occasionally happens - and to regard property insurance as an unnecessary appendage which only absorbs capacity. Every reasonable person knows that a nuclear power plant requires a heavy investment and that not only the operators, but also their creditors, should be protected. It is quite simply foolish to regard the loss of this investment as a sort of 'punishment' for having brought about a nuclear occurrence and to ignore the interests of the power supply company and the investors in safeguarding their material assets.

[36] NRC, 2004. Nuclear regulation. NRC's liability insurance requirements for nuclear power plants owned by limited liability companies. Report to Congressional Requesters, May 2004, 2

[37] ANI's Domestic Syndicate offers third-party nuclear liability insurance to domestic operators of nuclear power reactors, nuclear fuel fabrication facilities, waste disposal and other nuclear facilities. It also writes nuclear liability insurance for suppliers of products or services (including transportation services) to these facilities. The Foreign Syndicate provides reinsurance to foreign nuclear pools for placement at nuclear facilities overseas and in Canada and Mexico. Reinsurance is assumed on a facultative basis. The Foreign Syndicate also writes direct liability coverage for US suppliers of products or services to foreign nuclear facilities.

[38] A significant portion of NEIL is reinsured with ANI.

## 5.2 The nuclear mutual insurance systems

The origins of NEIL go back to 1973 when 14 American nuclear operators created a mutual insurance system called Nuclear Mutual Limited. After the 1979 accident at Three Mile Island, a second nuclear mutual insurer, NEIL, was created. These mutuals (or captives) were created to provide US nuclear operators with an alternative to the insurance offered by the American nuclear insurance pool ANIs.[39]

Today, NEIL insures nuclear reactors and their generating units for costs associated with certain interruptions of electrical generation (in the event of accidental physical damage to insured sites), decontamination expenses and other risks of direct physical loss at insured sites. The primary property programme provides insurance coverage of $500m per occurrence; the excess programme provides property insurance coverage of $2.25bn USD per occurrence.[40] Thus, total coverage of first-party property damage in the USA amounts to $2.75bn.

In the USA, then, there is a clear distinction in nuclear insurance: the American pool (ANI) offers only third-party liability cover. First-party property damage is insured with the operators' own mutual insurance scheme, NEIL. However, NEIL and ANI work closely together as far as reinsurance is concerned. In Europe, there is not such a clear distinction between third-party insurance and first-party property damage insurance, since the nuclear insurance pools offer both. However, in Europe several operators have also joined their forces into two mutual insurance associations.

In Europe, mutual insurance associations were created by nuclear operators as a reaction to the nuclear insurance pools. In 1978, the European Mutual Association for Nuclear Insurance (EMANI) was created with the intention of reducing its members' insurance premiums. EMANI offers cover for certain insurance risks relating not only to nuclear power stations, but also to other nuclear facilities, in several European countries. More specifically, it provides insurance capacity for material damage and business interruption. As EMANI is a mutual insurance association of nuclear operators, the capacity it offers is independent of the capacity of the nuclear insurance pools (the latter being basically associations of 'regular' insurance companies).

At the end of 2002 a second association, European Liability Insurance for the Nuclear Industry (ELINI), was created. Like EMANI, ELINI is a Belgian mutual insurance association; its aim is to provide insurance capacity for its members' nuclear liability risks. ELINI's capacity is again independent of that offered by the various nuclear insurance pools. It is thus able to provide additional insurance capacity for all the headings under the 2004 revised Paris Convention and Brussels Supplementary Convention. It can also offer insurance capacity for terrorism and for the 30-year prescription period. [41][42]

As such, ELINI is the first mutual insurance association of nuclear operators worldwide aiming to offer third-party liability coverage. [43] Whereas NEIL and EMANI are active on the first-party insurance market, ELINI is aiming to develop a (European) third-party liability insurance market – and is thus active in the same market as the traditional nuclear insurance pools.

## 5.3 Limits of the pools

While both in the USA and in Europe the nuclear insurance pools have been able to provide cover for operators' third-party nuclear liability, nevertheless the insurance system they represent has serious deficiencies. One problem is that, as already mentioned, most countries with nuclear power plants have their own national nuclear insurance pool,[44] restricting the insurance options open to nuclear operators.aaathe nuclear operators conducts a tendering exercise for the most favourable insurance offer, it willtheyIt may clear thatIt may clear thatEffectively. these pooling arrangements basically consist of arepresent cartels whereby insurers join forces to exclude competition specifically for the nuclear risk coverage and decide to join forces in order to provide coverage. For obvious reasons, those pools have been subject to debated both from an economic ands well as from a legal perspective. From an economic perspective, the question arose to what extent pools that essentially operate on a non-competitive basis can be reconciled with competition policy.

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[39] Dow, J.C., "The Organisation and Development of International Liability Capacity and National Market Pools with Special Reference to New Nuclear Countries", in: Nuclear Third Party Liability and Insurance: Status and Prospects, München Symposium IAEA/NEA IAEA/OECD, 1985, 172-182. In the 1970s, there were two nuclear insurance pools in the USA; however, since 1998 ANI has been the only one.

[40] NEIL. 2007. Annual Report 2006, p.20.

[41] ELINI. 2011. Annual report 2010, p.16. http://www.elini.net/ELINI_2010_(2011)_FINAL.pdf

[42] To guarantee sufficient compensation for future damage, ELINI makes reserves. The contributions made by members are put into a special bank account and can only been withdrawn after the dissolution of the pool or 30 years after the expiration of its policies.

[43] Faure, M.G. & Vanden Borre, T., "Compensating Nuclear Damage: A Comparative Economic Analysis of the U.S. and International Liability Schemes", 33 William & Mary Environmental Law and Policy Review, 2008, 219-287, p. 257.

[44] See for example Dow, J.C., Nuclear Energy and Insurance, Witherby & Co., 1989, p. 178.

A further problem is that, as explained above, these pools provide coverage for both third-party liability and damage to a nuclear power plant itself (first-party liability), meaning that the two forms of coverage must compete for insurance capacity, potentially to the detriment of third-party coverage.

Concluding, the fact that there is insufficient competition between nuclear insurers also leads to a lack of capacity and limited coverage. Nuclear insurers have urged the removal of first-party liability from the nuclear insurance pools.[45] They have spoken favourably of the prospect of removing the protectionism of the early civil nuclear age and the introduction of a more competitive system for nuclear insurance.[46] Initiatives have been taken by the nuclear industry, in cooperation with some brokers, to withdraw first-party insurance from the nuclear pools and to cover it through a new mutual insurance fund of nuclear power plant operators.[47]

## 5.4 Alternatives: pooling by operators

EMANI was established in 1978, and provides coverage for material damage, business interruption, machinery breakdown, terror and erection all risks. ELINI was created at the end of 2002 to provide insurance capacity for nuclear liability risks. It is the first worldwide nuclear pooling system aimed at providing nuclear third-party liability coverage.

ELINI makes an attempt at establishing an international pooling system for nuclear liability. If the in 2004 revised Paris Convention comes into effect and is accepted by sufficient countries, the additional capacity provided by ELINI may become more attractive. However, given the divergent liability requirements of different countries, and the lack of consistent and harmonised standards on nuclear safety, some nuclear operators may have little interest in establishing a mutual pool. This may be one of the reasons why the mutual associations have developed so slowly since their inception. After several decades, the capacity of EMANI had increased from €150m in its first decade of existence to a still modest €600m in 2010,[48] while the capacity of ELINI stood at a mere € 89m in 2011.[49]

## 5.5 Cost of insurance

There are 28 national nuclear insurance pools worldwide (for example, Assuratome in France, ANI in the USA, British Nuclear Insurers in the UK, Syban in Belgium). Insurers have brought together their capacity into these pools in order to cover the nuclear risk from the installations in their national territory. As a result, these nuclear pools effectively function as monopolies. Moreover, there is no competition between the various national nuclear pools as nuclear operators cannot insure their risks with a foreign pool. As a consequence, the nuclear insurance pools can set their premiums at whatever level they wish. Understandably, this monopolistic aspect of nuclear insurance markets has been criticised by the European Commission from the point of view of competition law,[50] particularly in its reports on the functioning of the EU regulation that exempts specific insurance activities from competition policy provided certain conditions are met.

Given this market structure, it is fair to assume that nuclear insurers are making a significant profit. Although other factors may explain the excessively high premiums paid by EDF in France,[51] it is fair to assume that in general insurance premiums for operators are apparently spectacularly high. As a result, it has unsurprisingly become worthwhile for nuclear operators to seek other ways of covering their nuclear risk, as discussed above.

This brief discussion of the current coverage of nuclear risk also shows that with respect to nuclear ageing and lifetime extension it would be dangerous from a policy perspective to rely too heavily on claims made by the nuclear insurance pools on which coverage for the nuclear risk they are able to make available. Given the highly monopolistic nature of the nuclear insurance market, reliable information on insurability cannot be expected from the insurers involved in the pools. From a societal perspective, and especially with regard to nuclear ageing, it therefore seems more important to make objective actuarial calculations of the potential damage that a nuclear incident could cause and look for alternative sources of coverage. It is obviously important that this approach should be accompanied by mandatory financial security, but this should not be a reason to limit liability.

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[45] See Faure, M.G. & Bruggeman, V. 2007. Catastrophic risks and first-party insurance. Presentation at the 24th Annual Conference of the European Association of Law and Economics in Copenhagen, Denmark: 13-15 September 2007.
http://www.cbs.dk/content/download/67298/930270/file/Véronique%20Bruggeman.pdf

[46] Vigneron, L.L.J., “Discussion in Session II of the Munich Symposium on Nuclear Third Party Liability and Insurance” (Sept. 10-14, 1984), in Nuclear Third Party Liability Insurance: Status and Prospects, Proceedings Of The Munich Symposium: 10-14th September 1984 (NEA-IAEA, 1985), p. 192.

[47] Michael G. Faure (1995) Faure, M., “Economic Models of Compensation for Damage caused by Nuclear Accidents: some lessons for the revision of the Paris and Vienna Conventions”, 2 European Journal of Law & Economics, 1995, 21-43, p. 26.

[48] Faure, M.G. & Vanden Borre, T., “Compensating Nuclear Damage: A Comparative Economic Analysis of the U.S. and International Liability Schemes”, 33 William & Mary Environmental Law and Policy Review, 2008, 219-287, p. 257.
EMANI. 2011[. 2010 annual report, ap.16.

[49] ELINI. 2011. Annual report 2010, p.18.

[50] Faure, M.G. & Van den Bergh, R., „Restrictions of competition on insurance markets and the applicability of EC antitrust law“, 48(1) Kyklos, 1995, 65-85.
Faure, M. & Van den Bergh, R., „Competition on the European Market for Liability Insurance and Efficient Accident Law“, 9(3) Maastricht Journal of European and Comparative Law, 2002, 279-306.
Faure, M. & Hartlief, T., Insurance and Expanding Systemic Risks, Paris, OECD, 2003.

[51] For an overview of those other possible explanations see Faure, M. & Fiore, K., “The Civil Liability of Nuclear Operators: which coverage for the new 2004 Protocols? Evidence from France”, 8 International Environmental Agreements, 2008a,227-248.

# 6. The need for a new compensation model

In the context of ageing nuclear reactors and their lifetime extension, it becomes all the more necessary to provide adequate financial security and/or reserves to cover the potential cost of an incident. One of the main problems with the nuclear liability conventions is that they suggest that all financial security should be covered by insurance. This is problematic given the monopolistic situation of the nuclear insurance market. As the foregoing discussion of that market has suggested, a considerable degree of "out of the box"-thinking is necessary to develop alternatives to the current monopolistic market that has never been able to generate substantial amounts of compensation. Various proposals have been formulated, in the literature, but increasingly also by relevant stakeholders from the international reinsurance industry. In this light pooling by operators, as developed in ELINI and EMANI, may represent a good alternative to the existing nuclear insurance pools.

## 6.1 The basic principles of a new compensation model

It goes without saying that a new compensation model for nuclear damage should keep the positive elements of the international nuclear liability conventions: strict liability and compulsory liability insurance. Under a system of strict liability, a victim does not need to demonstrate any fault or negligence, which is why this principle is applied to a variety of dangerous activities. Moreover, strict liability makes good sense from an economic viewpoint. In unilateral accident cases such as nuclear accidents (where only one party, the operator, has full overview of all factors and actors that can influence the accident risk) only strict liability leads to full internalisation of the accident risk, since it gives the operator the incentive not only to follow optimal care but also to adopt an efficient activity level.[52] Law and economics research has also demonstrated the usefulness of compulsory liability insurance, especially inasmuch as it protects victims of a nuclear incident against the operator's insolvency.

As already indicated, the system of limited liability, with states making additional sums available for compensation, acts in effect as a subsidy to the nuclear industry.

The argument traditionally used in defence of state subsidy of compensation is that, given the catastrophic nature of a nuclear accident, it is right for the state to pick up at least part of the cost. However, other industrial activities are also capable of causing catastrophic damage – yet (as far as the authors of this chapter are aware) there is no other sector for which the state in any country has consented ex ante to make public funds available.[53] Admittedly, from an economic point of view, there are arguments that can explain why, in an initial phase, a country might intervene and makes public money available in compensation for damage caused by a private entity. Indeed, in the 1960s the role of the state was largely conceived in terms of a response to the inadequacy of information available at that time. In the early years of the development of nuclear power plants no one, not even insurers, had any reliable data about either the probability or the possible costs of a nuclear accident. From an economic point of view it can make sense for the state to put public funds on the table for a short period of time. Exactly these reasons were put forward by the authors of the Preliminary Report[54] to call for government intervention. The USA has, however, been faithful to the economic logic of making public funds available only temporarily, and it abolished public funding of compensation in 1982. The parties to the international conventions seem to have forgotten this economic lesson, since the revised conventions actually provide for a higher level of public funding (in the case of the Paris Convention) or introduce such a provision for the first time (Vienna Convention, as well as the CSC).

Various objections to the legal channelling of all liability to the nuclear operator have already been indicated. However, it is worth looking at the alleged advantages of legal channelling from an economic viewpoint. Both the Harvard Report[55] and the preparatory work for the international nuclear liability conventions claim that exclusive liability of the nuclear operator has several advantages in terms of the costs of legal proceedings following a nuclear incident. The reasoning was that reducing the number of possible defendants would reduce administrative and legal costs. However, it has been shown that in the event of a catastrophic incident, the high administrative and legal costs relate in the first place to the huge number of plaintiffs (the victims of the incident) and much less to the number of defendants (the nuclear operator and, potentially, its suppliers).[56]

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[52] Trebilcock, M. & Winter, R.A., "The Economics of Nuclear Accident Law", 17 International Review of Law & Economics, 1997, 215-243.
Shavell, S., "Damage Measures for Breach of Contract", 11 Bell Journal of Economics, 1980, 466.
See also section 4.3

[53] The situation is different ex post when government may, for example after a national catastrophe, provide disaster relief. But this usually occurs only when no solvent debtor can be identified, as in cases of terrorism or natural disaster, but less so with manmade disasters.

[54] Arthur W. Murphy, 1956. Preliminary report on financial protection against atomic hazards. Atomic Industrian Forum, Inc. New York

[55] Polach, J. G., 1960. International problems of financial protection against nuclear risks, a forum report. The American Journal of Comparative Law Vol. 9, No. 1 (Winter, 1960), pp. 130-133. American Society of Comparative Law.

[56] Vanden Borre, T., Efficiënte preventie en compensatie van catastroferisico's. Het voorbeeld van schade door kernongevallen, Antwerp, Intersentia, 2001, p. 698.

During the preparatory work for the conventions, it was claimed that the restriction of the number of persons potentially liable (to the nuclear operator alone and not its suppliers) would bebeneficial to the victims of a nuclear incident. However, from the viewpoint of the victims it is surely more beneficial to be able to address a claim against several persons (corporations), as this can increase their chances of receiving compensation. This extension of liability would also have preventive effect, since all persons with an influence on the nuclear risk would have an incentive to avoid an incident.

Giving victims the ability to introduce a claim against several persons is likely to increase the procedural costs of the nuclear incident. However, this increase is unlikely to outweigh the benefits in terms of prevention and compensation of victims of a nuclear incident. The system of economic channelling, as under the Price-Anderson Act, can provide a better alternative since it keeps the liability of potentials injurers (including suppliers) intact while multiple lawsuits can still be dealt with before the same court.

The argument that legal channelling helps victims because they do not need to identify the possible person(s) liable is also not very convincing, since victims will be able to benefit from qualified legal assistance from specialised lawyers etc.

In short, there seems no good reason to maintain legal channelling. The economic channelling stipulated by the Price-Anderson Act does not have the negative features of legal channelling and should therefore be favoured. .

On the basis of the above analysis, the authors of this chapter are of the opinion that countries that consider reactor lifetime extension should abolish public funding of compensation, allow for the liability of nuclear suppliers, and introduce a system of unlimited liability of the nuclear operator while requiring it to have third-party liability insurance or other financial security up to a certain amount.

## 6.2 Alternative financial schemes

### 6.2.1 Advantages of risk sharing

A risk-sharing agreement is a system whereby operators mutually agree to share each other's losses. It resembles insurance, but there are, as will be explained in more detail, a few fundamental differences. The basic difference is that insurance involves a third party (the insurance company) whereas in a risk-sharing scheme the operators are both insured and insurer; there is hence no involvement of a third party.

Nuclear operators' risk pools[57] and pools under protection and indemnity (P&I) clubs[58] are examples of risk-sharing agreements. It is the potential injurers themselves that finance the risk pool: they can either make an advance payment or constitute an ex ante risk-sharing agreement. Such arrangements are referred to either as risk-sharing schemes, risk-sharing institutions[59] or mutuals[60] in the literature.

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[57] In the nuclear industry, as already explained, insurance is often supplied by a monopolist in a jurisdiction. i.e. a nuclear insurance pool., which leads to high premiums and limited coverage. Accordingly, some effort has been made by nuclear operators to establish their own risk pools to cover their third-party liability or damage to their own property. The retrospective premium system under the Price-Anderson Act and the NEIL mutual insurance system established by US operators are examples. The Price-Anderson Act was originally enacted by Congress in 1957 to amend the Atomic Energy Act of 1954 (Public Law 85-256).

[58] A P&I club is a non-profit-making mutual insurance association established by ship-owners and charterers to cover their third-party liabilities. Currently, 13 main clubs together make up the International Group of P&I Clubs, accounting for approximately 90 per cent of the world's ocean-going tonnage. See http://www.igpandi.org.

[59] M. Faure and G. Skogh have discussed risk-sharing agreements as an alternative compensation mechanism for environmental damage and nuclear damage. See:
Faure, M., "Alternative Compensation mechanisms as a remedy for insurability of liability", The Geneva Papers on Risk and Insurance, 2004, 455-489.
Faure, M. & Skogh, G., "Compensation for Damages caused by Nuclear Accidents: a Convention as Insurance", 17 The Geneva Papers on Risk and Insurance, 1992, 499-513.
Skogh, G., "Risk-sharing Institutions for Unpredictable Losses", 55(3) Journal of Theoretical and Institutional Economics, 1999, 505-515.
Skogh, G., "A European nuclear accident pool. A proposal based on the restated diversification theorem", working paper, paper presented at the joint conference of the European Association for Law and Economics (EALE) and the Geneva Association for the Study of Risk and Insurance, Lecce, 15-16 June 2007.

[60] See Bocken, H., "Alternative Financial Guarantees for Environmental Liabilities under the ELD", European Energy and Environmental Law Review, 2009, 146-170.

A risk-sharing agreement has a few important theoretical advantages over (and differences from) insurance:

- It creates strong incentives for mutual monitoring, since the members are dependent on each other, i.e. a bad risk can create the likelihood that the members will have to intervene.
- In the case of highly technical and complicated (particularly new) risks, operators themselves may have better information than insurers regarding the best preventive technologies, which they can reflect in a differentiation of contributions to the scheme (or by withdrawing membership from bad risks).
- A risk-sharing agreement does not require actuarial information ex ante on the probability of an incident and the scope of the potential damage, for the simple reason that no ex ante premium has to be fixed. Information is needed only on the relative contribution of each member to the risk, but this does not necessarily have to be translated into a premium. Ex ante costs to administer a risk pool can hence be lower, especially in cases where actuarial information may not be available (for example because the risk is new and statistical information is lacking).
- Since ex ante premiums do not have to be paid, risk-sharing creates less liquidity problems. It can be based on an agreement between the members to share on the moment that the damage emerges.
- Unlike with insurance, when damage does not occur, no premiums have been paid to an insurance company that are (at least in the view of the operator) ‘lost’. If the damage for which the risk-sharing agreement is concluded does not emerge, the members of the scheme simply do not have to contribute.
- This also points to the relative flexibility of a risk-sharing mechanism: if during a particular period a number of accidents happen, the scheme can ex post ask for additional contributions from its members on an ad hoc basis.

However, while a risk-sharing mechanism may have all these advantages if the number of members is relatively restricted, when the membership is very large (e.g. all car drivers in a particular area) the administrative costs of running the scheme become disproportionately large and the comparative benefits vis-à-vis insurance disappear. Moreover, the comparative benefits apply mostly to highly technical (and new) risks.

### 6.2.2 Risk-sharing for marine oil pollution

The international regime dealing with marine oil pollution compensation has been developed since the late 1960s as a reaction to some major oil spill incidents. Initially, as a reaction to the 1967 Torrey Canyon spill, two international conventions were established to provide compensation for pollution victims: the International Convention on Civil Liability for Oil Pollution Damage 1969 (the CLC 1969)[61] and the International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage 1971 (the Fund Convention 1971).[62] The CLC 1969 imposes strict liability exclusively on the registered ship-owner up to a certain amount, along with a requirement for compulsory insurance or financial guarantee for pollution liability. The most popularly used instrument is insurance, especially P&I policies.

The insurance of ocean-going ships is provided mainly by so-called P&I clubs.[63] Thirteen P&I clubs form the International Group of P&I Clubs (the Group).

One important characteristic of the P&I clubs is that they are risk-sharing agreements rather than private insurers. The ship-owners are both insurers and insured. This gives them an incentives to exercise mutual monitoring via the P&I clubs.

The Group provides reinsurance for the P&I clubs. At present, for the ship-owners’ policies, each club retains the first $8m as its retentions. The amount between $8m and $60m is divided among all the clubs. The Group’s captive insurer (Hydra Insurance Company) and reinsurance with the international insurance market also play an important role in providing reinsurance for the upper layers. This brings the upper limit of the reinsurance programme to $3.06bn. Of this amount, compensation for oil pollution is limited to $1.06bn.[64] The large market share of the P&I clubs and the potential restriction on competition posed by their sharing agreement and International Group Agreement have led to concerns being raised by the European Commission.[65]

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[61] The original CLC was adopted in 1969 and revised in 1992 (hereinafter the CLC 1969 and the CLC 1992). For the CLC 1969, 973 UNTS 3, RMC I. 7.30, II 7, 30; for the CLC 1992, see Misc 36 (1994), Cm 2657, RMC I, 7.51, ii. 7.51.

[62] The original Fund Convention was adopted in 1971 and revised in 1992 (hereinafter the Fund Convention 1971 and the Fund Convention 1992). For the Fund Convention 1971, see 1110 UNTS 57, Cmnd 5061; for the Fund Convention 1992, see RMC I.7.111, II.1.7.111, Misc 37 (1994), Cm 2658

[63] Coghlin, T.G., “Protection and Indemnity Clubs”, Lloyd’s Maritime and Commercial Law Quarterly, 1984, 403-416.
Faure, M. & Hartlief, T., Insurance and Expanding Systemic Risks, Paris, OECD, 2003.

[64] http://www.igpandi.org/Group+Agreements/Pool+reinsurance+programme.

[65] The European Commission opened formal proceedings to investigate whether the agreements between the P&I Clubs might infringe European anti-trust rules on 26 August 2010 (http://europa.eu/rapid/pressReleasesAction.do?reference=IP/10/1072&format=HTML&aged=0&language=EN&guiLanguage=en). This investigation closed in 2012 with the conclusion that it could not confirm the concerns over anti-trust issues (European Commission. 2012. Antitrust: Commission closes investigation in P&I Clubs case, press release, available at: http://europa.eu/rapid/press-release_IP-12-873_en.htm).

### 6.2.3 Toward an EU nuclear risk-sharing scheme?

Given the theoretical advantages of a risk-sharing agreement compared with insurance and given the positive example of the maritime insurance sector (with the P&I Clubs and the International Oil Pollution Compensation Fund financed by operators), the suggestion has been madein the literature that a risk-sharing agreement could also constitute a solution for nuclear liability at the international level. It has also been argued that when the Paris and Vienna Conventions were revised, risk pooling between operators would be able to generate substantially larger amounts of coverage than are currently available for nuclear damage under the international conventions.[66]

The possibilities and financial consequences of risk-sharing by operators in Europe have been analysed in detail in a study co-authored by one of the authors of the present chapter.[67] Notwithstanding the theoretical advantages of risk-sharing by nuclear operators, a Europe-wide operators' nuclear liability pool has so far not emerged. European countries with nuclear power plants have varying political, legal and economic circumstances, which creates a challenge for international pooling. This may be less of a problem in the EU, whose Member States already share other transboundary risks. Since pooling is based on trust and confidence, it should be possible for EU operators to conduct mutual monitoring or set up an organisation to monitor the risks of its members. However, an EU-wide approach towards safety regulation and standards, and a single regulatory body, are still lacking.

### 6.2.4 An EU Price-Anderson Act: retrospective pooling?

As noted in section 3, the Price-Anderson Act that regulates nuclear liability in the USA stipulates multiple layers of coverage. There is one aspect of the US system's compensation provisions that merits particular attention. If an accident creates damage in excess of $375 million, payment of a retrospective premium is required from all American nuclear operators licensed by the NRC, up to a maximum of $121.255m each. This arrangement is similar to a risk-sharing agreement, with the crucial difference that it is a mandatory system imposed by statute.

The retrospective premiums can be paid over a number of years, up to an annual amount not exceeding $18.963m per incident. Since the obligation to pay arises only after damage has occurred, a special arrangement is needed to ensure that operators are able to pay their retrospective premiums in the case of damage. According to NRC regulations, operators need to provide one of the following guarantees: a surety bond, a letter of credit, a revolving credit/term loan arrangement, the maintenance of escrow deposits of government securities, an annual certified financial statement, or some other type of guarantee approved by the NRC.[68]

If an operator fails to pay the retrospective premium, the nuclear pool ANI advances the necessary sum and after failure to pay this premium, the NRC reserves the right to pay it on the operator's behalf and then recover it from the operator.[69] The NRC does not differentiate limited liability companies from others and does not conduct in-depth financial reviews to determine operators' ability to pay retrospective premiums. ANI, however, requires limited liability companies to provide a letter of guarantee from their parent or other affiliated companies with sufficient assets to cover retrospective premiums as a condition of issuing a bond for payment of retrospective premiums.[70]

### 6.2.5 Munich Re proposal

#### *6.2.5.1 Compensation for oil spills*

An interesting proposal has been developed by the largest reinsurer in the world, Munich Re. After the Deepwater Horizon incident in the Gulf of Mexico, Munich Re developed an instrument referred to as SOS (Sudden Oil Spill) which would be able to generate aggregate amounts up to $10–20bn of cover for companies engaged in offshore oil exploration. The concept was developed to cover drilling operations in the USA and more particularly in the Gulf of Mexico.[71]

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[66] Faure, M., "Economic Models of Compensation for Damage caused by Nuclear Accidents: some lessons for the revision of the Paris and Vienna Conventions", 2 European Journal of Law & Economics, 1995, 21-43.

[67] Faure, M.G. & Fiore, K., "The Coverage of the Nuclear Risk in Europe: Which Alternative?", 33 The Geneva Papers on Risk and Insurance, 2008b, 288-322.

[68] 10 C.F.R. § 140.21.

[69] GAO (2004), Report to Congressional Requesters, Nuclear Regulation: NRC's Liability Insurance Requirements for Nuclear Power Plants Owned by Limited Liability Companies, p. 8.

[70] GAO (2004), Report to Congressional Requesters, Nuclear Regulation: NRC's Liability Insurance Requirements for Nuclear Power Plants Owned by Limited Liability Companies, p. 9.

[71] Guy, J. 2011.Munich Re first to create potential pollution liability solution. Business Insurance (online), 20 July 2011. http://www.reinsurancemagazine.com/articles/munich-re-first-create-potential-pollution-liability-solution

The instrument would require the participation of multiple insurers and reinsurers and would be strongly reliant upon improved risk management. There would be three different models under which the facility could work: a consortium of insurers and reinsurers, each providing uniform prices and conditions and fixed capacity; traditional insurance or reinsurance on a subscription basis, with flexible pricing, conditions and limits; or a pool for oil drilling companies with contributions reflecting market share.[72] Munich Re made clear that this instrument would require the raising of the limit of coverage of $75m currently stipulated in the US Oil Pollution Act. Coverage would moreover only be provided above a retention of $1–1.5bn.[73] Munich Re itself would commit as much as $2bn to provide the total cover of $10–20bn.[74]

The mainbasic reason why the instrument would enable a much higher level of coverage to be generated is that separate coverage would not be provided for each installation, as is the case today. Such a high level of cover can only be provided if it is constructed as natural catastrophe (NatCat) cover. Although de facto third party liability would still be covered, the structure of the facility would be different.

Normal liability cover for an offshore installation provides on average only £1bn of coverage. The reason is that such cover is potentially a long-tail liability risk, meaning that not all damage ensues in the first moments after an accident but is spread over a long time. The originality of the proposed instrument is that it transforms a long-term into a short-term risk, just as in the case of NatCat cover. Today natural catastrophes are insured against in many countries  for several billions of dollars

### 6.2.5.2 Proposal for nuclear liability

Within the European Commission an expert group has been working on a proposal to generate substantially higher amounts of nuclear liability cover than are currently available in the current regimes. Again, an important role is being played by Munich Re, which presented a proposal within its working group whereby the national nuclear insurance pools would provide coverage up to €2bn while Munich Re creates a second layer providing coverage between €2bn and €10bn. The coverage type would be the same as for natural catastrophes. This would mean that others could participate in the facility and, for example, provide coverage for €10m for one year. Long-tail risks would hence be excluded. This approach would be more like a capital market solution. If during the year no incident occurred, the participating insurer could take its benefit and withdraw from the facility.[75] A condition for intervening through such a facility would be that damage was of a sudden and accidental nature, again excluding long-tail risks. Munich Re itself would of course not generate the total capacity, but would invite others to participate in the facility. Risk differentiation via the facility would be minimal: the assumption would be that there would be an EU-wide regulation of nuclear risk that would result in stringent mandatory standards for all operators.[76]

### 6.2.5.3 Pooling as a solution to generate higher amounts of cover?

The examples already considered of risk-sharing in the nuclear sector have shown that one of the theoretical advantages of a risk-sharing agreement (the strong incentive for mutual monitoring) is only realised if there is a certain level of harmonisation of safety regulation. If operators can at least rely on the fact that all members will have to comply with minimum safety regulations, their new task of mutual monitoring will be relatively limited. Since such safety regulations are enforced in the USA by the NRC, risk sharing is easier in the USA than in Europe, where there has been considerable reluctance given the absence of mandatory Europe-wide safety requirements.

This offers an important lesson at the policy level: if a policy-maker (such as the European Commission) wishes to stimulate risk sharing by operators, it can play an important role by providing minimum safety standards, thus reducing the need for very intensive mutual monitoring. In the absence of minimum safety standards, there will always be a risk of negative redistribution and adverse selection, since in these circumstances the risk-sharing agreement will be most attractive to the bad risks, as a result of which the good risks will not be willing to join.

In this connection another interesting lesson (although perhaps with less straightforward policy implications) may be drawn from the Price-Anderson Act, under which substantial amounts of cover are generated in a second layer (unlike the nuclear liability regimes under the international conventions, which effectively provide large subsidies to the nuclear industry by state underwriting of risk). However, risk sharing is mandated by the Act rather than being voluntary. The way risk sharing is arranged under the Price-Anderson Act has, however, the advantage that funds do not have to be made available upfront, as a result of which the tying up of significant financial capacity is avoided. Moreover, the NRC prefinances the second layer of cover and then calls for contributions from all operators via limited annual retrospective premiums. Guarantees are provided that the operators will be able to meet their obligations. This model seems more attractive than the compensation regime under the international conventions.

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[72] Coccia, R. 2010. Munich Re outlines liability coverage innovation for offshore oil risks. Business Insurance (online), 12 September 2010. http://www.businessinsurance.com/article/20100912/NEWS/100919977

[73] Guy, J. 2011.Munich Re first to create potential pollution liability solution. Business Insurance (online), 20 July 2011. http://www.reinsurancemagazine.com/articles/munich-re-first-create-potential-pollution-liability-solution

[74] Suess, O. 2010, Munich Re , brokers work on deepwater oil-drilling cover after Gulf spill. Bloomberg news (online). http://www.bloomberg.com/news/2010-12-21/munich-re-brokers-work-on-oil-drilling-cover-after-gulf-spill.html

[75] Interview with Hermann Kramer, Munich Re Insurance Company, 12 March 2013.

[76] Interview with Hermann Kramer, Munich Re Insurance Company, 12 March 2013.

# 7 Conclusions

Countries that opt for reactor lifetime extension should do so only in the context of substantially improved arrangements for compensation of victims of a nuclear incident – a higher level liability will not only be beneficial for the victims of a nuclear incident but will also have an important preventive effect.

There seems to be little doubt about the advantages of some of the principles of the international nuclear liability regimes, especially as far as strict liability and compulsory insurance are concerned. There has, however, been much criticism of legal channelling, limited liability and state funding. Strict liability favours victims because they do not need to prove negligence or a fault on the part of an operator in order to be compensated. Compulsory insurance guarantees that a certain level of compensation will be available even if, for example, an operator goes bankrupt after a nuclear incident.

The other principles of the conventions were created in favour of the nuclear industry: the limitation of liability is the most striking example of this. The amount of limited liability was set not as a function of the potential cost of the damage caused by an incident, but as a function of the capacity of operators to buy financial security for their third-party liability. Limited liability is an effective subsidy to the nuclear industry and should be abolished. Nuclear operators must be subject to unlimited liability just like any other industrial corporations.

Concentration of liability (legal channelling) also clearly favours the wider nuclear industry because suppliers cannot be held liable for damage caused by goods or services they supplied. Closely linked to concentration of liability is the concentration of jurisdiction. The aim of this provision is to guarantee that no judge in a country other than that where the incident occurred will accept jurisdiction and apply legislation denying limited and concentrated liability. Overall, the balance of the conventions is largely to the advantage of the nuclear industry, which is unsurprising given that their principles are based on studies conducted on behalf of the US Atomic Forum the mentioned Preliminary and Harvard studies).

Given the conclusion that a nuclear operator should not be able to benefit from any limitation of liability, there is little advantage in advocating that the liability levels of power plants whose reactors have been granted lifetime extensions should be higher than those of other nuclear power plants. To allow such a difference would be implicitly to favour limited liability for ‘non-extended’ reactors. There is no reason why non-extended reactors should continue to receive such a subsidy.

The question then arises whether given its larger risk, a life-extended nuclear reactor should perhaps be subject to a higher level of compulsory liability insurance. Such a proposal is unconvincing. If European operators were pooled in an US-type system of retrospective premiums, the operators would mutually monitor one another. We can assume that they would not allow a bad risk into their system. If a life-extended reactor represented a higher risk, this would inevitably be reflected in the premium demanded of the operator.

Another severe criticism of the current nuclear compensation system offered by the conventions is that it would potentially compensate only about one per cent of the damage caused by a major nuclear incident. This situation needs to be changed not only in the framework of reactor lifetime extension, but also for all current and newly built nuclear power plants.

In order to create an incentive for nuclear operators to search for all available capacity for third party liability coverage, a rule should be introduced according to which first-party insurance cover can never be higher than the amount available for third-party liability.

Given the clear advantages of the US nuclear liability and insurance system, other countries should envisage the creation of a similar model. It is true that the US system is not perfect either, since for example it also limits operators’ liability. Moreover, the retrospective premium creates a potential insolvency risk, while it is to be feared that the US Government would intervene if damage were to exceed the second tier of coverage. However, the Price-Anderson Act does internalise the costs of a nuclear accident to a much greater extent than the system defined by the nuclear liability conventions.

The key issue in an enhanced model of nuclear liability would be the phasing out of all state funding of nuclear compensation schemes. In other words, the EU’s current collective state funding needs to be replaced by a collective tier funded by the EU nuclear operators. Plant lifetime extension should only be allowed if such an enhanced system of compensation is adopted.

# Politics, public participation and nuclear ageing

Ir. Jan Haverkamp[1]

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[1] Although the author works for Greenpeace, the views in this chapter are his own as independent expert and do not necessarily coincide with those of Greenpeace.

## Content

# 1 Introduction

This chapter explores  the means by which the public can influence decisions on the lifetime extension of nuclear reactors. As already described in earlier chapters, the decision to extend the lifetime of an ageing nuclear reactor is made on the basis of interactions between a range of factors. Nuclear safety is one of these, and at least in terms of nuclear public relations it is given priority. Reality shows, however, that economic or political arguments can play an overriding role.

This was illustrated during the first stage of the German nuclear phase-out. In the legislation introduced in 2002 by the then Red-Green government, Germany's reactors were allocated a maximum lifetime of 32 operational years each, but with the possibility of operational time being transferred from one reactor to another. The original idea was that operators could close older designs that fulfilled lower safety standards than newer reactors, and transfer their remaining operational years to their newer designs. This was a logical move from the point of view of safety. However, operators counted on the nuclear phase-out decision being overthrown by a subsequent Christian Democrat-led government. Accordingly they shifted operational years from their newer reactors to their oldest ones in order to keep them open long enough for such a change in policy to take effect, so that they could then take advantage of the renewed possibility of lifetime extension. Given the large profit margins on the operation of old reactors, this economic logic prevailed over the priority of safety. We now know that this trick backfired after what the entire nuclear industry feared most: another accident level 7 on the International Nuclear Event Scale (INES), this time three-fold, at Fukushima, Japan on 11 March 2011. The aphorism "a nuclear accident anywhere is a nuclear accident everywhere", first coined by nuclear physicist Alvin Weinberg to describe the wide impact of the Chernobyl catastrophe, turned into an economic slogan: every nuclear accident has a direct influence on the chances of development of the entire industry worldwide. And most spectacularly so in Germany, where the oldest eight reactors were immediately closed down and the lifetime of the remaining reactors strictly limited to a period between 33.5 and 37 years with the last one to be closed in 2022.

Even though this story leaves the impression that, in the minds of operators and some politicians, safety is the least important when deciding to limit the operational lifetime of nuclear power stations, the safety argument plays a key role in economic and political debates about how long reactors are allowed to operate. As Chapter 2 shows, falling gas prices have meant that in the USA safety upgrades of nuclear power plants have not been economically viable in recent years, which led to early closure of reactors. Again, concerns about the lack of capacity of the city and port of Antwerp to respond to a beyond design basis accident at the Doel nuclear power plant in Belgium have unquestionably played a role in the decision not to prolong the 40-year lifetime of its oldest reactors by another 10 years, whereas the Tihange 1 reactor near the city of Liège did receive such an extension.

As Chapter 1 explains, in terms of nuclear safety we are entering a new era of risk. Due to the short-lived nuclear construction boom starting in the 1970s, the number of reactors operating beyond their originally foreseen design lifetime of 30 or 40 years is growing rapidly. And after Fukushima, public concerns around nuclear power are growing as well. These anxieties have already brought a de facto end to the nuclear renaissance previously talked up by the industry, with reactor construction worldwide slowing considerably.[2] However, the industry is also weary of any increase in public concern about old reactors, hiding the reality behind acronyms such as PLEX (plant life-time extension) or the more recently introduced term LTO (long-term operation). Few people know that these terms denote plans to increase  the lifetime of what are already outdated nuclear designs by 50 or even 100 per cent. If they knew, many might feel that this was an unacceptable gamble on technology.

This chapter aims to investigate the opportunities available to the public to engage with the decision-making process in order to highlight the risk of continuing to operate ageing nuclear power stations and to counter the power of economic and political arguments.

Figure 4.1 shows in which European countries ageing nuclear reactors are currently an issue. It indicates what percentage of each country's nuclear reactor fleet will reach its design lifetime (and thus be due for lifetime extension) in the coming three years, and where public debates are therefore most opportune. It also shows what percentage of each national nuclear reactor fleet is over 30, 35 and 40 years old.

Later in this chapter, we will see in more detail how, especially around the date of a reactor's design lifetime, the Espoo Convention gives citizens the right to demand involvement in the debate on lifetime extension. The Implementation Commission of the Espoo Convention on Environmental Impact Assessment in a Transboundary Context concluded that a decision to prolong the lifetime of a nuclear reactor should automatically trigger a full environmental impact assessment (EIA), including a public consultation.

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[2] Schneider, M., Froggatt, A. et al. 2013. The world nuclear industry status report 2013. Mycle Schneider Consulting, Paris & London. http://www.world-nuclearreport.org/-2013-.html
Schneider, M. 2014. World nuclear industry status on 1 January 2014. http://www.worldnuclearreport.org/World-Nuclear-Industry-Status-on-1-235.html

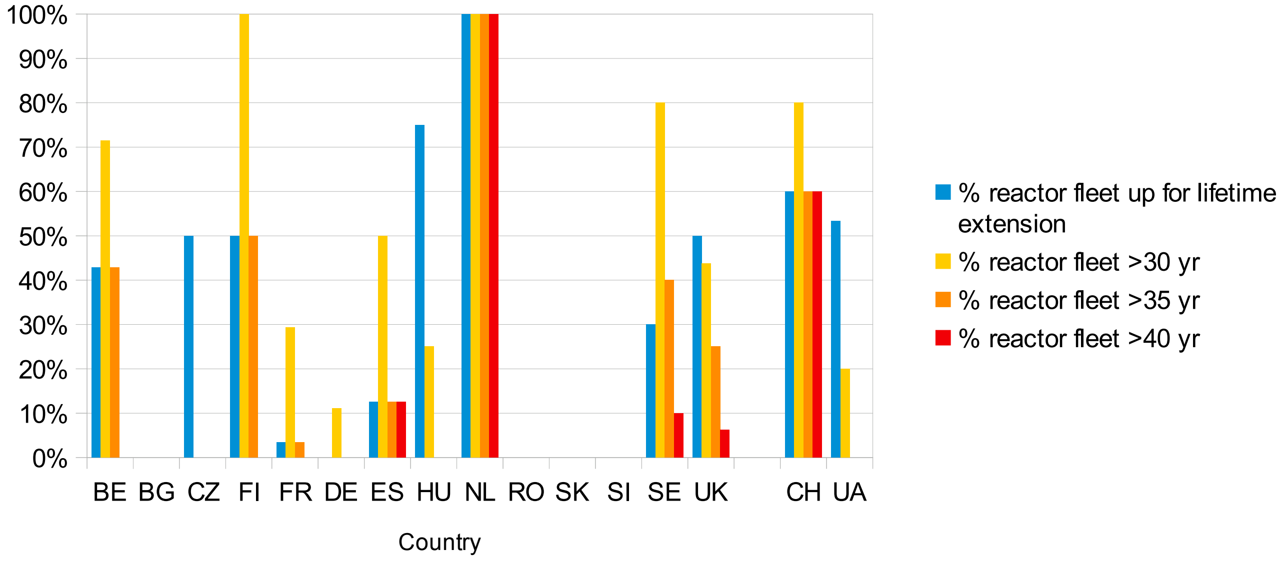

**Figure 4.1** – Ageing nuclear reactors in Europe. Source of data: IAEA PRIS database http://www.iaea.org/PRIS

## 2 Decisions about lifetime extension

As described in Chapter 2 , different countries have different regulations governing nuclear reactor lifetime extension.

### 2.1 Limited operating licence

In this category we find countries such as Hungary and the USA. Hungary awarded its reactors (all at the Paks power plant) a 30-year operating licence, while the USA gave all its reactors  an initial licence for 40 years. At the end of these respective periods, a new licence must be awarded if operation is to continue, and in both cases the renewal application is for a 20-year period.

### 2.2 Unlimited operating licence

In most countries in Europe, nuclear reactors have received some form of unlimited operating licence at the start of operation. The reactor is thereafter allowed to run as long as the country's nuclear regulator agrees to its continued operation. After every outage – whether planned, for fuel change and/or maintenance, or unplanned – the regulator has to give permission for the reactor to restart. However, a reactor's design lifetime still represents an important psychological point of focus for nuclear operators. In the Czech Republic, the State Office for Nuclear Safety (SÚJB) reached a gentlemen's agreement with the operator ČEZ that the latter could count on a positive approach from SÚJB to a 20-year lifetime extension of its VVER 440 reactors at the Dukovany power plant, provided that certain upgrades were implemented before the reactors reached the end of their 30-year design lifetime. These upgrades had to be implemented before ČEZ could submit a formal request to SÚJB to restart the reactors.[3]

In the Netherlands, the privatised operator of the Borssele power plant, EPZ, argued during the early 2000s successfully that an earlier political decision to close its reactor after 40 years had no force as long as the Dutch nuclear regulator deemed the reactor safe enough, because it had an unlimited operating licence. It threatened to pursue compensation claims if the Dutch government enforced earlier closure.[4]

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[3] SÚJB. 2010. First Czech nuclear power plan [sic] turns 25.
http://www.sujb.cz/en/news/archive/first-czech-nuclear-power-plan-turns-25/
Joint Project. 2013. PLEX in Czech Republic. http://www.joint-project.org/plexcz2012.htm

[4] WISE Amsterdam. 2005. Netherlands: discussion on Borssele closure date. WISE/NIRS Nuclear Monitor 628, 27 May 2005, p 2.
http://www.nirs.org/mononline/nm628.pdf
WISE Amsterdam. 2005. Perverted deal: Borssele NPP to stay open. WISE/NIRS Nuclear Monitor 634, 16 September 2005, p. 11; http://www.nirs.org/mononline/nm634.pdf

## 2.3 Periodic safety review

The West European Nuclear Regulators Association (WENRA) strongly recommends a so-called periodic safety review (PSR) at least every 10 years,[5] in which the operator has to identify areas of potential improvement that are then assessed by the national regulator. In France, the operator is obliged to implement measures prescribed by the regulator, the Autorité de Sûreté Nucléaire (ASN) (the prescriptive model). However in Sweden, for example, the operator has to propose concrete measures to meet more general criteria set by the regulator, the Strålsäkerhetsmyndigheten

(SSM) (the reactive model). One of the reasons for this difference is the sheer size of the ASN in comparison with the SSM. The ASN has a lot of in-house expertise, and can also draw on the assistance of a relatively large technical support organisation, the Institut de Radioprotection et de Sûreté Nucléaire (IRSN). Other countries in Europe employ a hybrid between the prescriptive and reactive models, though mostly leaning to the reactive side. Because of this, PSRs rely strongly on the initiative of the nuclear operator.

## 2.4 Politically limited reactor lifetime

As Chapter 2 explains in more detail, some European countries have introduced legislation limiting reactor lifetimes. Germany enforced a closing date for its reactors after the Fukushima disaster. Belgium limited the lifetime of its reactors to 40 years, with the exception of Tihange 1, which was allowed to operate up to 50 years. In these cases, further extension of lifetime would require a change in the law.

Thomas already pointed out in Chapter 2 that most reactor closures in Europe have been based on political decisions.

# 3 Factors negatively influencing the priority of nuclear safety

Over the last few years, when the first decision-making procedures for reactor lifetime extensions started, several factors appeared to threaten the priority of nuclear safety, potentially compromising the implementation of possible actions to reduce the risks that ageing nuclear reactors can pose.

## 3.1 Cost of upgrades and cost recovery time

During the debate on the provision of safety upgrade funds by the European Bank for Reconstruction and Development (EBRD) for Ukraine's VVER reactors, it became clear that the Ukrainian state operator Energoatom would not be able to finance its share of the costs if it could not count on a payback time that required a reactor lifetime extension of 20 years. At the time of writing, the State Nuclear Regulatory Inspectorate of Ukraine (SNRIU) is under pressure from the operator and politics to grant such a lifetime extension for the reactors of the South Ukraine nuclear power plant in spite of serious shortcomings in its documentation.[6] The EBRD has granted funds for the so-called, safety upgrade while flatly refusing to acknowledge that it linked with a 20-year lifetime extension.[7]

## 3.2 Ownership status of the operator

In a number of countries, such as Ukraine, the Czech Republic and Hungary, the nuclear operator is a state-owned company and dividends from the operation of nuclear power plants go to the state budget. This can compromise the government's objectivity concerning lifetime extension of older reactors, because their continued operation will help to meet budget commitments. Because the respective governments also have a seat on the board of their state-owned utilities, the national nuclear regulator has to withstand coordinated pressure from both sides.

Conversely, privatisation can also lead to complications in reactor lifetime decisions. We have already mentioned the example of Borssele in the Netherlands, where after privatisation of the state-owned utility, the lifetime restriction to 40 years (the reactor's design lifetime) was overturned and the reactor's lifetime prolonged by 20 years under threat of large compensation claims. The Dutch nuclear regulator, de Kerntechnische Dienst, which is part of the Ministry of Economic Affairs, Agriculture and Innovation,

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[5] http://www.wenra.org/media/filer_public/2013/04/05/rhwg_position_psr_2013-03_final_2.pdf

[6] CEE Bankwatch. 2013. South Ukrainian nuclear power plants – not ready for a safe operation in over-design period. http://bankwatch.org/sites/default/files/briefing-SUNPP1-25Nov2013.pdf

[7] Reiserer, A. 2013. EBRD contributes to safety of Ukraine's nuclear power stations – financing to improve reliability and efficiency of reactors and strengthening of independent regulator. http://www.ebrd.com/pages/news/press/2013/130312a.shtml

is currently under pressure of this political promise for an extended lifetime in its assessment to allow prolonged operation after a PSR.

### 3.3 Political clout of the operator

When Angela Merkel became Chancellor of Germany for the second time in 2009, she had to fulfil her election promise to the four nuclear operators, in return for supporting her new party, that she would reassess the nuclear phase-out law adopted in 2002. This reassessment resulted in September 2010 in an average extension of reactor lifetimes of 8 years for older reactors and 14 years for newer reactors. However, this decision was reversed a few months later after the Fukushima disaster.

### 3.4 Other factors

There are in addition other factors, known from previous nuclear decisions, that may influence a decision to grant a lifetime extension to an ageing nuclear reactor. These include energy security arguments (especially where there is little awareness of potential alternatives), legal complexity, lack of access to information (for example where the operator has an information monopoly on crucial data), and undue influence on the operator's part on the national media (for example as a major advertiser).

## 4 The regulator under pressure

Among the stakeholders in the decision process around lifetime extension, a country's nuclear regulator holds a key position. Not only can it order the closure of a nuclear reactor that it deems substandard, it can also demand proposals for upgrades, prescribe upgrades or prescribe changes in management and safety culture. In addition to nuclear safety, its decisions will have implications for the economics of the power plant and its operator, as well as for its organisational culture. Given the powerful position most nuclear operators hold in national life – many of them have a significant share of the national electricity market, in some cases amounting to more than half – the regulator's decisions are also highly political.

Accordingly, proven independence is vital to enable the nuclear regulator to maintain a non-negotiable emphasis on nuclear safety.

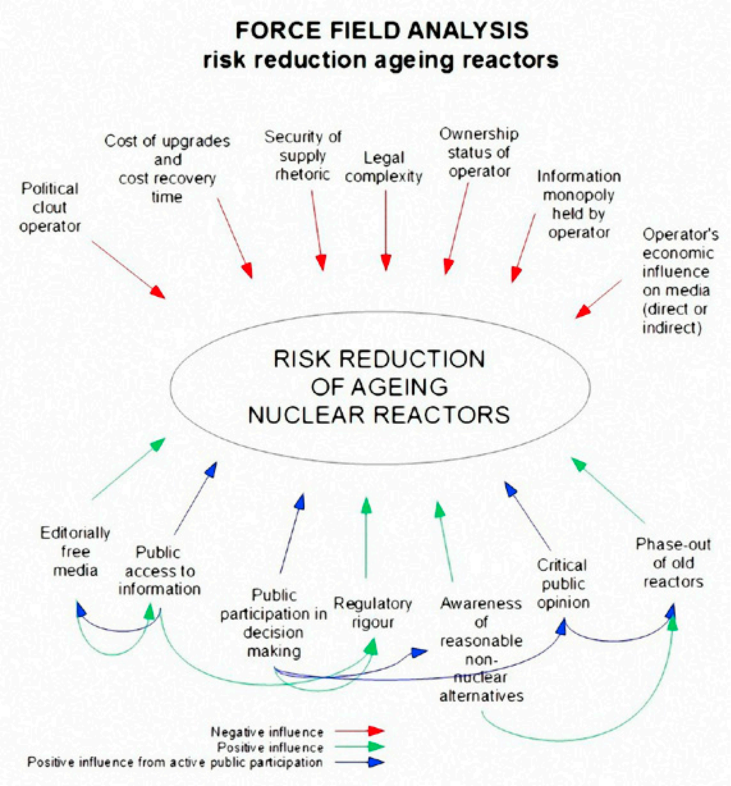

**Figure 4.2** – Force field analysis of risk reduction of ageing nuclear reactors

## 5 The general public's influence on decisions about ageing nuclear reactors

Figure 4.2 schematises the factors that enable the public to influence decisions about ageing nuclear reactors. It should be borne in mind, as Chapter 2 explains, that such decisions can be made on a technical, economic, regulatory or political level or a combination of these.

**Public access to information** can help to guarantee that the highest standards of nuclear safety are considered. First of all, a high level of legally guaranteed access to information will help editorially free media to give a full picture of the situation. If it is easy for journalists to access crucial data related to the risks of ageing nuclear installations, it will be easier for them to produce informed articles and documentaries. If the public can easily check the information provided by media because it also has access to the data, this will help the media to withstand any pressure from operators or politicians with an interest in the decision.

Even though the situation in France is far from perfect, as illustrated by the recent withdrawal of NGOs from some of the legally required local information committees around nuclear installations (Comités Locaux d'Information, CLIs), these independent CLIs[8] nevertheless have wider access to nuclear safety information than can be found elsewhere in Europe. This enables them to put pressure on both the operator EDF and the regulator ASN to ensure greater transparency, while making it more difficult for both the operator and the regulator to hide known weaknesses without running the risk of being caught out. Moreover, the independence of the ASN is supported by this insistence on a high level of transparency: the regulator has to prove it has taken all information into account if it does not want to lose credibility. The ASN and its technical support organisation IRNS therefore actively support the work of CLIs.

The UN Economic Commission for Europe Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters, known as the Aarhus Convention, guarantees a high degree of transparency in nuclear issues under its article 4[9] and is valid in all European countries with nuclear power stations, with the exception of Russia.

**Public participation in decision-making** should ideally enable all concerns to be put on the table and so help to ensure that they are addressed. In addition, it should empower the wider public to demand the justification of decisions with reference to other reasonable alternatives, if only because those who have an interest in those alternatives cannot be excluded from the discourse. However, in current public consultations in the nuclear sector, non-nuclear alternatives are seldom taken into account – even though the Aarhus and Espoo Conventions, as well as the implementing EU Directives,[10] demand this. Interested citizens should furthermore have access to justice in case they are denied participation, providing some guarantee that active engagement will bear fruit, even if in the long term given that legal procedures can easily take many years.

Public participation also helps to uphold the independence of the nuclear regulator, because of the resultant need for it to justify its decisions.

What appears of paramount importance is the need for **critical public opinion**. This does not mean that all people, or even a majority, need to be critical of nuclear power, but that there should at least be a group in society that is informed and critical enough to voice genuine concerns, and that this group should be strong enough for these concerns not to be drowned out by those with economic or political interests in greater tolerance of nuclear risk. At Fukushima, for example, complacency was an important factor in the disaster. Critical public opinion keeps all decision-makers on their toes: regulators, politicians, suppliers and operators. For that reason, public authorities, nuclear regulators and nuclear operators should not try to suppress critical public opinion, but should rather give it a genuine voice at the table.

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[8] A list of all CLIs in France can be found on the website of the Association of CLIs ANCCLI: http://www.anccli.fr/Annuaire-des-CLI/

[9] The UNECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters: http://www.unece.org/env/pp/treatytext.html
Art. 2(3b) defines environmental information as 'any information in written, visual, aural, electronic or any other material form on: […] b. Factors, such as substances, energy, noise and radiation, and activities or measures, including administrative measures, environmental agreements, policies, legislation, plans and programmes, affecting or likely to affect the elements of the environment within the scope of subparagraph (a) above, and cost-benefit and other economic analyses and assumptions used in environmental decision-making'. This clearly includes information concerning nuclear safety, which considers potential impacts of radiation, and activities, measures, policies that can lead under certain circumstances to emissions of radiation.

[10] EIA Directive or DIRECTIVE 2011/92/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment.
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32011L0092:EN:NOT
SEA Directive or DIRECTIVE 2001/42/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment.
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2001:197:0030:0037:EN:PDF

The public can influence the relevant decision-makers on each of the levels indicated in Chapter 2. An example of influence on the economic level is the previously mentioned case of reactor lifetime extension in Ukraine, where the NGO CEE Bankwatch drew attention to the fact that the necessary upgrades for lifetime extension could only be financed thanks to a loan from the EBRD.[11] During late 2012 and early 2013, the EBRD came under heavy pressure to reconsider its decision to support the Ukrainian nuclear upgrade programme, with direct action by Ukrainian NGOs together with Greenpeace and intensive lobbying from CEE Bankwatch, Greenpeace and Friends of the Earth Europe. That this opposition did not change the final decision has harmed the EBRD's reputation as a bank that only finances nuclear programmes in order to bring about an increase in safety.

On the political level, the mass demonstrations in Germany in 2010 after Chancellor Merkel's cancellation of the phase-out were definitely a factor in her change of heart when the Fukushima disaster took place.

## 6 Referenda

Chapter 2 refers several times to the use of referenda in nuclear decision-making. Referenda have led to nuclear phase-outs and cancellations in Italy, Austria and Lithuania. While these examples show the potential of referenda , there are also instances where referenda did not lead to reactor closure or cancellation, such as the 1996 attempt in Slovenia, which failed to secure enough signatures to secure a referendum on a nuclear phase-out.[12]

While referenda do spur debate, the quality of this debate is strongly dependent on the other factors mentioned above: access to information, transparency, and the independence of the nuclear regulator and of the media. In the case of the 2012 referendum in Lithuania, the national media were not allowed to publish critical information and there was thus no media debate. Critical viewpoints and concerns could only be vented in the regional media and on social media (YouTube and Facebook played an important role). The result of the referendum was to a large extent influenced by the fact that the voters were fed up with being manipulated by the nuclear and political elite. In Italy in 2011, the Berlusconi-owned media heavily propagated nuclear power, and although a vast majority of Italians was already pitched against nuclear power, only the Fukushima disaster motivated a sufficient participation to secure a quorum and thus a legally valid 'no' vote.

In order to reduce nuclear risk, referenda on nuclear decisions need a genuine open-ended discourse, with a neutral state, a free and independent media landscape, and full transparency in content as well as in financing of the different parts of the debate. Otherwise they may simply provide a cover for manipulated decision-making, potentially resulting in higher levels of risk. In the absence of these factors, a decision against nuclear power must depend on a miracle, as in Austria or Lithuania (an unexpected outcome of the referendum) and Italy in 2011 (a nuclear catastrophe elsewhere in the world during the campaign).

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[11] CEE Bankwatch. 2013. Nuclear power plant safety upgrades, Ukraine. http://bankwatch.org/our-work/projects/nuclear-power-plant-safety-upgrades-ukraine

[12] Calta, P. 1995. Referundum in Slovenia? WISE. http://www.wiseinternational.org/node/1440
WISE. 1996. Campaign to close Krsko fails. http://www.wiseinternational.org/node/1565

# 7 The need for public consultation on national energy strategies – the role of the Aarhus and Espoo Conventions

Every country within the EU and the European Energy Community[13] regularly produces an update of its national energy strategy. Such a strategy is a plan under the Strategic Environmental Assessment (SEA) Directive[14] and the Kiev Protocol to the Convention on Environmental Impact Assessment in a Transboundary Context (covering strategic environmental assessment),[15] and for that reason has to be submitted to public consultation in which the public can express also its viewpoints and concerns in relation to the lifetime extension of nuclear reactors. Such a public consultation also needs to meet the Aarhus Convention criteria[16] (article 7 and related parts of article 6) – meaning among other things that the public must be consulted at an early stage when all options are open, and that public viewpoints and concerns need to be taken into due account. Citizens with an interest and environmental NGOs also have an associated right to access justice.

The Espoo Convention's Kiev protocol and the EU SEA Directive also prescribe that this SEA includes transboundary public consultation, because energy strategies have not only potential environmental consequences within the borders of a country. Apart from the risk of emissions from a nuclear catastrophe, also issues of climate change, health effects from the use of coal or indeed transboundary transport of energy leave their environmental traces on an international level. For that reason, Poland notified the entire European Union and its non-EU neighbours of its nuclear energy programme.

What does that mean in practice? Any government or state institution that is developing an energy strategy that includes the use of ageing reactors must submit it to a public consultation in which it will have to justify that the extra risk posed by ageing reactors is outweighed by the benefits in comparison with the zero variant or reasonable alternatives. Public concerns must be taken into account regarding the following factors, among others:

- additional risk;
- additional and unknown costs and consequences of upgrading, waste and spent nuclear fuel management and decommissioning;
- extended public exposure to a situation of insufficient emergency response preparedness in case of a large accident, as described in Chapter 1; and
- an extended period of insufficient liability coverage in case of a large accident, as described in Chapter 3.

In our view, reasonable alternatives need to include the option in which ageing nuclear reactors are phased out. That includes scenarios which focus on an increase of renewable energy sources combined with the implementation of policies to promote energy efficiency. Such scenarios also need to show how energy needs will be met on a realistically long term of, say, 30 years or longer. And it is up to the responsible authority to justify lifetime extension of ageing reactors when practicable alternative scenarios exist.

The conduct of the ensuing debate must guarantee that the risks of ageing reactors are assessed not only in terms of the limited interests of their operators or political proponents. In our view, any such debate will show that there are indeed reasonable alternatives to reactor lifetime extension.

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[13] http://www.energy-community.org/portal/page/portal/ENC_HOME

[14] SEA Directive, or DIRECTIVE 2001/42/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment.
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2001:197:0030:0037:EN:PDF

[15] http://www.unece.org/env/eia/about/sea_text.html

[16] The UNECE Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters.
http://www.unece.org/env/pp/treatytext.html

## Poland’s nuclear energy strategy

One of the first transboundary strategic environmental assessments (SEAs) of an energy policy was that conducted on Poland’s nuclear energy strategy, which was finally approved in February 2014. This SEA commenced in 2010. Because it was among the first procedures of its kind, there are some vital lessons to be learnt from it.

**The strengths of the assessment included the following:**

- It eventually included an ‘appropriate’ (Kiev Protocol and SEA Directive) and ‘reasonable’ (Aarhus Convention) timeframe for the public to respond to the approximately 1,500 pages of documentation: an initial three-week period was extended to three months, with another six weeks added after a new potential nuclear power plant location was added during the course of the procedure.
- The notification of the transboundary procedure was disseminated to all countries that could be environmentally affected by this strategy, including all EU Member States as well as Belarus, Russia, Ukraine and Switzerland. The widespread interest in the proposed policy – with responses received fromSlovakia, the Czech Republic, Lithuania, Finland, Sweden, Denmark, Germany, Austria and Luxembourg – showed that such a nuclear energy strategy is indeed perceived to have a wide impact.

**The procedure also highlighted several issues that need to be addressed in future:**

- An inadequate initial interpretation of Polish law led at the start to an inappropriate and unreasonably short timeframe for public consultation of only three weeks, including a public holiday.
- There was no possibility for the public to express its views other than in writing – there were no public hearings or other forms of person-to-person public consultation. After written public input is taken into due account in a draft text, it would be advisable to have some form of facilitated discourse about the impact of the public’s views.
- An English translation of all documentation was available in the transboundary procedure, but not in the national procedure. The fact that the text was available in Polish only seriously handicapped people in the country with limited understanding of Polish, including expatriates working for foreign firms and recent immigrants. The availability of at least an English text alongside the national one would improve this situation. The same English text could also be used for the transboundary procedure.
- The SEA report that formed with the Polish Nuclear Energy Programme the basis for the public consultation was based on an outdated and ineffective perception of what an EIA (as opposed to an SEA) report should look like. The form of these reports needs updating in order to make them more accessible to the public and enable effective public discourse that can lead to better decision-making.
- The first official response to the public submissions reacting on the documentation (programme, SEA report and its annexes) took the form (nowadays universally adopted but nevertheless unacceptable) of a to the SEA report annexed spreadsheet summarising all the submissions along with – mostly dismissive – comments from the consultant who had written the SEA report. This was not ‘taking into due account’, but rather a defensive reaction. The final text of the documentation has still not been released at the time of writing (early January 2014), so it is not yet known how the public discourse has been taken into account.

## 8 The need for transboundary environmental impact assessments, including public consultation

On 25 March 2013, the Implementation Committee of the Convention on Environmental Impact Assessment in a Transboundary Context, also known as the Espoo Convention,[17] sent a letter to the government of Ukraine, informing it that it was in breach of the Convention for not providing a transboundary EIA for the lifetime extension of the Rivne 1 and 2 reactors, which had reached their design lifetime of 30 years and were to be given a 10-year extension.

The Committee left no room for doubt when it wrote that it 'had concluded that Ukraine had not applied the Convention in relation to the planned extension of the NPP and also that the extension of the lifetime of an NPP, even in absence of any works, was to be considered as a major change to an activity and consequently subject to the Convention's provisions.' [18]

This conclusion is important for several reasons. First of all, it defines the lifetime extension of a nuclear power plant as a major change as defined under the Convention. This interpretation also has its consequences for the Aarhus Convention, which under its article 6 also prescribes the need for public consultation over major changes in projects that fall under Annex 1: 'Any change to or extension of activities, where such a change or extension in itself meets the criteria/thresholds set out in this annex, shall be subject to article 6, paragraph 1 (a) of this Convention.' Because the text refers to change or extension, there is no doubt that reactor lifetime extension should be submitted to public consultation under the Aarhus Convention.

Secondly, the Espoo Convention Implementation Committee's conclusion states that it is not necessary for any works to have taken place in order for a transboundary EIA to be necessary. The proposed lifetime extension itself constitutes an important change. The public has a reasonable expectation that a reactor's operational life will be as indicated by its design lifetime. For VVER 440 reactors such as Rivne 1 and 2, this was set at 30 years, and for most other designs 40 years. When this lifetime is prolonged, the public needs to be consulted as part of the environmental justification process for that extension, no matter whether it entails a power upgrade (which as Chapter 1 and 2 explain often coincides with lifetime extension) or other extensive upgrades for which an EIA including public consultation would already be required.

This conclusion of the Committee means in our view that every reactor lifetime extension in a country that is party to the Aarhus and/or Espoo Conventions needs to be submitted to an EIA with full public consultation, culminating in either a proper justification for the increased risk or the implementation of an alternative strategy including closure of the old reactor.

Because public consultation is meant to improve the quality of decisions (Aarhus Convention), it is immaterial how or by whom the decision on lifetime extension is to be taken – whether it takes the form of a licence renewal by the nuclear regulator (as for instance in Hungary), a restart permission after an outage following a PSR (as for instance in the case of the Rivne 1 and 2 reactors in Ukraine, or in France), or a political decision (such as the German government's 2010 decision to increase average plant lifetime or the 2013 decision in Belgium to extend the life-time of Tihange 1). The quality of each of these decisions can be improved by public consultation, and the appropriate context for public consultation is defined under the Espoo Convention as an EIA.

Of course, there is still much criticism on the way in which public consultation is ensured within the EIA process. Much of this was expressed during the various sessions of the Implementation of the Aarhus Convention in the Nuclear Sector (ACN) process organised by the European Commission, the French government and the French umbrella organisation of local nuclear information committees, the ANCCLI, between 2009 and 2013.[19] In order to improve the situation, a cross-party group of members of the European Parliament along with environmental NGOs from various European countries founded Nuclear Transparency Watch in November 2013.[20]

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[17] http://www.unece.org/env/eia/

[18] Economic Commission for Europe. 2013. Meeting of the Parties to the Convention on Environmental Impact Assessment in a Transboundary Context – Implementation Committee, Twenty-seventh session, Geneva, 12–14 March 2013, page 6, item V/A 21. http://www.unece.org/index.php?eID=tx_nawsecuredl&u=0&file=fileadmin/DAM/env/eia/documents/ImplementationCommittee/2011-2014/28th_session/ece.mp.eia.ic.2013.4.e_advance_copy.pdf

[19] http://www.anccli.fr/Europe-International/ACN-Convention-d-Aarhus-et-nucleaire-Aarhus-Convention-Nuclear

[20] http://www.anccli.fr/Europe-International/Nuclear-Transparency-Watch-english-version

Issues that have been raised during this ACN process include the following:

- EIA processes are not always open to all interested members of the public, either formally or simply as a result of poor implementation, such as insufficient publicity, the organising of hearings on public holidays, etc.
- EIAs are not always carried out at an early stage when all options are open. For example, Slovakia carried out an inadequate and voluntary EIA for the Mochovce 3,4 project while construction was ongoing. The first EIAs for radioactive waste storage (temporary or final) are often conducted when the waste has already been produced, even though considerations of radioactive waste are largely excluded from EIAs of activities that will give rise to such waste, such as the construction or lifetime extension of a nuclear reactor.
- Unreasonable and inappropriate timeframes are often set for the public to express its views on large quantities of sometimes very technical documentation. A period of three weeks or one month, though legally permissible and in some national legislation even prescribed, is neither reasonable nor appropriate to comment on several thousand pages (see also the example of the SEA for the Polish nuclear energy programme above). In cases where national law does not accomodate for a reasonable or appropriate time, international (the Conventions and EU law) law is overruling.
- There is sometimes insufficient transboundary consultation.Whereas Hungary informed the entire EU about its EIA of a proposed new nuclear power station at Paks, the UK refused to give any notification to surrounding countries of its EIA procedure on the new nuclear project at Hinkley Point C in spite of the possibility of beyond design basis nuclear accidents.
- The content of nuclear EIAs is currently insufficient. For example, nuclear EIAs do not address reasonable alternatives not involving nuclear power, the impacts of a beyond design basis accident, the waste and decommissioning parts of the project chain, nor the impacts of uranium mining and fuel production.
- Public input is virtually never taken into due account, being simply reproduced in spreadsheets attached to the EIA documentation, along with dismissive responses from a defensive project promoter or consultant.

Citizens and NGOs have several ways to object to such shortcomings. They can bring them to court under article 9 of the Aarhus Convention. This has been done in the past in the case of the Belene nuclear project in Bulgaria, the Mochovce 3 and 4 project in Slovakia, the Visaginas project in Lithuania and the Borssele lifetime extension in the Netherlands, with varying degrees of success. But the legal route is slow and can be expensive, and lower courts are often reluctant to rule against state institutions, forcing the citizen or NGO to continue appealing to the highest level.

Another pathway is offered by the Aarhus Convention Compliance Commission (ACCC),[21] with which citizens and NGOs can file complaints against improper implementation of the Convention. This pathway guarantees a high-quality assessment of the question of whether public participation has been adequate and sufficient, and leads to binding conclusions and recommendations. Because the UN bears much of the cost, it is also affordable. But the capacity of the ACCC is limited, and proceedings can again take a long time. Moreover, while ACCC decisions, once confirmed by the Meeting of Parties (MoP) of the Aarhus Convention, may be binding, it is difficult to get them enforced. For instance, the ACCC concluded that Slovakia had carried out the voluntary EIA for Mochovce 3 and 4 in a manner that breached the Convention, and that ongoing construction made early public participation with all options still open de facto impossible. This finding should have led to a new EIA procedure and a temporary halt to construction work. That interpretation was confirmed by the Aarhus MoP and even by the Slovak supreme court, but the responsible authority – the Slovak nuclear regulator UJD – let construction continue and has so far refused to redo the EIA.[22]

The Espoo Convention, similarly, has its Espoo Convention Implementation Committee,[23] which until recently accepted complaints only signatory states, but is now also open to NGOs.

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[21] http://www.unece.org/env/pp/cc.html

[22] http://aarhusclearinghouse.unece.org/news/1000576/

[23] http://www.unece.org/?id=2771

# 9 Conclusions

The Aarhus Convention, the Espoo Convention and the Kiev Protocol, together with their implementing EU Directives[24] and national implementing laws, have provided a legal framework for effective public consultation, but that a lot of work still needs to be done for this framework to be functionally implemented. When citizens and NGOs actively take the opportunities that this framework delivers, we will be nearer to successful implementation, and every challenge to a failure of consultation will force ears open to the important arguments the public brings to the discourse.

The opportunity created by the conclusions of the Espoo Convention Implementation Commission in the case of lifetime extension of the Rivne 1 and 2 nuclear reactors in Ukraine should most certainly be used by NGOs and citizens to enforce public participation in decisions about reactor lifetime extensions elsewhere, no matter what the decision-making procedure. It is clear that the discourse created by public participation will have its effect on all of the lines of decision-making on reactor lifetime extension identified elsewhere in this report: technological, economic, legal and political. The new era of risk that reactor lifetime extensions signify certainly demands the fullest possible degree of public involvement in decision-making.

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[24] See footnote 9 – EIA and SEA Directives

# Annex 1

# Relevant articles from the Aarhus Convention, the Espoo Convention, its Kiev Protocol

CONVENTION ON ACCESS TO INFORMATION, PUBLIC PARTICIPATION IN DECISION-MAKING AND ACCESS TO JUSTICE IN ENVIRONMENTAL MATTERS

done at Aarhus, Denmark, on 25 June 1998[25]

**Article 6**
PUBLIC PARTICIPATION IN DECISIONS ON SPECIFIC ACTIVITIES

1. Each Party:
(a) Shall apply the provisions of this article with respect to decisions on whether to permit proposed activities listed in annex I;

4. Each Party shall provide for early public participation, when all options are open and effective public participation can take place.

5. Each Party should, where appropriate, encourage prospective applicants to identify the public concerned, to enter into discussions, and to provide information regarding the objectives of their application before applying for a permit.

8. Each Party shall ensure that in the decision due account is taken of the outcome of the public participation.

10. Each Party shall ensure that, when a public authority reconsiders or updates the operating conditions for an activity referred to in paragraph 1, the provisions of paragraphs 2 to 9 of this article are applied mutatis mutandis, and where appropriate.

**Article 7**
PUBLIC PARTICIPATION CONCERNING PLANS, PROGRAMMES AND POLICIES RELATING TO THE ENVIRONMENT

Each Party shall make appropriate practical and/or other provisions for the public to participate during the preparation of plans and programmes relating to the environment, within a transparent and fair framework, having provided the necessary information to the public. Within this framework, article 6, paragraphs 3, 4 and 8, shall be applied. The public which may participate shall be identified by the relevant public authority, taking into account the objectives of this Convention. To the extent appropriate, each Party shall endeavour to provide opportunities for public participation in the preparation of policies relating to the environment.

**Article 8**
PUBLIC PARTICIPATION DURING THE PREPARATION OF EXECUTIVE REGULATIONS AND/OR GENERALLY APPLICABLE LEGALLY BINDING NORMATIVE INSTRUMENTS

Each Party shall strive to promote effective public participation at an appropriate stage, and while options are still open, during the preparation by public authorities of executive regulations and other generally applicable legally binding rules that may have a significant effect on the environment. To this end, the following steps should be taken: (a) Time-frames sufficient for effective participation should be fixed; (b) Draft rules should be published or otherwise made publicly available; and (c) The public should be given the opportunity to comment, directly or through representative consultative bodies.

The result of the public participation shall be taken into account as far as possible.

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[25] http://www.unece.org/env/pp/treatytext.html

**Article 9**
ACCESS TO JUSTICE

2. Each Party shall, within the framework of its national legislation, ensure that members of the public concerned

(a) Having a sufficient interest or, alternatively,
(b) Maintaining impairment of a right, where the administrative procedural law of a Party requires this as a precondition, have access to a review procedure before a court of law and/or another independent and impartial body established by law, to challenge the substantive and procedural legality of any decision, act or omission subject to the provisions of article 6 and, where so provided for under national law and without prejudice to paragraph 3 below, of other relevant provisions of this Convention.

4. In addition and without prejudice to paragraph 1 above, the procedures referred to in paragraphs 1, 2 and 3 above shall provide adequate and effective remedies, including injunctive relief as appropriate, and be fair, equitable, timely and not prohibitively expensive. Decisions under this article shall be given or recorded in writing. Decisions of courts, and whenever possible of other bodies, shall be publicly accessible.

**Annex I**
LIST OF ACTIVITIES REFERRED TO IN ARTICLE 6, PARAGRAPH 1 (a)

1. Energy sector:

-Nuclear power stations and other nuclear reactors including the dismantling or decommissioning of such power stations or reactors

1) (except research installations for the production and conversion of fissionable and fertile materials whose maximum power does not exceed 1 kW continuous thermal load);

- Installations for the reprocessing of irradiated nuclear fuel;
- Installations designed:
- For the production or enrichment of nuclear fuel;
- For the processing of irradiated nuclear fuel or high-level radioactive waste;
- For the final disposal of irradiated nuclear fuel;
- Solely for the final disposal of radioactive waste;
- Solely for the storage (planned for more than 10 years) of irradiated nuclear fuels or radioactive waste in a different site than the production site.

## CONVENTION ON ENVIRONMENTAL IMPACT ASSESSMENT IN A TRANSBOUNDARY CONTEXT

done at Espoo (Finland), on 25 February 1991[26]

**Article 1**
DEFINITIONS

(v) “Proposed activity” means any activity or any major change to an activity subject to a decision of a competent authority in accordance with an applicable national procedure;

(ix) “Competent authority” means the national authority or authorities designated by a Party as responsible for performing the tasks covered by this Convention and/or the authority or authorities entrusted by a Party with decision-making powers regarding a proposed activity;

**Article 2**
GENERAL PROVISIONS

4. The Party of origin shall, consistent with the provisions of this Convention, ensure that affected Parties are notified of a proposed activity listed in Appendix I that is likely to cause a significant adverse transboundary impact.

6. The Party of origin shall provide, in accordance with the provisions of this Convention, an opportunity to the public in the areas likely to be affected to participate in relevant environmental impact assessment procedures regarding proposed activities and shall ensure that the opportunity provided to the public of the affected Party is equivalent to that provided to the public of the Party of origin.

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[26] http://www.unece.org/env/eia/about/eia_text.html

**Article 3**
NOTIFICATION

7. When a Party considers that it would be affected by a significant adverse transboundary impact of a proposed activity listed in Appendix I, and when no notification has taken place in accordance with paragraph 1 of this Article, the concerned Parties shall, at the request of the affected Party, exchange sufficient information for the purposes of holding discussions on whether there is likely to be a significant adverse transboundary impact. If those Parties agree that there is likely to be a significant adverse transboundary impact, the provisions of this Convention shall apply accordingly. If those Parties cannot agree whether there is likely to be a significant adverse transboundary impact, any such Party may submit that question to an inquiry commission in accordance with the provisions of Appendix IV to advise on the likelihood of significant adverse transboundary impact, unless they agree on another method of settling this question.

**Article 5**
CONSULTATIONS ON THE BASIS OF THE ENVIRONMENTAL IMPACT ASSESSMENT DOCUMENTATION

The Party of origin shall, after completion of the environmental impact assessment documentation, without undue delay enter into consultations with the affected Party concerning, inter alia, the potential transboundary impact of the proposed activity and measures to reduce or eliminate its impact. Consultations may relate to:

(a) Possible alternatives to the proposed activity, including the no-action alternative and possible measures to mitigate significant adverse transboundary impact and to monitor the effects of such measures at the expense of the Party of origin;

**Article 6**
FINAL DECISION

1. The Parties shall ensure that, in the final decision on the proposed activity, due account is taken of the outcome of the environmental impact assessment, including the environmental impact assessment documentation, as well as the comments thereon received pursuant to Article 3, paragraph 8 and Article 4, paragraph 2, and the outcome of the consultations as referred to in Article 5.

**Appendix I**
LIST OF ACTIVITIES

2. Thermal power stations and other combustion installations with a heat output of 300 megawatts or more and nuclear power stations and other nuclear reactors (except research installations for the production and conversion of fissionable and fertile materials, whose maximum power does not exceed 1 kilowatt continuous thermal load).

3. Installations solely designed for the production or enrichment of nuclear fuels, for the reprocessing of irradiated nuclear fuels or for the storage, disposal and processing of radioactive waste.

## PROTOCOL ON STRATEGIC ENVIRONMENTAL ASSESSMENT TO THE CONVENTION ON ENVIRONMENTAL IMPACT ASSESSMENT IN A TRANSBOUNDARY CONTEXT[27]

**Article 2**
DEFINITIONS

For the purposes of this Protocol,

5. “Plans and programmes” means plans and programmes and any modifications to them that are:

(a) Required by legislative, regulatory or administrative provisions; and
(b) Subject to preparation and/or adoption by an authority or prepared by an authority for adoption, through a formal procedure, by a parliament or a government.

6. “Strategic environmental assessment” means the evaluation of the likely environmental, including health, effects, which comprises the determination of the scope of an environmental report and its preparation, the carrying out of public participation and consultations, and the taking into account of the environmental report and the results of the public participation and consultations in a plan or programme.

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[27] http://www.unece.org/env/eia/about/sea_text.html

**Article 4**
FIELD OF APPLICATION CONCERNING PLANS AND PROGRAMMES

2. A strategic environmental assessment shall be carried out for plans and programmes which are prepared for agriculture, forestry, fisheries, energy, industry including mining, transport, regional development, waste management, water management, telecommunications, tourism, town and country planning or land use, and which set the framework for future development consent for projects listed in annex I and any other project listed in annex II that requires an environmental impact assessment under national legislation.

**Article 8**
PUBLIC PARTICIPATION

1. Each Party shall ensure early, timely and effective opportunities for public participation, when all options are open, in the strategic environmental assessment of plans and programmes.

**Article 11**
DECISION

1. Each Party shall ensure that when a plan or programme is adopted due account is taken of:

(a) The conclusions of the environmental report;
(b) The measures to prevent, reduce or mitigate the adverse effects identified in the environmental report; and
(c) The comments received in accordance with articles 8 to 10.

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Jan Haverkamp
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