International
Nuclear Risk
Assessment Group

Summary

Risks of Life-time Extension of Old Nuclear Power Plants

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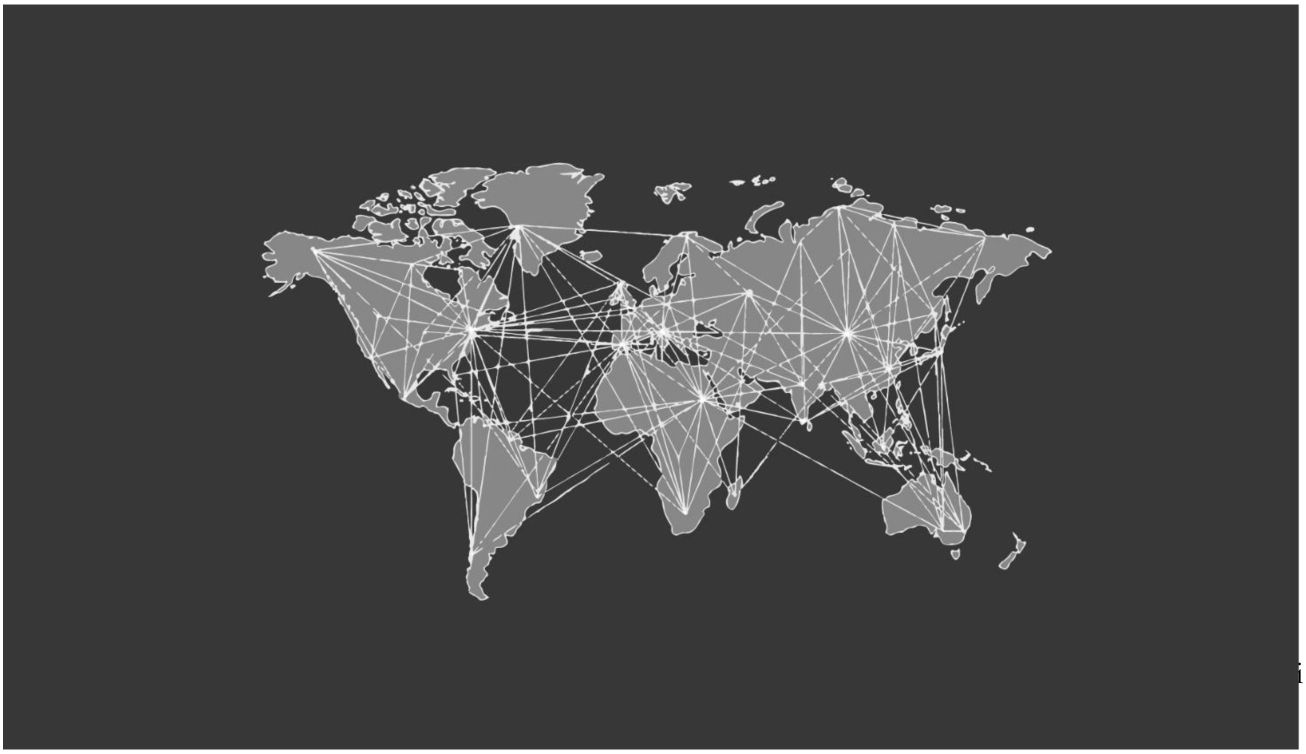
For the
Alliance of Regions for Phasing out Nuclear Power across Europe

ALLIANCE OF REGIONS
FOR PHASING OUT
NUCLEAR POWER
ACROSS EUROPE



Impressum

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Introduction

A look at the age structure of existing nuclear power plants shows the importance of analysing risks of life-time extension and long-term operation. Some of the world's oldest plants are located in Europe. Of the 141 reactors in Europe, only one reactor came into operation in the last decade, and more than 80 percent of the reactors have been running for more than 30 years (see Figure 1). Nuclear power plants were originally designed to operate for 30 to 40 years. Thus, the operating life-time of many plants are approaching this limit, or has already exceeded it.

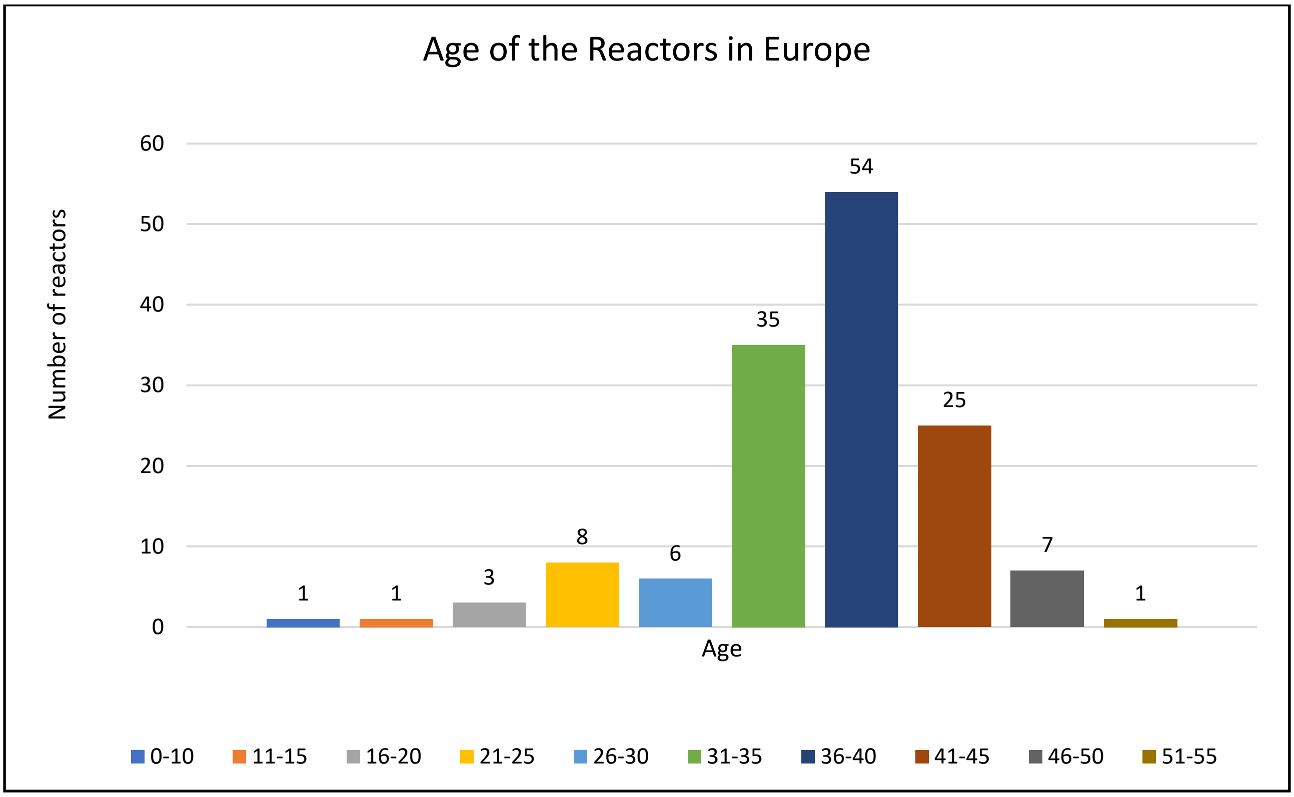

Figure 1: Age of European reactors (IAEA PRIS 2021)

The term "life-time extension" refers to operation of nuclear power plants beyond the original design licensing horizon of 30 to 40 years. In the context of this study, the terms "life-time extension" and "long-term operation" are used synonymously. Regarding life-time extension, reactors in Europe can be roughly divided into three categories:

- Countries where the government decided upon a final date for end of operation of nuclear reactors (e.g.: Germany, Belgium)
- Countries where operating licenses are unlimited in time and where nuclear power plant operators are likely to keep reactors in operation as long as possible (e.g.: Finland, UK, Sweden),
- Countries where regulators have already approved life-time extensions for more than 40 years (e.g.: Bulgaria, Slovakia, Slovenia, Czech Republic).

There are few new nuclear power plant projects in Europe. Such projects have become increasingly difficult over the past two decades due to significantly higher safety requirements, rising construction costs, problems in obtaining funding and complex new reactor designs. And the few new builds of state-of-the-art reactors encountered enormous cost increases and delays (Flamanville, Olkiluoto, and Hinkley Point C, for example). Therefore, life-time extensions of existing plants play a central role for the future of the nuclear industry and the use of nuclear energy.

Method

The objective of the study is to analyze the risks of life-time extensions of ageing nuclear power plants.

First, nuclear power plants in operation are characterized. Age profiles of existing power plants are established and are further developed by looking at reactors which are planned or even already under construction.

In order to approach the ageing problem, a distinction is made between the physical ageing of materials and obsolescence (technological and conceptual ageing). In the case of physical ageing, ageing of components with manufacturing defects, physical ageing of special components, ageing management, time-dependent failure rates, and handling of ageing-related reportable events are analyzed, as well as countermeasures and their limitations. Technological ageing (the lack of spare parts, suppliers, industrial capacity of a component because it is no longer manufactured) and conceptual ageing (design obsolescence) are shown through technological developments and illustrated by case studies. Maintenance issues and limitations of retrofitting are discussed. In addition, dwindling knowledge of plant design and operation is discussed based on literature and expert interviews.

In addition to technological issues, regulatory aspects must also be considered for a comprehensive analysis. Therefore, regulatory concepts and regulations for life-time extensions are analyzed. The different approaches for life-time extensions are presented and the applicable standards for safety assessments of nuclear power plants in case of life-time extensions are discussed. Here, the question of “reasonably practicable” retrofitting plays a special role. The status of international regulatory requirements for life-time extensions is elaborated by looking at the approach of IAEA, WENRA and the EU. However, since there is no binding international regulatory framework for life-time extension, it is analyzed whether the WENRA safety targets for new reactors can be used as a benchmark for life-time extension.

The implementation of the analyzed concepts differs from country to country and among different nuclear power plants. Therefore, practical experiences with the ageing of nuclear power plants will be discussed. For this purpose, key challenges and problems of selected nuclear power plants are elaborated. The case studies deal with the nuclear power plants Beznau, Bohunice, Bugey, Cattenom, Doel, Dukovany, Fessenheim, Hunterston B, Kozlodui, Krsko, Mochovce, Mühleberg, Temelin, Tihange and Tricastin. In addition, generic examples of reactors of related design line are presented. The challenges of life-time extension in the U.S. are discussed in general terms.

Transparency and public participation are recognized as an important element in licensing of any type of nuclear facility and must therefore also be considered in the context of ageing management and life-time extensions. The regulatory basis for transparency and participation with a focus on life-time extensions is presented. National and international regulations and guidelines are presented. Examples of how transparency and participation were handled in life-time extensions and long-term operation of nuclear power plants are discussed. Based on the findings, further requirements for transparency and participation are developed.

Conclusions are presented based on the results and analyses of the study. The conclusions were drawn up and written in the course of expert workshops.

Results

Ageing of nuclear power plants

A distinction is made between ageing (of the materials) and obsolescence (technological and conceptual ageing). In all technical systems, the quality and reliability of components decrease with increasing operating time (physical ageing).

The state of science and technology with regard to the required safety is continuously developing, which is reflected in higher requirements in national and international regulations and thus improved plant concepts. Although there is a requirement to retrofit old plants up to the current state of science and technology, the possibilities for technical retrofits are limited. Differences remain between the safety level achieved in old plants and the safety level required for new plants according to the current state of science and technology.

In addition, knowledge of older plant design and operation is generally dwindling. Knowledge of the original design is being lost and the generation of experts who designed and commissioned the plants is moving into retirement. In addition, the existing documentation is often incomplete and does not meet today's requirements.

Physical ageing

The ageing, which means the deterioration of material properties, and thus the decreasing functionality and reliability of structures, systems and components (SSCs) with increasing operating time of a plant inevitably leads to the reduction of original safety margins. This subsequently leads to a higher probability of failure, most importantly if special load cases occur. The dependence of the failure rate with the operating time can be described by the so-called bathtub curve, which basically applies to all technological systems. After a start-up phase, the failure rate generally remains constant at a comparatively low level over a further period of time until finally ageing processes lead to an increased number of failures.

Because of the lower safety reserves of the individual components, old nuclear power plants are more susceptible to undiagnosed damaging mechanisms or a confluence of several independent damaging events and loads. The number of events, faults and incidents increase - for example small leaks, cracks, short circuits or the failure of electrical components. Thus, there is a higher incidence of abnormal operational events which can develop into an accident.

Retrofitting and its limits

Systematic ageing management is required by the EU (Euratom), as it is generally accepted that ageing increases risks. In order to increase the safety of existing nuclear power plants, according to the European Nuclear Safety Directive (NSD) (EU Directive 2014/87/EURATOM), Topical Peer Reviews (TPR) are to be carried out in European NPPs. The topic of the first TPR, which was conducted in 2017, was ageing management. The result was that in none of the participating countries the existing requirements for ageing management programs were fully met.

The negative ageing effects could be counteracted by intensifying inspections and monitoring. However, these measures can only be successful if cracks and other damage can be detected before they lead to failure.

However, the change in material properties often cannot be tested non-destructively. Therefore, it is difficult to establish the condition of ageing materials with certainty. Although non-destructive testing methods make it possible in many cases to track crack development, surface changes and wall thickness weakening - not all components can be fully tested since some components are inaccessible or in zones with high radiation exposure.

Calculation methods for the determination of loads and their effects on the material behavior generally can only be validated on specimens, and uncertainties for results of said calculations for the nuclear power plant are therefore difficult to specify. Unknown damage mechanisms can occur with increasing age of the nuclear plants and cannot be taken into account in calculation models.

Due to ageing problems, the replacement of components or parts in nuclear power plants is necessary. However, the replacement of components opens up new sources of faults if components not conforming to specifications are used or assembly errors occur.

Some “measures” of ageing management are only carried out on paper: Conservatism or safety margins in safety analyses are reduced by “more precise calculations”.

Theoretically, it is possible to counteract negative ageing processes by reducing thermal loads. In reality, however, reactor life-time extensions are often linked to power increases for economic reasons.

With increasing knowledge and improved testing methods, manufacturing-related defects continue to be discovered, also because manufacturing-related defects often only have an effect after a certain period of operation. This shows by way of example that the presumed and claimed safety level of old NPPs does not necessarily correspond to the actual safety level simply due to the emergence of previously unknown defects.

In practice, event analyses often lack sufficient depth and are incomplete, so that the connection between analysis results and derived corrective measures (technical, organizational, personnel) is not comprehensive. Thus, as long as the cause of an event has not been fully identified, no appropriate corrective action can be taken. Repeated deleterious occurrences may occur, with common cause failure events (i.e. events affecting several safety systems at the same time) in particular posing a special danger.

Not all design deficiencies can be eliminated by retrofitting. This is because a significant proportion of the safety standard is already determined during the design of any nuclear power plant. Retrofits of additional safety systems are possible only to a limited extent. Compliance with today’s safety standards would, in practice, require the development and construction of a completely new nuclear power plant.

The differences that cannot be remedied generally relate to the degree of redundancy, diversity, functional independence and spatial separation of safety trains, as well as further protection of the plant against external impacts, including additional precautions against beyond-design-basis accidents. Thus, despite extensive retrofits, current safety standards are not and can not be achieved in old nuclear power plants.

As a consequence of the March 11, 2011 disaster at the Fukushima Dai-ichi nuclear power plant in Japan and the EU ‘stress tests’, countries presented concepts to address the identified deficiencies. But only some countries planned new permanently installed and partially bunkered systems. Instead of extensive retrofits or permanent shutdown of particularly vulnerable nuclear plants, most countries are attempting to compensate for design deficiencies with the purchase of mobile equipment.

In theory, retrofits offer the regulatory authority the opportunity to demand technically possible safety improvements to a certain extent. However, in practice, retrofitting is determined not only by safety criteria but also by economic criteria. It is also common practice to carry out retrofits spread out over a period of years during the scheduled downtime for overhaul/fuel element replacement in order to avoid economic losses due to additional downtime. Often 10 - 20 years pass between the recognition of safety deficits and their elimination. Safety improvements often are judged as not economical and are omitted with reference to the limited remaining operating life time of the plant.

Safety concepts and regulatory requirements

On July 8, 2014, the Council of the European Union adopted Directive 2014/87/EURATOM amending Directive 2009/71/EURATOM establishing a Community framework for the nuclear safety of nuclear installations. However, this directive establishes a de facto double standard. The double standard consists in the specification for the technical design of the safety measures and facilities to achieve the radiological protection objective (Article 8a, Paragraph 1). Plants that have been granted the initial license for construction after August 14, 2014, must meet the safety objective defined in Article 8a as part of the design. For these facilities, it must be shown that releases of radioactive materials can only occur to a limited extent and that they will not occur early in the accident sequence. For existing plants, on the other hand, this requirement applies only as a "reference" for determining "reasonably practicable safety improvements" and implementing them in a "timely manner".

The design of new plants must aim to prevent accidents and, in the event of an accident, to mitigate effects, as well as to prevent early releases that require off-site emergency response measures. Furthermore, large releases requiring protective measures that can not be limited in space or time must be precluded. For existing facilities, these goals are considered a reference for the timely implementation of reasonably practicable safety improvements to be used in the periodic safety reviews. The periodic safety review (at least every ten years) is intended mainly to demonstrate compliance of the current design to the existing operating license. Further safety improvements are to be identified taking into account ageing, operating experience, recent research results and developments in international standards – provided their implementation is "reasonably practicable."

This requirement for safety improvements in the 2014/87/EURATOM Directive is implemented differently by the regulatory authorities of the individual countries, because the Directive leaves open what "reasonably practicable" means and in what time frame an implementation is still "timely". Often the process of such analyses and decision by the regulator is performed without information being communicated to the general public. This, despite the fact that it remains especially important to communicate openly and transparently when a decision is made to extend the operating life-time of a plant. In other words, in our view, the public should be informed which retrofits can be made, but also which retrofits are no longer reasonably feasible.

The WENRA guidelines for new and existing nuclear power plants mean that new reactors are expected to meet higher overall safety levels, and new reactors must meet them – yet existing ageing reactors do not achieve the safety level of a new reactor in all respects, nor is this required.

Examples of challenges and problems of life-time extensions

The main report discusses key problems and challenges of life-time extension for Beznau, Bohunice, Bugey, Cattenom, Doel, Dukovany, Fessenheim, Hunterston B, Kozlodui, Krsko, Mochovce, Mühleberg, Temelin, Tihange, and Tricastin. Furthermore, the challenges of life-time extension in the USA are discussed in general. Here, the problems of distinguishing between ageing (of the materials) and obsolescence (technological and conceptual ageing) are discussed, with particular attention to the limits of retrofitting. As examples of the detailed analyses selected results of the three nuclear power plants Tihange, Dukovany and Cattenom are presented.

Tihange

Design of safety systems

Each of the three reactors at Tihange NPP has a spent fuel pool outside the containment. The degree of protection of external spent fuel pools is significantly lower than that of spent fuel pools inside the containment.

There are differences between three reactor units at Tihange regarding the design of the safety systems: There are only two trains of safety systems at the first unit. The trains of the safety systems are not independent of each other and in some cases are not spatially separated. At Unit 2 and 3 there are three trains of safety systems and are largely independent of each other. The design of the steam generator emergency feed water supply is common for all units: One turbine-driven pump (100%) and two motor pumps (2 x 50%) powered by the emergency diesel generators. The safety design of the safety systems of unit 1 as well as the design of the steam generator emergency feed water supply deviates significantly from current NPP safety requirements.

For protection of the structures against external events such as aircraft crash, civil building standards were applied at Tihange unit 1, while nuclear standards, i.e. standards that go beyond civil building standards, were applied at Tihange unit 2 and 3.

Design against earthquakes

Tihange unit 1 was designed against a design-basis earthquake (DBE) with a ground acceleration of 0.1 g. This was also the basis for the design of Tihange unit 2 and 3. A reassessment of the site in 1985 led to an increase in the assumed ground acceleration for all three reactor units at the Tihange site to 0.17 g. This reassessment took place after the construction of Tihange unit 1 and during the construction of units 2 and 3. Tihange unit 1 is said to have been retrofitted accordingly, while the modifications required for Tihange unit 2 and 3 could be taken into account during construction. It remains open how the retrofits for the building structures of Tihange unit 1 were carried out and it can be assumed that for this purpose, an attempt was made to demonstrate the required resistance of the building structures by utilization of existing safety reserves. However, the use of safety reserves to demonstrate compliance with requirements in the design area is far from good practice.

Design extension safety related features - safety level 4

In the area of the 4th safety level, there is a major deficit in the thickness of the foundation, which is significantly less than in new plants (Tihange unit 1: 2.15 m, Tihange unit 2 and 3: 2.64 m). In the event of a core meltdown accident, the integrity of the containment cannot be adequately guaranteed. Effective retrofitting is practically impossible here. A core catcher, similar to the European Pressurized Reactor (EPR), cannot be retrofitted here.

Embrittlement of the reactor pressure vessel

In autumn 2012, after thousands of flaws were observed in the Doel unit 3 reactor pressure vessel (RPV) wall, thousands of flaws were also observed in Tihange unit 2 RPV in the rings near the core. As in the case of Doel 3, manufacturing-related hydrogen flakes were assumed to be the cause of the flaws. Such a large number of flaws should have been detected by quality assurance after manufacturing the RPV ring. However, in Tihange, no indication of such findings was documented after fabrication. The use of such crack-prone material for a RPV fundamentally contradicts the principle of the basic requirement of the concept of defence in depth, according to which high-quality RPV materials only are to be used.

In summary, it must be stated that Tihange unit 2, apart from the fact that this RPV would not have been approved if the flaws were found post-manufacture, represents an incalculable risk for further operation because of the uncertainty regarding actual properties and embrittlement of key components of the nuclear power plant.

Dukovany

Design

The original reactor design of the VVER 440/213 reactor type (including Dukovany 1-4) dates back to 1967. Since the time of the design, the state of reactor science and technology has developed significantly. Although attempts have been made to implement various findings via retrofits, the original construction structures, among other things, act as limiting factors.

The original design of the VVER 440/213 reactors is affected by significant safety deficiencies, which have only been recognized over time.

- High susceptibility of the RPV to embrittlement in the area of the reactor core due to design and material.
- Susceptibility to coolant leakage in the steam generator from the primary to the secondary side of the reactor.
- Safety deficiencies in safety-relevant systems such as safety valves on the primary system pressurizer, in the emergency feedwater system on the secondary side, in the bubbler condenser in the event of an accident, in the emergency core cooling systems in the event of a loss-of-coolant accident during long-term operation (e.g.: Risk of pump or cooler clogging by detached thermal insulation material).
- Relatively high leakage rate of the confinement and insufficient hydrogen management in the confinement boxes in case of a severe accident.
- Safety deficiencies in instrumentation and control (I&C), such as lack of separation of systems for control and protection functions.
- Poor seismic qualification of instruments.
- Inadequate precautionary measures for a safe stay of the operating personnel in the control room during incidents and accidents.
- Inadequate qualification of electrical equipment for extreme situations and the capacity of emergency power generators.
- Inadequate design against external hazards, e.g. against fire, external flooding, aircraft crash, or seismic loads.

The VVER 440/213 units at Dukovany, which are grouped as twin units, share certain systems and buildings in whole or in part. From an economic point of view, it is an advantage that systems can be shared. Safety-wise, there are fewer safety reserves available for the twin units in case of failure of common systems. Some of these safety deficiencies could be eliminated or at least mitigated through retrofits, but significant others could not.

Deviation of safety levels

Like all Generation II nuclear power plants, all VVER 440/213 reactor units in Dukovany have certain weaknesses already in the original safety design, which cannot be compensated subsequently. Among the most important are:

- The VVER 440/213 reactor units are not equipped with conventional containment structures typical of other pressurized water reactors.
- Spent fuel pool outside the confinement: for geometric and design reasons, the spent fuel pools are not integrated into the confinement and are thus, on the one hand, at risk from massive external impacts (e.g., aircraft crash). On the other hand, severe accidents in the spent fuel pool can lead to massive destruction of the reactor building by hydrogen detonation and facilitate the release of radioactive substances into the environment.
- Risk increase due to failures affecting several units: The high-energy feedwater and steam lines are situated in close proximity at the 14.7 m level, in the area of the intermediate building between the reactor building and the turbine hall without physical protection between the lines, so that in case of failure of one-line, consequential failures of others cannot be excluded.
- Problem of transferring experimental results of scaled test facilities to the nuclear power plant for the Severe Accident Management concept of in-vessel melt retention (IVR) in the reactor pressure vessel.

In units with shared structures and systems, under certain circumstances, accidents may occur in which two or more blocks can be affected simultaneously as a consequence.

The design pressure for the confinement is 0.25 MPa (0.15 MPa gauge pressure). Limit strength calculations performed for the utility show a 50% probability of failure when the confinement pressure increases to 0.35 MPa (0.25 MPa gauge pressure). This results in a safety factor of only 2; whereas most PWRs have safety factors of 2.5 to 4 against overpressure failure.

It has not been adequately demonstrated, based on evaluation of the available evidence, that the retrofitted passive autocatalytic hydrogen recombiners (PAR) can safely prevent hydrogen explosion and/or deflagration to detonation transition (DDT).

Embrittlement of the reactor pressure vessel

Since there exists (strongly differing) published data on embrittlement of the reactor pressure vessel, it follows that RPV weld metal embrittlement may be far advanced. If we assume a limit value for embrittlement of 135°C (Tka) as assumed for Bohunice, then the RPV in Dukovany unit 1 is alarmingly highly embrittled. Already since 1994, the emergency core cooling water has been heated to 55-60°C to mitigate the consequences of thermal shock in case of emergency core cooling.

Currently, a reassessment program on the state of embrittlement of the reactor pressure vessels (specific Ageing Management Programme for reactor pressure vessels) is underway, which was launched in 2015. As a result of the program, the determination of the specified value of Tka (Tk value) according to the state of science and technology, and taking into account the current condition of the plant, is expected in 2020.

In summary, it must be assumed that the embrittlement of the RPV weld metal is already alarmingly high, especially for the first unit.

Cattenom

Design and degree of redundancy

The safety system of the Cattenom plant is basically designed with 2 safety trains (redundancy level n+1), i.e. protected against single failure. According to good practice reactor design, which has been valid for a long time, this is not sufficient. If one safety system fails and the other safeguarding redundant system is under repair, then there is no further safety system to fall back on. The control of incidents is then no longer guaranteed. This applies, among other things, to the equipment for primary-side long-term cooling, primary-side make-up and containment cooling in the event of loss-of-coolant accidents, containment cooling in the event of loss-of-coolant accidents, and cooling of the spent fuel pool. A higher degree of redundancy is only available with regard to the active equipment, such as pumps for the safety functions of the secondary-side steam generator feed as well as the primary-side boration system and the sealing water supply of the main coolant pumps. Incidentally, the design for these system functions is also basically 2-trains.

The planned retrofit of the Hardened Safety Core adds reserves for individual safety functions but does not increase the degree of redundancy of the safety systems. The design of the existing system remains unchanged. According to the state of the art in science and technology, a higher degree of redundancy n+2 has already been consistently implemented in other reactor concepts in the past. Cattenom does not achieve this safety standard.

Design against earthquakes

The French regulations on which the seismic design of Cattenom is based do not require a systematic uncertainty analysis. In the absence of such analysis it is not transparent as to whether uncertainty contributions were taken into account in the design. The procedure to derive the DBE requires independent site location in order to assess the intensity of the strongest historical earthquake (and increase it by one in the appropriate scale). This margin may not be sufficient, as realistic uncertainty bands demonstrate. Overall, it cannot be confirmed as to whether the protection against seismic risk is sufficiently conservatively calculated. For example, no exceedance probabilities are given for the design earthquakes at Cattenom.

Not all safety-relevant components are designed against the design earthquake. At Cattenom, these include:

- Parts of the intermediate cooling system (consequence: cooling failure).
- Pipelines of the fire extinguishing system (consequence: flooding of rooms of the auxiliary cooling water system, cooling failure).
- Pipelines for hydrogen distribution (consequence: possible release of hydrogen into the plant, subsequent fires or explosions).

Within the plants, only a part of the emergency diesel generators and mobile equipment is protected against earthquakes. The capacity of the emergency power supply is limited after a design earthquake. For measures of plant-internal emergency protection, systems can also be used that are not qualified as safety systems and are not equivalently designed against earthquakes, -for example the fire extinguishing system for cooling water supply or mobile facilities. It can be assumed that in the event of an earthquake, these facilities will no longer be available to deal with emergency situations.

As consequence of the reactor accident in Fukushima, the HSC (Hardened Safety Core) was developed and adopted as a required retrofit. The design earthquake assumptions for the HSC exceed the basic design of the existing plants. No retrofits are planned in this regard for the existing safety system. Known weaknesses of the previous approach are thus only compensated to a very limited extent by the more stringent requirements. The more stringent requirements apply only to a narrowly defined part of the safety equipment to be retrofitted. In the case of such retrofits, there is always the problem of interfaces with the existing weaker-designed systems, which can fail prematurely. The protection level of a full design according to the current state of science and technology is not obtained.

Transparency and public participation

At present, life-time extensions in Europe do not have to be comprehensively relicensed according to the state of the art in science and technology. Time limited licenses can be extended by decision of the competent authorities. However, such decisions do not meet the requirements of NPP licensing procedures in regard to public participation. More often than not environmental impact assessments with public participation are not carried out. However, the situation has changed with the ruling of the European Court of Justice of 29th of July 2019 on the life-time extension of the Doel NPP (Belgium) and the new guidance under the ESPOO Convention. Accordingly, environmental impact assessments with transboundary public participation are now required for life-time extensions.

However, there are still no binding assessment standards for life-time extensions. It is still up to each regulatory authority to decide what and how to assess. In particular, the authorities are not obliged to carry out a comprehensive licensing procedure in which all safety issues are comprehensively examined according to the current state of knowledge.

This leaves a clear regulatory deficit at the European level.

Up to now, there has been no 'risk report' to complement the safety report as a component of a participation procedure under nuclear law, in particular of any public participation concerning decisions on life-time extensions. A risk report should have to contain the presentation and overall assessment of all deviations from the current state of the art and of the remaining risks according to the safety analyses carried out in a comprehensible form.

Conclusions

Life-time extensions and the operation of ageing nuclear power plants increase nuclear risks in Europe.

The ageing of nuclear power plants leads to a significantly increased risk of severe accidents and radioactive releases. The risk of continued operation of old plants is further significantly increased due to their further life-time extension and power increase. Partial retrofits can, in practice, do little to change this.

The age structure of operating nuclear power plants in Europe shows that many plants are already approaching or have already exceeded the age of their original technical design. However, they are expected to continue operating beyond this point.

Ageing processes increase the risk of transients and accidents.

The cause of many safety-relevant events can be traced back to ageing processes. This is shown by operating experience. Ageing processes such as corrosion, abrasion or embrittlement reduce the quality of systems, structures and components to the point of failure. Safety reserves vanish, the effectiveness and reliability of safety functions and thus also the potential for controlling accidents are limited as a result.

In the early years of nuclear power plant development and construction, the materials, manufacturing processes and test methods used were of lower quality than today. Similarly, knowledge of the nature and extent of age-related damage to the materials used was limited compared to today. Therefore, ageing processes are a particular problem for old nuclear power plants.

All pan-EU ageing power plant concepts are, in practice, outdated in terms of safety.

Most power plant concepts date back to the 1970s and 1980s. The construction and operating licenses of many nuclear power plants are already 30 years old and more. At that time, they were approved for operation as “safe” after licensing reviews. Essential safety principles (such as diversity, spatial separation and protection against external impacts) were not used or were used only to a limited extent; in this respect, from today's perspective, old nuclear power plants have numerous design weaknesses.

Structural separation of safety areas, redundancy, independence of the levels of the staggered safety concept, the installation of diversified technologies, were all implemented far less consistently than would be required according to today's knowledge and standards. With the increasing age of the plants, these conceptual deviations from the safety level required today for new plants become bigger and bigger.

Many nuclear power plants are operated beyond the limit of the original technical design and at an outdated technical level.

The technical license review of nuclear power plants was carried out within the framework of the original licensing with regard to an operating time of 30-40 years. Nevertheless, today nuclear power plant life-times are to be extended to 60 or more years without a new license review and without fundamental modernization. The even older underlying concepts of these nuclear power plants would then, at decommissioning, be up to 100 years old.

New threats have emerged.

Terrorist attacks, airplane crashes and other disruptive actions as well as extreme natural events as a result of ramping climate change, can no longer be neglected, and represent risks. As such, they require special protective measures which were not foreseen in the design of the existing plants and can only be implemented to a very limited extent. Compliance with today's safety standards would practically require the development and construction of a completely new nuclear power plant.

To justify life-time extensions original safety margins are reduced.

In order to reduce the risk of operating nuclear power plants, safety margins are introduced in the design of individual systems and components in accordance with deterministic safety philosophy. These safety margins are used to compensate for unforeseen errors in the material, in the mode of operation, in the design, or in the safety-related calculations as a precaution. These safety margins are reduced or are no longer present in ageing nuclear plants. In addition, safety calculations carried out today utilze safety margins in order to be able to show that the corresponding safety limit has not yet been reached. The risk of failure increases accordingly.

The old plants cannot be licensed according to today's standards

The severe accidents at Three Mile Island, Chernobyl and Fukushima have each shown that nuclear power plants are not as safe as had been claimed and assumed. This means that the risk of the old plants was underestimated at the time they were licensed. As a result of these accidents in particular, the state of the art in science and technology was expanded and the requirements for new plants were tightened. However, these new requirements cannot be sufficiently implemented in old plants.

This means at the old plants a risk is accepted that would not be acceptable for new projects. No EU member state would grant a new construction permit to any of the ageing nuclear power plants currently in operation.

The statement that the safety of old nuclear power plants has been continuously improved by retrofitting is misleading.

Retrofits often serve to reduce deficiencies in the plant or to protect against risks that had been accepted or not recognized at the time of licensing. Thus, retrofits often serve to establish the "safe" condition that was assumed at the time of approval, but not for the present.

There are limits to retrofitting on principle. Major conceptual weaknesses of old nuclear power plants remain.

Safety requirements according to the current state of science and technology cannot be fully implemented in the design of old nuclear power plants. Elementary weaknesses of the outdated safety concepts cannot be eliminated. A significant part of the safety standard is already determined in the design of the nuclear power plant.

The state of the art in science and technology has evolved. Reactor safety research has gained new insights into previously unrecognized risks. Added to this is the accumulated experience from incidents, accidents and even severe accidents. This has resulted in extended requirements for systems, structures and components, which have grown over decades, in order to eliminate previously unrecognized weaknesses.

When comparing the design concepts of existing plants with the concepts of new-builds, there are striking differences, for example, in the degree of redundancy, the independence of safety systems, protection against external events and the design features against severe accidents.

New, advanced requirements that affect the fundamentals of the safety concept and the basic design of large structures (e.g. core catcher) cannot be retrofitted in existing plants, partly because of spatial constraints.

For certain accident sequences, attempts are made to compensate for design deficits with additional mobile equipment kept on standby. This is not equivalent to safety provisions in the basic design. Additional measures taken by the operator can not achieve the same level of safety as structural measures (e.g. fire protection).

The possibilities of ageing management are limited.

Repair and replacement of components affected by ageing, if possible at all, can only eliminate deficiencies locally. Damage in structures, systems and components that cannot or should not be replaced (such as the reactor pressure vessel) means a permanent and (as ageing processes progress) increasing reduction in originally installed safety margins. Measures such as additional inspections or tests, which are often introduced as a substitute for remedying the identified deviations, can at best observe the damage progression, but cannot compensate for the loss of safety. This continued operation at lower safety levels is justified by the competent authorites by allowing substitute measures instead of requiring to restore an acceptable condition.

The complexity of ageing phenomena does not allow for an overall reliable prediction of ageing effects and makes precaution-oriented strategies for their control more difficult. New or inadequately considered phenomena, as well as unexpected interactions, result in premature and unexpected failures of safety equipment. In reality, the actual development of age-related damage can deviate significantly from the prediction. The system of in-service functional tests and inspections is not able to reliably detect all ageing processes before they lead to visible damage or failures. Even in areas that are extremely sensitive in terms of safety, damage can exist undetected for long periods of time and reach a considerable extent. Under higher operating loads, such as those that occur in the event of an incident, such latent defects can become acute. The introduction of ageing management can mitigate, but not eliminate, the ageing related increase in risks.

Retrofitting and repairs in old plants lead to additional risks

By interfering with the safety technology of the existing plant, new risks can be created - for example through unforeseen interactions. New technical solutions may show incompatibilities with the existing technology. In the case of ageing components, the problem of procuring spare parts increases if they are taken out of the delivery program or no longer developed further. Changes (design, material, manufacturing process) in the supply chain can lead to unexpected failures. Sufficient quality, a prerequisite for safe operation, can then often no longer be demonstrated.

Lack of documentation and loss of know-how and know-why make it difficult to assess the safety of old plants.

The original safety documentation for old nuclear power plants often has gaps that cannot be filled subsequently. The available technical documentation sometimes does not correspond to the actual status on site. Information is incorrect or incomplete. This means that the current condition and the actual properties of the plant areas or components concerned cannot be determined and evaluated with sufficient certainty. Meanwhile, missing data are often replaced by assumptions that cannot be sufficiently verified.

The technical documentation from the time of planning, construction and commissioning differs significantly from today's standard. In many cases, the available data and other information do not permit verification of a quality that would currently be required for a new design.

Not all aspects and characteristic values required to demonstrate adequate safety according to the current state of knowledge have been taken into account and are documented. Safety assessments are only possible under assumptions that cannot be adequately substantiated. This is aggravated by an age-related loss of know-why and know-how, as experience and knowledge retire with the personnel.

The risks of old plants must be known in order to assess their safety.

Operators and regulatory authorities under whose direction old nuclear power plants are operated are responsible for assessing and reviewing their safety. Their final statement about the safety of a plant are merely legal normative assessments. The reliability of the statement on safety depends crucially on the quality of the available information and on the assessment, standard applied. The decisive factor is what information is available and what assessment standard is applied.

One hundred percent technical safety, i.e. the exclusion of an accident, is a fiction. The decision on "safe" or "not safe" consists in an evaluation of which of the remaining risks can still be tolerated in nuclear power plants. The statement that an old nuclear power plant is safe is worthless and not comprehensible if the remaining risks are not recognized at the same time, and transparent information is not provided about them.

For affected groups nuclear risks remain hidden because no information is provided about them.

The information released to the public is mostly incomprehensible to those potentially affected and does not address critical safety issues. There is no obligation, either on part of the operators or on part of the competent authorities, to provide adequate information about the remaining risks. Without their own experts, those affected by civil society are largely helpless because the information provided cannot be interpreted and critically scrutinized. There is a lack of resources, for example in the form of funding for independent experts selected by the interested public as part of participation procedures, which would be necessary in order to enable effective public participation. As long as there is no obligation for operators and authorities to report actively, comprehensibly and transparently on safety issues and the potential effects on people and the environment, there can not be real participation.

Lack of transparency makes it difficult for third parties to assess risks.

The procedure for safety reviews of operating nuclear power plants is not transparent for third parties. There is lack of procedural specifications to ensure adequate access to information and appropriate participation in the decision-making processes for all parties concerned. The evaluation of the risk of the actual condition of the plant as distinct to the current state of science and technology is not part of the procedure.

There is no established possibility for transboundary participation, although the risks may have transboundary consequences.

Binding cross-border public participation is not yet an established part of life-time extension. While the construction of new power plants today necessarily involves international participation, the decision on the continued operation of old plants is made sovereignly. However, radionuclides released in the course of an accident do not stop at national borders. Independent inspections to assess the current condition of plants and the implementation of necessary retrofit measures are an important instrument of international cooperation. Compliance with international safety standards as a minimum requirement (e.g. WENRA Reference Levels, IAEA Safety Standards), which may also exceed national requirements, is not mandatory.

There is no independent international review body and no internationally binding rules for the implementation of safety requirements for old plants.

There are no independent international inspection bodies that could monitor the implementation of rules. In addition, internationally agreed safety requirements, when applied to old plants, always allow the exception that measures only have to be implemented if they are “reasonably practical” or “reasonably achievable”. In many cases, this is also determined by economic factors. This leaves it largely up to national regulatory authorities to determine the extent to which current requirements are applied and actually implemented. There are no internationally binding standards, not even in Europe.