Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Eidgenössisches Nuklearsicherheitsinspektorat ENSI
Inspection fédérale de la sécurité nucléaire IFSN
Ispettorato federale della sicurezza nucleare IFSN
Swiss Federal Nuclear Safety Inspectorate ENSI

Implementation of the obligations of the

Convention on Nuclear Safety

CNS

July 2019
Switzerland's Eight National Report
to the Convention on Nuclear Safety

Convention on Nuclear Safety

Switzerland's Eight National Report on Compliance
with the Obligations of the Convention on Nuclear Safety

July 2019

Contents

Foreword

Switzerland signed the Convention on Nuclear Safety (CNS) on 31 October 1995 and ratified the Convention on 12 September 1996, which then came into force on 11 December 1996. In accordance with Article 5 of the Convention, Switzerland has prepared and submitted country reports for the regular Review Meetings of Contracting Parties organised in 1999, 2002, 2005, 2008, 2011, 2014 and 2017, and for the Second Extraordinary Meeting in 2012. The corresponding Review Meetings at the IAEA headquarters in Vienna were also attended by a Swiss delegation.

This eighth report by the Swiss Federal Nuclear Safety Inspectorate (ENSI) provides an update on Switzerland's compliance with the obligations of the Convention. In addition, the report gives due regard to issues and trends in nuclear safety, such as those identified by the Contracting Parties at the seventh Review Meeting, at the Organisational Meeting and in the Principles agreed upon in the Vienna Declaration on Nuclear Safety (VDNS).

The report begins with general information about Switzerland, a brief history of the country's nuclear power programme and an overview of its nuclear facilities as well as a short description of Switzerland's waste disposal programme and site selection process for geological repositories. The «Summary and Conclusions» chapter provides an overview of the contents of the report and its conclusions on the degree of compliance with the obligations of the Convention, followed by a comprehensive overview of the status of nuclear safety in Switzerland as of March 2019. The numbering of the ensuing chapters in the report matches that of the CNS Articles 6–19. The comments for each section indicate clearly how Switzerland complies with the key obligations of the Convention.

The implementation of the Principles in the Vienna Declaration on Nuclear Safety is reported upon under a separate chapter. Furthermore, a subchapter of the Summary and Conclusions gives answers to the Challenges identified by the seventh Review Meeting. Appendix 1 contains a list of abbreviations used in the text; Appendix 2 provides a list of ENSI's guidelines currently in force.

Introduction

Country and State

Switzerland is located in the middle of Europe and is surrounded by France to the west, Germany to the north, Austria and Liechtenstein to the east and Italy to the south. With a total surface area of 41 285 km² – more than half of which is mountainous – and a population of just over 8.5 million, Switzerland is a small, densely populated country. The sources of the Rhine, Rhone and Inn rivers are in the Swiss Alps. Switzerland has four official languages: German, French, Italian and Rhaeto-Romanic, the latter being spoken by some 0.5% of the Swiss population. About 24% of current residents are foreign nationals.

Structurally, Switzerland has evolved into a federal state with 26 member-states, known as cantons. The federal authorities are responsible under the Constitution for certain central functions. At each level, a significant number of political rights are guaranteed to the people. All other legislative power remains with the cantons, which therefore retain a high degree of autonomy. Municipalities also enjoy considerable rights of self-government.

The Federal Council consists of seven ministers of equal rank, acting as the federal government. Ministers are elected by the Swiss Parliament. The Parliament consists of two chambers. The National Council represents the population as a whole. It has 200 members elected for a term of four years. The Council of States has 46 members representing the Swiss cantons. The electorate has the constitutional right to introduce and sanction changes to the Federal Constitution and a right to vote in referendums on federal legislation. The electorate can also request changes or additions to the Federal Constitution through a popular initiative signed by at least 100 000 voters. Any change to the Constitution must be submitted to an obligatory national referendum. If a minimum of 50 000 voters challenge a decision by parliament to pass a new federal law or change an existing law, the issue is put to a facultative national referendum. The federal rules on popular initiatives and referendums are replicated in cantonal constitutions.

In 2017, Gross Domestic Product in Switzerland per capita was approximately CHF 80 000 (EUR 71 000). The most important economic sectors are banking, tourism, mechanical engineering, chemical and pharmaceutical industry, foodstuffs, watches and medical technology. Its major export partners are Germany, USA, China, Italy, France, United Kingdom and Japan.

Total energy consumption in Switzerland was about 849 790 TJ in 2017. Electricity consumption accounts for about 25% of energy consumption. The main sources of electricity in Switzerland are hydroelectric (2017: 59%) and nuclear power (32%).

Background to nuclear power in Switzerland

Until the late 1960s, Switzerland generated electricity exclusively from hydropower and did not resort to fossil fuels since the latter were not available as a natural resource in Switzerland. By the mid-1950s, there was interest in the use of the relatively new nuclear energy technology to cover the increasing demand for power. In accordance with the general policy on electricity production, it was left to the private sector to promote and use nuclear energy. However, it was recognised that any nuclear programme would require a legislative framework to ensure safety and radiation protection. It was further recognised that such legislation should be exclusively at federal level. As a result, an Article was added to the Swiss Constitution, which was approved by a vote of the Swiss population in 1957. The Atomic Energy Act came into force in 1959 based on this Article.

In 2005, Switzerland enacted a new Nuclear Energy Act and its related ordinance to replace the Atomic Energy Act of 1959. Under the new Nuclear Energy Act, the unconditional authority of the Federal Council to grant general licences for new nuclear power plants (NPP) was abolished with decisions on general licences for new NPPs being subject to a facultative national referendum. In addition, the Federal Government leads the site selection process for geological waste repositories.

As nuclear power production is part of the private sector, there is no national nuclear programme as such. During the 1960s, a series of projects for NPPs was initiated, four of which were built. This resulted in the current five operating units, which were commissioned between 1969 and 1984. Several other projects were cancelled.
Licensing procedures for three new units at existing sites were ongoing in Switzerland before the events at Fukushima Daiichi occurred in 2011. ENSI was involved in the procedures and had issued the three corresponding safety evaluation reports (SER). The safety evaluations focused on reassessing potential hazards relating to the specific site characteristics. Shortly after the Fukushima Daiichi accident, the Federal Council suspended these procedures. Over the course of 2011, the Federal Council and the Swiss Parliament decided to phase out nuclear energy by prohibiting the building of new plants, while the existing plants are to continue operating for as long as they can safely do so.
On 21 May 2017 there was a referendum on the government's Energy Strategy 2050, which was approved by a 58% majority, with a turnout of 42%. It includes the provision for a gradual withdrawal from nuclear power and a greater reliance on hydro and intermittent renewables. No construction licences will be issued for new nuclear power reactors.
In May 2016 a people's initiative calling for Swiss nuclear power plants to be shut down after no more than 45 years of operation was rejected by the Swiss voters. This means that five existing reactors in Switzerland will be allowed to remain in operation as long as ENSI considers them safe.

The regulatory authority

The first experimental nuclear reactor started operation in Switzerland in 1957. At this time there was no regulatory authority established in Switzerland. The canton in which a reactor was located was responsible for its safety. The first nuclear regulator in Switzerland was the Swiss Federal Nuclear Safety Commission, which was set up in 1960. Between that date and 1982, its secretariat evolved in several stages into an independent authority. In 1964, the Federal Council decided to create the Department for the Safety of Nuclear Facilities, which later became the Swiss Federal Nuclear Safety Inspectorate (ENSI). The duties of the regulatory body were formally defined in an ordinance published in 1982. Until the end of 2008, ENSI was part of the Swiss Federal Office of Energy (SFOE).
The fact that ENSI reported directly to SFOE contravened the independence stipulated in both the Swiss Nuclear Energy Act of 2005 and the Convention on Nuclear Safety. The Act on the Swiss Federal Nuclear Safety Inspectorate ENSI – approved in 2007 – created a statutory framework for making ENSI formally independent of the SFOE. This was achieved on 1 January 2009 when ENSI became an authority constituted under public law. ENSI itself is supervised by an independent body, the ENSI Board. Its members have specialist knowledge of nuclear safety as well as management experience and are elected by the Federal Council for a term of office of four years on each occasion. The Board consists of five to seven Members and reports directly to the Federal Council.

Nuclear power plants

Switzerland has five NPPs – Beznau I and II, Mühleberg, Gösgen and Leibstadt. They are located on four different sites and have four different reactor and containment designs provided by three different reactor suppliers (Westinghouse, General Electric and Kraftwerk Union). Local suppliers contributed to civil engineering, buildings and mechanical and electro-technical equipment. The Beznau NPP is operated by Axpo Power AG, the Mühleberg NPP by BKW AG, the Gösgen NPP by Kernkraftwerk Gösgen-Däniken AG, and the Leibstadt NPP by Kernkraftwerk Leibstadt AG.

Table 1: *Main technical characteristics of the Swiss NPPs (as of March 2019)*

	First generation NPPs			Second generation NPPs	
	Beznau I	Beznau II	Mühleberg	Gösgen	Leibstadt
Licenced thermal power P^{th} [MW^{th}]	1130	1130	1097	3002	3600
Nominal net electrical power P^{el} [MW^{el}]	365	365	373	1010	1275
Reactor type	PWR	PWR	BWR	PWR	BWR
Containment type	Large dry, free standing steel inside concrete building	Large dry, free standing steel inside concrete building	Pressure suppression, Mk I inside concrete building	Large dry, free standing steel inside concrete building	Pressure suppression, Mk III inside concrete building
Normal heat sink	River Aare	River Aare	River Aare	Wet cooling tower (River Aare)	Wet cooling tower (River Rhine)
Number of reactor coolant pumps	2	2	2	3	2
Number of turbine sets	2	2	2	1	1
Number of fuel assemblies	121	121	240	177	648
Fuel	UO_2	UO_2	UO_2	UO_2	UO_2
Number of control assemblies	25	25	57	48	149
Reactor supplier	W	W	GE	KWU	GE
Turbine supplier	BBC	BBC	BBC	KWU	BBC
Site Licence	1964	1967	1965	1972	1969
Construction licence	1964	1967	1967	1973	1975
First operating licence	1969	1971	1971	1978	1984
Commercial operation	1969	1971	1972	1979	1984
Backfitted bunkered automatic ECCS and residual heat removal system since:	1993	1992	1989	Included in the original design	Included in the original design
Filtered containment venting system since:	1993	1992	1992	1993	1993

Abbreviations:

Mk I, Mk III	GE Containment Types Mark I and Mark III
PWR	Pressurised Water Reactor
BWR	Boiling Water Reactor
W	Westinghouse Electric Corporation
GE	General Electric Technical Services Corporation
KWU	Siemens Kraftwerk Union AG (now Areva NP)
BBC	Brown Boveri & Cie, AG (now Alstom)
UO_2	Uranium oxide
ECCS	Emergency core cooling system

Because of Switzerland's mountainous landscape, the number of suitable sites for NPPs is limited. Two sites are located near the German border; Leibstadt is situated 0.5km and Beznau 5km from the border. The other two sites are located about 40km from the French and 20km from the German border respectively. The geographic location of all Swiss nuclear facilities is shown on the map in Figure 1.

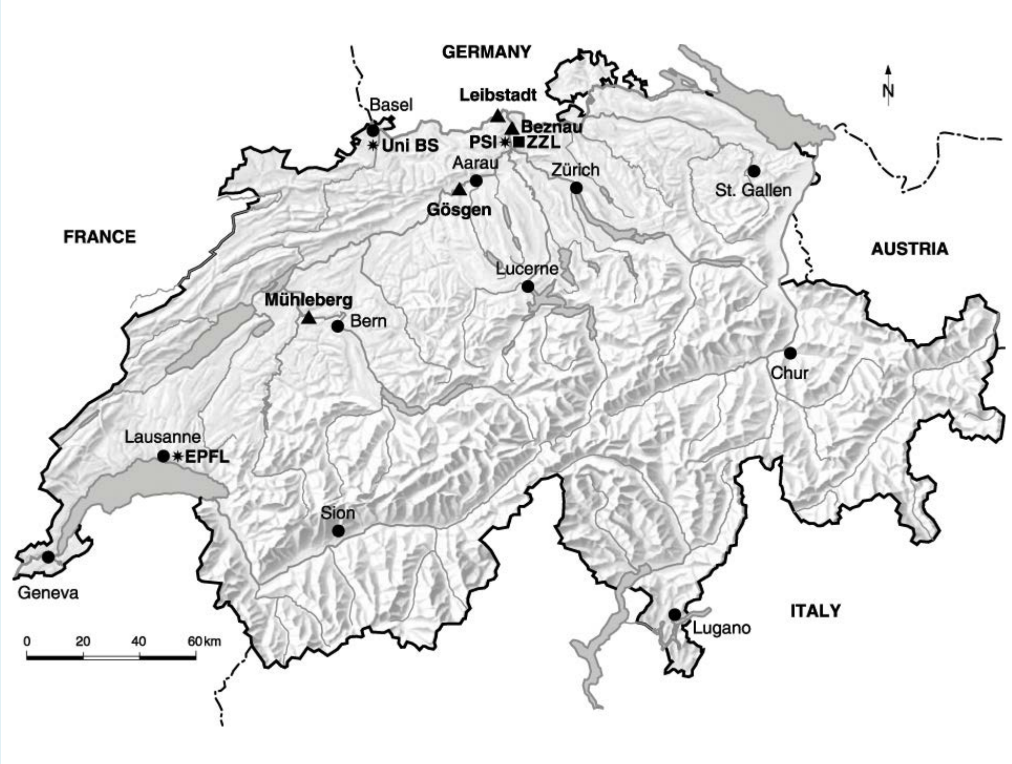


Figure 1: *Geographic location of Swiss nuclear facilities. Triangles mark the NPP sites. Asterisks mark experimental and research installations. Squares mark facilities for nuclear waste management. The dots are major cities.*

Facilities for nuclear education, research and development

Most nuclear research in Switzerland is performed at the Paul Scherrer Institute (PSI). Research at PSI is conducted in collaboration with other national and international research institutes and industry. It covers the following areas: elementary particle physics, biological sciences including radiation protection, solid-state research and material science, nuclear energy research, non-nuclear energy research and environmental research related to energy production, medical research and medical treatment (oncology).

Several nuclear installations are located at the PSI site, of which the Hot Laboratory Facility is the most significant where nuclear safety is concerned. The DIORIT, SAPHIR and PROTEUS research reactors are in various stages of shutdown or decommissioning.

Apart from the above-mentioned former research reactors at PSI, there are two small teaching reactors (P < 2 kWth) at the University of Basel and at the Swiss Federal Institute of Technology in Lausanne. The reactor in Basel was shut down in late 2013. In 2015 the remaining highly enriched uranium from the reactor was sent back to the USA. The University of Basel submitted the decommissioning project for review in February 2017. The zero-power (100 W) teaching reactor in Lausanne is still in operation.

Processing and interim storage of nuclear waste

Swiss legislation requires immediate conditioning of radioactive waste from nuclear installations except for technical optimisation in periodic conditioning campaigns. Consequently, each NPP is equipped with facilities for waste conditioning and interim storage. On-site facilities for storage of spent fuel are located at the Beznau site (dry storage, also for waste) and at Gösgen NPP (wet storage, spent fuel elements only). Both facilities started operation in spring 2008.

In addition to the on-site facilities, there is a centralised storage and conditioning facility (Zentrales Zwischenlager ZZL), owned by ZWILAG, which is located adjacent to the PSI campus. This facility provides interim storage capacity for spent fuel, intermediate and low-level radioactive waste. Any returned waste from the reprocessing of Swiss spent fuel at La Hague (F) and Sellafield (UK) is stored here. The facility also contains installations for the conditioning of specific waste categories and the incineration or melting of low-level waste. The Central Interim Storage Facility began active operation in June 2001.

PSI operates the national collection centre for all institutional radioactive waste: waste from medicine, military applications, industry and research. The waste can be treated either at PSI installations or at ZWILAG followed by interim storage at the Federal Interim Storage Facility, which is also located on the premises of the PSI.

Current status of the process to select sites for geological repositories

The site selection process for deep geological repositories for radioactive waste in Switzerland (Sectoral Plan) is divided into three stages and is described in detail in the 6th National Report of Switzerland in accordance with the Joint Convention on the safety of spent fuel management and on the safety of radioactive waste management (pages 17–24). The second stage of the Sectoral Plan has been completed: based on the Swiss implementing organisation Nagra's proposals, reviews by the federal authorities and a public consultation, the Swiss Government decided on 21 November 2018 that

- in the final stage 3 of the site selection process, the geological siting regions Jura Ost, Nördlich Lägern, Zürich Nordost need to be investigated further,
- the previously proposed siting regions Jura-Südfuss, Südranden and Wellenberg will remain reserve options and
- the Swiss implementer must in particular examine and explain the advantages and disadvantages of combined disposal for LLW, ILW and HLW/SF in the same siting region as compared to two repositories in separate siting regions.

Based on the results of the geological investigations for stage 3 and the comparison of long-term safety performance across the three remaining siting regions, the Swiss implementer will announce the location or locations for which a general license application will be prepared. The potential siting regions must be compared in accordance with the safety criteria defined in the Sectoral Plan and the requirements recently specified by ENSI.

Summary and Conclusions

On 21 May 2017 the Swiss electorate accepted the revised Federal Energy Act which prohibits the construction of new nuclear power plants. The existing plants will continue to operate as long as they are considered safe by ENSI and fulfil all legal and regulatory requirements in this respect. Against this background, Swiss activities for the current reporting period can be summarised under the following points:

Safe operation of existing plants

In Switzerland, ongoing activities regarding safety assessment of the different stages in the lifetime of nuclear installations consist of periodic assessments and assessments of long-term operation (LTO) for existing Swiss NPPs. Assessments of LTO have been performed for two Swiss NPPs which have been in commercial operation for over 40 years. A detailed examination demonstrated that the conditions for the taking out of service of an NPP are not yet and will not be reached by these two plants (Beznau NPP and Mühleberg NPP) within the next 10 years. Nevertheless, it is mandatory to continue with the scheduled ageing management, maintenance and backfitting activities. A third NPP, Gösgen, will enter into LTO in 2019 and has submitted its LTO report which is being reviewed by ENSI.

Shutdown of Mühleberg NPP

In late 2013, BKW Energy Ltd announced that Mühleberg NPP will be decommissioned at the end of 2019. The plant will shut down on 20 December 2019. The single 373 MWe boiling water reactor began operating in 1972. It will be the first Swiss nuclear power plant to be decommissioned. The preparatory work for decommissioning is well under way. For more information, see Article 6.

International peer reviews and cooperation

Switzerland participated in the 2017 European Topical Peer Review on Ageing Management on a voluntary basis and hosted an IPPAS mission in 2018. An IRRS Mission was held in 2011 with the follow-up mission in 2015. The IRRS reports are publicly available on the ENSI website. The next IRRS mission to Switzerland is planned for 2021.
All Swiss NPPs have undertaken OSART missions and every Swiss NPP is a WANO member. Since 2005, all Swiss NPPs have been involved in the WANO peer review process. The cycle for WANO peer reviews and WANO follow-up missions is about six years, i.e. the NPPs are involved in either a WANO peer review or a WANO follow-up mission every two to three years.

Safety and oversight culture

ENSI has continued its efforts to oversee human and organisational factors in plant modernisation projects and in event analysis, and launched a programme to investigate how learning from project experience is anchored in the organisational structure of the operating organisations. ENSI has developed a mutual understanding of nuclear safety and security culture. Its approach to safety and security culture is based on an integrated understanding of the culture of a (nuclear) organisation. Nuclear safety and security both serve the same purpose of protecting people and the environment. Thus, ENSI explicitly refrains from drawing a distinction between safety and security culture in its supervisory activities, although it does consider the specific requirements for security and nuclear safety. The themes of safety and security are dealt with under the generic term safety culture. The operators of the Swiss nuclear power plants share this same approach. The ENSI reports «Integrated Oversight»[1] and «Oversight of Safety Culture»[2] contain basic statements on the ENSI supervisory culture. The «Integrated Oversight» report is the result of the increasing systematisation of all supervisory activities in recent years. The reports are available to the public.

[1] https://www.ensi.ch/en/documents/integrated-oversight/
[2] https://www.ensi.ch/en/documents/oversight-of-safety-culture-in-nuclear-installations/

Post-Fukushima Daiichi Actions

Following the accident at Fukushima Daiichi, ENSI undertook a series of actions to understand the sequence of events in Fukushima Daiichi and its causes. The knowledge obtained from analysing the events of the accident at Fukushima Daiichi was reviewed to determine how it applies to Switzerland, and a summary of insights was compiled in an ENSI report entitled «Lessons Learned» in the form of a series of checkpoints. Further points were added on completion of the analyses for the EU stress tests. Processing and implementation of the identified points were updated and published annually in the Fukushima Action Plan until February 2015. With the publication of the summary report containing all measures identified and implemented post-Fukushima by the end of 2016, Switzerland concluded its post-Fukushima Action Plan.

Answers to the requirements of the Guidelines regarding the National Reports under the CNS – INFCIRC/572

Challenges from the Seventh Review Meeting:

The following challenges were identified for Switzerland during the seventh Review meeting of the CNS:

Challenge 1: Open issues from the IRRS Follow-Up Mission in 2015:
«The government should:

- **strengthen ENSI's independent regulatory authority by giving ENSI the ability to issue binding technical safety requirements, licence conditions on nuclear safety, security and radiation protection**

Activity performed in this regard:
In 2013, a Parliamentary Administrative Control (PAC) investigated the independence of the Swiss supervisory and regulatory authorities. In its report of 2 February 2015, the PAC came to the conclusion that a supervisory and regulatory authority can only exercise its independence if it also possesses the corresponding supervisory and regulatory powers (powers to issue ordinances and to issue orders and instructions). In its statement of 18 December 2015 on the PAC report, the Federal Council pointed out that it had identified no need to change the situation for ENSI. ENSI's competence to issue regulations of this kind would not bring any additional benefit. The existing competence to issue directives is sufficient to effectively exercise safety oversight over nuclear installations. However, DETEC has agreed to examine this point in a future revision of the Nuclear Energy Act.

- **and strengthen ENSI's position as the competent, technical authority, by having NSC provide their technical safety input to ENSI solely in an open and transparent manner.»**

Activity performed in this regard:
In March 2014, ENSI and the NSC regulated the handling of NSC recommendations. The agreement, which was signed by ENSI and NSC on 20 March 2015, concerns licences for nuclear installations and for geoscientific investigations. It determines how the recommendations of the NSC are taken into account in ENSI reports. According to the agreement, the NSC sends its opinion to the authority responsible for the procedure and to ENSI. In an annex to its report, ENSI documents the conclusions and recommendations of the NSC and describes how this second opinion is to be dealt with in the future.

The Federal Council responded to the recommendation of the 2015 IRRS follow-up mission that it is convinced that it is at most theoretically conceivable, but practically impossible, for the Federal Council and DETEC, which are bound by the requirements of the nuclear energy legislation for the protection of people and the environment, to disregard ENSI's safety assessments in the licensing of nuclear installations for reasons unrelated to the subject matter. An institutional precaution to prevent such an unlikely scenario is therefore not necessary.

If the IRRS recommendation were implemented, ENSI would be the only authority to take final decisions on issues relating to the safety of nuclear installations. The Federal Council is of the opinion that this would weaken the role of both DETEC and NSC. In particular, the function of the NSC as a second opinion body would be greatly devalued. The distribution of roles between DETEC, ENSI and NSC is expressly desired by Parliament. If these were changed, this would not least be an intervention in the concept of the concentrated procedure (planning approval procedure), which goes beyond nuclear energy legislation and is also prescribed in other infrastructure legislation.

As a result, the Federal Council – unlike the IRRS experts – comes to the conclusion that the existing nuclear energy legislation already takes the concerns of the IRRS mission into account. The Federal Council does not share the experts' fears, which it considers theoretically conceivable at most, that existing legislation could lead to incorrect decisions in the field of nuclear safety. The existing legislation and jurisprudence take sufficient account of these concerns.

Challenge 2: Finalizing the investigations concerning UT indications at Beznau RPV

Activity performed in this regard:

After completing an extended materials characterisation programme and validating ultrasonic testing (UT) techniques, Beznau NPP submitted its final Safety Case for Beznau Unit I. The review of UT validation and the Safety Case by ENSI and its international expert group (International Review Panel IRP) was completed early in 2018. The IRP and ENSI came to the conclusion that the UT indications are caused by agglomerates of alumina inclusions, formed during manufacturing, which do not significantly affect the materials properties relevant for structural integrity or irradiation sensitivity. They were able to confirm that the ultrasonic testing procedures used are reliable and able to detect all relevant flaws. A fracture mechanics assessment of the flaws, using highly conservative assumptions, demonstrated that the case is robust. After ENSI accepted the Beznau 1 RPV Safety Case, the unit went back into operation in March 2018. ENSI has issued a requirement to repeat the UT inspection of the base material of the RPV Shell C where the indications with the highest UT amplitudes are located.

Challenge 3: Decommissioning of Mühleberg NPP

Activity performed in this regard:

On 18 December 2015, BKW submitted the application documents to decommission its NPP (the final decommissioning plan) to the Federal Department of the Environment, Transport, Energy and Communication (DETEC). The application comprises the main report detailing the decommissioning project's conceptual framework and three sub-reports: accident analyses and emergency protection measures; the environmental impact report and the nuclear security report.

The requirements for the final decommissioning plan are described in the Nuclear Energy Act, the Nuclear Energy Ordinance and in ENSI's Technical Guideline G17. The Decommissioning Guideline ENSI-G17 is in accordance with the WENRA Safety Reference Levels and the respective IAEA Safety Standards on decommissioning.

The documents were reviewed by the authorities. ENSI also wrote an advisory opinion. Based on the relevant authorities' advisory opinions, DETEC issued the decommissioning order regulating the decommissioning process in June 2018 – more than one year before final shutdown. No objections to the order were made to the Federal Administrative Court. The decommissioning order is legally binding. This ensures that any necessary preparations can be finalised before the plant's planned shutdown on 20 December 2019.

The decommissioning of Mühleberg NPP is the first project of its kind in Switzerland. Immediately after final shutdown, BKW Energy Ltd plans to begin some preparatory dismantling activities with spent fuel still on site. In the first phase the planned activities include the clearing out of the turbine building and installing decontamination facilities, as well as removing the RPV internals. According to BKW's plans, decommissioning will be completed within 11 years.

Suggestion 1: Report on the progress of the root cause analysis concerning the dry out issue of the Leibstadt NPP during the 8th RM

Activity performed in this regard:

At the end of cycle in 2014, two weeks before the planned refuelling shutdown, the off-gas showed increased activity indicating a fuel rod leaker. After identifying the affected SVEA-96 Optima2 fuel assembly during the subsequent outage, visual inspections detected a V-shaped mark with a hole in one rod beneath the second-uppermost spacer, which had been caused by enhanced oxidation and spalling. A nearby rod also showed signs of oxidation spalling at the same axial location. During the outage in 2015, further fuel assemblies were inspected for comparable V-shaped marks. Only three very small indications were identified. Rods with marks were measured by F-SECT, an eddy current method, which is able to measure the lift-off (oxide plus CRUD). For these V-shaped marks as well as the leaking rod, the fuel vendor identified dry-out as the cause of the enhanced oxidation, despite a considerable safety margin of the critical power ratio (CPR).

In the inspection programme during the next refuelling outage in 2016, further findings were identified in a larger number of fuel assemblies, but no leaker occurred. The findings showed V-shaped marks with an axial length of up to 260 mm on some fuel assemblies. Additional fuel assemblies showed weaker indications of V-shaped marks. Again, the regions beneath the two uppermost spacers of the next-to-corner rods adjacent to the one-third part-length corner rod in SVEA-96 Optima2 fuel assemblies were affected.

The fuel assemblies with V-shaped marks were located in positions with the highest power output, mainly in a ring around the centre of the core. The assemblies affected were primarily located at orifice positions in the corner of core support beams. The V-shaped marks only appeared at assemblies which had a power above 7.4 MW during their first cycle. Moreover, the phenomenon appeared to aggravate with higher coolant flows. For this reason, the assembly power and the total core flows were limited for subsequent fuel cycles.

An extensive root cause analysis (RCA) involving different experts and research facilities was initiated after the findings on the fuel rods in 2016. The RCA was supposed to detect new effects or underestimated uncertainties not accounted for by standard design methods in order to assess their potential for contributing to a reduction in CPR safety margin. All national and international experts involved in the analysis agreed on the theory that dry-out was the reason for the indications. This diagnosis was especially supported because of the location beneath the two uppermost spacers and the alignment of the marks.

In August 2017, three rods with V-shaped marks extracted from three different SVEA-96 Optima2 fuel assemblies, which represent different appearances of the V-shaped marks, were sent to the hot cell facilities at the Paul Scherrer Institute (PSI) in Villigen, Switzerland for non-destructive (NDT) and destructive testing (DT). The NDT focused on visual inspection, profilometry and gamma scanning of the three rods. These results were then used to select the position of the specimen for the DT. The DT focused on metallography and Electron Probe Microanalysis (EPMA) investigation to determine the exact form, structure and qualitative composition of the observed V-shaped marks.

The visual inspections confirmed the findings of the poolside inspection for all rods, and showed that the cladding wall thickness complied with the design specification for all three rods. No atypical oxide coverage was found. Instead, Zn-rich CRUD-deposition was identified as the reason for the V-shaped marks. Waterside oxide thickness up to 20 µm was measured in one-cycle rods. Furthermore, the hydrogen uptake (hydride imaging) and distribution in the cladding were typical for their burn-up. No relevant variation in grain size was found.

After these results were released by PSI, the fuel vendor reviewed the results of the F-SECT measurements and found that a calibration error (caused by a key sign error) was to blame for misinterpretation of the dry-out hypothesis. The CRUD deposits were misinterpreted as a creep-down of the cladding, which would be typical of dry-out. After correcting the results by mirroring, the results of the F-SECT measurements fitted perfectly with the PSI results.

From the operator's point of view, a steam pocket between the lateral cladding surface and the CRUD deposit is the most plausible explanation for the leaker mechanism of the failed rod in 2014. The heat conductivity between the fuel and the coolant was disrupted in a way that made the oxide layer grow very fast, which led to the complete corrosion of the fuel rod wall.

The reason for the high local CRUD deposits is still under investigation. Numerous inspections during the 2017 and 2018 outages have shown no new local CRUD deposits, which thus suggests that the reduced assembly power and core flow measures have proved successful.

Description of significant changes to Switzerland's national nuclear energy and regulatory programmes and measures taken to comply with the Convention's obligations

As a result of the events at Fukushima Daiichi, Switzerland has decided to phase out nuclear energy. Therefore, no nuclear new builds are allowed.

The nuclear phase-out was decided as part of the Energy Strategy 2050, which entailed a partial revision of the Nuclear Energy Act. Following these discussions, both Chambers of Parliament decided to refrain from restricting the operational lifetimes of Swiss nuclear power plants. This was also confirmed by the Swiss electorate in a referendum in November 2016, when Swiss voters rejected a Green Party initiative calling for a 45-year limit to be placed on the operating lives of existing plants.

Apart from the revision of the Nuclear Energy Act, the following relevant legal documents relating to nuclear energy have been revised since the last Swiss CNS national report.

- Nuclear Energy Ordinance (SR 732.11)
- Ordinance on the Assumption of Hazards and the Evaluation of Protection against Major Accidents in Nuclear Installations (SR 732.112.2)
- Radiation Protection Ordinance (SR 814.501)
- Ordinance on the Methodology and Boundary Conditions for the Review of Criteria for the Provisional Shutdown of Nuclear Power Plants (SR 732.114.5)
- Ordinance on the Organisation of Operations in the Event of NBC and Natural Disasters (SR 520.17)
- Ordinance on the Warning, Alerting and Security Radio Network of Switzerland (SR 520.12)
- Ordinance on Emergency Management in the Surrounding Area of Nuclear Facilities (SR 732.33)

New regulatory guidelines issued by the Inspectorate have been introduced (see Appendix 2). By involving the stakeholders and the general public in the procedure of issuing guidelines, the regulatory process is transparent. Furthermore, each new regulatory guideline includes the related international WENRA and IAEA requirements. (See Introduction, Articles 7 and 8.)

Major Common Issues from the Seventh Review Meeting

During the peer review of the seventh Review Meeting, a number of common issues were identified in the Summary Report. The issues identified have been dealt with in the corresponding chapters mentioned in Table 2.

Issue	Reported
Vienna Declaration on Nuclear Safety	Separate chapter on VDNS
Safety Culture	Articles 8, 12
International Peer Reviews	Introduction, Articles 7, 8
Legal Framework and Independence of Regulatory Body	Articles 7, 8
Financial and Human Resources	Article 8
Knowledge Management	Article 9, 12
Supply Chain	Articles 9, 13
Managing the Safety of Ageing Nuclear Facilities and Plant Life Extension	Articles 6, 14, 18
Emergency Preparedness	Article 16
Stakeholder Consultation&Communication	Articles 7, 8
Cyber Security	See text below

Table 2: *Major Common Issues from the Seventh Review Meeting below.*

Cyber Security

Cyber security («computer security» according to IAEA terminology) in nuclear installations is an integral part of the Swiss nuclear regulatory body's supervision. Within the regulatory body, responsibility for this topic is assigned to the «Nuclear and Cyber Security» section in the «Radioprotection Department». The section currently has 7.5 FTE. Since a national cyber strategy (NCS) was drawn up in 2012, cyber security has been the focus of attention at Swiss national level too. Recently the Federal Council issued the second national cyber strategy which it intends to use to further coordinate activities and implement protection measures.

In general, the supervision of cyber security follows the same process as for nuclear safety and security, e.g. establishing criteria and requirements, monitoring compliance with regulations including inspections and reports, and granting, suspending or withdrawing permits (see chapter «Article 8 – Regulatory body»). Regular cooperation and exchanges with other sections in the regulatory body are established and well received.

A series of inspections relating to cyber security have been conducted since 2016. The topics chosen for cyber security range from broad (i.e. organization, management system, overarching processes) to very specific on the basis of the inspection results obtained previously.

With respect to cyber security, the physical protection DBT also includes aspects relating to IT systems as targets or attack paths. Further detailing of the cyber DBT is part of the draft Regulatory Guideline ENSI-G22 focussing on cyber security (the guideline is due to enter into force in 2019).

In 2018 Switzerland hosted an IPPAS mission (IAEA Physical Protection Advisory Service) which included Module 5 (Computer Security). ENSI has also provided experts for IPPAS missions in other member states since 2014, in particular with expertise in cyber security. These experts also actively participate in international cyber security working groups, meetings and workshops.

Summary of the detailed answers to Articles 6–19 of the Convention

Article 6 – Existing nuclear installations

The general safety level of Swiss NPPs is high. The first generation of NPPs in Switzerland (Beznau units I and II and Mühleberg) – which started operation in the late 1960s and early 1970s – has been the subject of progressive backfitting following major developments in NPP safety technology as well as in response to the Fukushima Daiichi accident. First-generation NPPs have been the subject of regular safety reviews. The most recent periodic safety review (PSR) for Beznau NPP was submitted towards the end of 2012 and the Inspectorate's review report was published in 2016. The second generation of NPPs (Gösgen and Leibstadt) incorporated various safety and operating improvements in their initial design. The analogue control technology in Gösgen NPP is currently being replaced by a modern digital system. The project is expected to be finished in 2022. Preparations for a similar replacement of the control technology in Leibstadt NPP are under way. Upgrading of the bunkered emergency systems in Gösgen NPP started in 2018. The purpose of backfitting is to cope with a broader spectrum of external hazards.

All PSRs conducted in Switzerland are reviewed in depth by the Inspectorate. The Inspectorate's final review reports are available on the Inspectorate website (www.ensi.ch).

In conclusion, all Swiss NPPs have undergone the safety review process required under the Convention and have incorporated the improvements identified in the respective safety review reports. The Swiss policy of continuously improving NPPs based on the current state of the art of science and technology ensures a high level of safety.

Article 7 – Legislative and regulatory framework

The legislative and regulatory framework for nuclear installations is well established in Switzerland. It provides the formal basis for the supervision and continuous improvement of nuclear installations. The main legal provisions for authorisations and regulation, supervision and inspection are regulated in the Nuclear Energy Act, the Nuclear Energy Ordinance, the Radiological Protection Act and the Radiological Protection Ordinance. The Nuclear Energy Act and its ordinance came into force in 2005. Safety requirements and regulations are detailed in the over 40 regulatory guidelines issued by the Inspectorate, covering all aspects of the lifetime of an NPP, i.e. operation and decommissioning, nuclear waste, transport and disposal, as well as radiation protection and emergency preparedness. The Nuclear Energy Act also provides the legal basis for inspections and safety assessments performed by the Inspectorate, and for the enforcement of applicable regulations and the terms of the licence. The Nuclear Energy Act and the Nuclear Energy Ordinance are well established. The decision to phase out nuclear energy is incorporated in the revised versions. The Inspectorate has also issued new guidelines. By involving the stakeholders in the procedure of issuing guidelines and publishing draft guidelines for public comments, the regulatory process is transparent. Furthermore, each new regulatory guideline includes the related international IAEA and WENRA requirements.

Article 8 – Regulatory body

The Federal Council (Federal Government) grants general licences. DETEC grants construction licences and operating licences for nuclear facilities. ENSI is the supervisory authority for nuclear safety including radiological protection and nuclear security.

The Inspectorate's responsibilities and tasks have increased over the last 25 years, causing the workforce to gradually increase to about 151, with 138 FTEs, including more than 100 specialists in reactor safety, radiation protection, waste management, etc. In addition, its structure has been adapted to reflect changed requirements.

The Inspectorate is fully independent of organisations concerned with the promotion or utilisation of nuclear energy and the licensing of NPPs. It was made independent of the Federal Office of Energy by Act of Parliament on 1 January 2009, is controlled by its own strategic board (ENSI Board), and has its own budget.

The Inspectorate uses a process-oriented management system, which was initially awarded ISO 9001 certification in December 2001. In November 2007, it was also awarded ISO 14001 certification (environmental management). Accreditation of the inspection activities according to ISO/IEC 17020 was achieved in 2015. The management system applies to all relevant activities and is subject to continuous improvement based on management reviews, international expert missions, evaluation of performance indicators, internal audits and routine checks by the certification agency. As a result, the Inspectorate's management system is well established and provides effective support for both management and daily operations. The entire system was considered a Good Practice in the IRRS mission of 2011. The management system is actively maintained and subject to regular minor modifications for further development and improvement. About one quarter to one third of the documentation is updated every year.

Article 9 – Responsibility of the licence holder

The responsibilities of the licence holder for the safe operation of an NPP are explicitly stated in the Nuclear Energy Act. Each NPP has accepted the conditions laid down for operation and a corresponding statement is included in the preamble of the operating manual for each NPP. The Inspectorate conducts a variety of oversight activities (inspections, document reviews, safety reviews and regulatory meetings) to ensure that the licensees assume full responsibility for the safety of their installations.

The Inspectorate's senior management team meet periodically with the licensees' senior management to address technical, financial and human aspects of the NPPs.

The Swiss nuclear industry has undergone drastic changes in recent years. The Inspectorate addressed the related challenges posed by these changes and their safety implications as part of a specialists' discussion on safety culture in 2018. All NPPs have a well-established network of contractors and good contacts with their vendors. In the case of changes due to restructuring, for example (see above), the NPPs consider remedial action. One such action may entail insourcing specific skills to keep specific nuclear competencies in-house.

Article 10 – Priority to safety

Safety has always been afforded the highest priority by all organisations actively involved in operating, decommissioning and dismantling nuclear installations in Switzerland. To give the highest priority to safety is, by law, a general obligation of each licence holder. All licensees have fulfilled this obligation in their management system and this is also demonstrated by these organisations' commitment to external comparison, peer review and improvement. All Swiss NPPs have undergone OSART missions, including follow-up missions. Since 2005, all Swiss NPPs have regularly taken part in the WANO Peer Review Process involving a WANO peer review and a WANO follow-up mission over a cycle of about six years. The Inspectorate is legally obliged to carry out an international peer review every ten years.

Article 11 – Financial and human resources

NPP operators in Switzerland have sufficient financial resources to maintain a high level of safety throughout the lifetime of an NPP. Should an NPP no longer fulfil the regulatory safety requirements, its licence would be revoked and it would not be able to continue operating. Decommissioning and waste disposal are financed by dedicated funds.

As required by the Swiss Nuclear Energy Act, corresponding ordinances and regulatory guidelines, the installations have sufficient qualified staff who are capable of managing and controlling nuclear installations. Over the reporting period, staffing levels have remained largely stable at all Swiss NPPs.

NPP personnel receive regular instruction and training. Ongoing training is provided so that personnel can keep abreast of advances in science and technology and plant modifications. All Swiss NPPs operate plant-specific full-scope replica simulators.

Article 12 – Human factors

The licensee's obligation to establish a suitable organisation (i.e. organisational structures and processes) is firmly embedded in the Swiss legislative framework. The Nuclear Energy Ordinance sets out requirements concerning the organisation that are specified in detail in Guideline ENSI-G07 «Organisation of Nuclear Power Installations». Attention is also given to the safety culture concept. The above-mentioned guideline stipulates that the licensee must permanently incorporate measures in its management system to observe, assess and strengthen its safety culture. In addition, the Inspectorate has sought to establish a common understanding of the term «human and organisational factors» and on this basis a systemic approach to overseeing these factors.

The Nuclear Energy Ordinance lays down a series of NPP design principles, including a human factor principle: «Workstations and processes for the operation and maintenance of the installation must be designed so that they take account of human capabilities and their limits». The Inspectorate pays particular attention to this principle in its oversight of plant modernisation projects.

All NPPs conduct thorough investigations of human and organisational factors whenever they are identified as the root cause or a contributing factor in events with a relevance to safety.

Article 13 – Quality assurance

All Swiss NPPs have an integrated management system and are certified according to the current standards. All NPPs have incorporated appropriate self-assessment processes in their management systems.

The Inspectorate regularly performs inspections on the safety-relevant processes of the licensee's management systems to assess the effectiveness of quality assurance measures.

In the context of continuously improving management systems, ENSI has paid particular attention to feedback from internal and external operating experience regarding quality assurance processes.

Due to several international incidents concerning the use of unclassified components in the classified area, a supply chain management inspection was designed and carried out as the 2017 focal inspection.

Article 14 – Assessment and verification of safety

In Switzerland, the review and assessment procedure include an evaluation of the safety analysis report (SAR), safety-relevant systems, deterministic accident analyses, probabilistic safety analysis (PSA), reports on ageing surveillance programmes together with other safety-related documents if requested by the Inspectorate. As part of the integrated oversight approach, an annual systematic assessment of nuclear safety is conducted for each NPP based on event analyses, inspection results, operator licensing reviews, safety indicator data and information in the periodic licensee reports. The assessment of the periodic safety review (PSR) by an NPP is documented in a Periodic Safety Review evaluation report. PSRs are required at least every 10 years. Plant documentation must be regularly updated, including the SAR and PSA. The licence document includes important conditions and operating requirements. The Nuclear Energy Ordinance contains a requirement for a PSA and for PSRs.

An Ageing Surveillance Programme is in place for all Swiss NPPs. This programme serves to collect information on the structures, systems and components of relevance for the monitoring of ageing and understanding of ageing mechanisms in order to maintain safety margins and the safety functions of structures, systems and components throughout the life of a plant. It is a prerequisite for LTO.

Backfitting and replacement of safety-related equipment are necessary when existing equipment no longer satisfies current standards or when it becomes difficult to maintain. The Inspectorate reviews the process for such activities and thereby monitors the process closely. In most cases, the Inspectorate must approve the design, installation, modification and commissioning of the equipment.

Article 15 – Radiation protection

Based on the recommendations of the International Commission on Radiological Protection (ICRP), both the Radiological Protection Act and the Radiological Protection Ordinance were revised and came into force in 1994. The Inspectorate has subsequently issued revised versions of most of its relevant guidelines.

The Swiss Radiological Protection Ordinance has been revised to obtain inter alia compatibility with the new European Safety Directive and the IAEA Basic Safety Standards.

The supervisory and control methods currently applied by the Inspectorate are in compliance with the Convention's requirement to keep radioactive doses to personnel, the public and the environment as low as reasonably achievable and also to keep the generation of radioactive waste associated with the use of nuclear power at the lowest possible level.

Calculated doses on the base of annual emissions for a virtual most exposed population group, including exposure due to deposition from former years, have always been well below 0.2 mSv per year. Since 1994, values due to annual releases have been below 0.01 mSv per year for all Swiss NPPs.

Since 1994, with two exceptions, no individual dose above 20 mSv per year has been accumulated by plant personnel or contractors during their work in Swiss NPPs. Since 1987, all annual collective doses have remained well below 4 man-Sv per unit and all have been kept around 2.0 man-Sv since 1995. The low annual individual and collective doses prove the effectiveness of the measures based on the most recent recommendations of the ICRP (e.g. guidelines, job planning and supervision).

The Inspectorate reviews the NPPs' radiation planning process as part of its supervisory duties. Additionally, the Inspectorate reviews all periodical reports issued by the power plants on the subject of radiation protection measures.

Article 16 – Emergency preparedness

The legal basis of emergency preparedness and concepts relevant to emergency preparedness and response have been revised or are in the process of being updated as a result of the efforts of the official federal working group to review emergency preparedness measures in case of extreme events in Switzerland (IDA NOMEX). The scenario used for emergency planning purposes is now characterised by an unfiltered, substantially higher source term than previously assumed. As a consequence, awareness of emergency preparedness and response beyond the outer radius of Zone 2 (i.e. 20 km) has been raised, and this is reflected in the revised concept for emergency protection in the event of an accident at a nuclear power plant.

Severe accident management guidelines (SAMGs) are available for all plant states at Swiss NPPs. They are generally symptom-based and thus suitable for covering a comprehensive set of scenarios. The use of mobile or accident management equipment to cope with a Station Blackout (SBO) recently received special attention, including topical inspections by ENSI.

On-site and off-site emergency plans exist for each Swiss nuclear installation. Emergency planning zones around NPPs are defined. Emergency protective measures, e.g. sheltering and the availability of iodine tablets, have also been established.

There is an automatic dose rate monitoring and emergency response data system (MADUK) around all NPPs in Switzerland. The data is transmitted electronically to the Inspectorate, the National Emergency Operations Centre and the Ministry of the Environment of Baden-Württemberg (Germany). The ANPA system also provides the Inspectorate with online access to measurement data for approximately 25 important plant parameters. The Inspectorate has also set up an automated system for radiological forecasting.

Appropriate channels exist for alerting the public, the National Emergency Operations Centre and neighbouring countries. Bilateral agreements between Switzerland and neighbouring countries covering alerts in the event of an emergency are in place. Switzerland's approach to emergency preparedness and response is regularly verified at international level by participating in international exercises conducted by the IAEA or ECURIE.

Article 17 – Siting

The licensing procedure includes the steps required to evaluate the relevant NPP site-related safety factors. Under the Nuclear Energy Act and the Nuclear Energy Ordinance, a general licence for a nuclear installation can only be granted if the site is suitable. The decision on whether to grant a general licence is subject to a facultative national referendum. When evaluating the suitability of a potential NPP site, a comprehensive investigation of the external hazards must be carried out as a basis for an appropriate plant design. All site-related factors must be included in a Safety Analysis Report (SAR). Furthermore, the general licence application must include an environmental impact report, a decommissioning concept and other safety-related documents. Applicants for a construction licence must submit an updated SAR, a deterministic safety analysis (which can be part of the updated SAR) and a probabilistic safety analysis (PSA) as described in the section on Article 14. The Inspectorate reviews these documents and publishes the results in a safety evaluation report. Those living in the areas surrounding the site of a proposed NPP (including areas in neighbouring countries) are invited to participate in the comprehensive public consultation conducted as part of the licensing procedure. Switzerland has signed agreements on the exchange of information with its neighbours Austria, France, Germany and Italy and is a signatory to the ESPOO convention. Site-related factors are re-evaluated periodically as part of a Periodic Safety Review. In May 2011 the Swiss Government decided to phase out nuclear power in Switzerland. This is enshrined in Article 12a of the revised Federal Energy Act which is in force since January 1, 2018.

The applicability and effectiveness of the Inspectorate's re-evaluation process has been demonstrated by the probabilistic re-assessment of seismic hazards at Swiss NPP sites (PEGASOS). This project was carried out by Swiss licensees in response to a requirement in the Inspectorate's PSA review process. In 2008, Swiss licensees launched a follow-up project – PEGASOS Refinement Project (PRP) – to take advantage of recent findings in earth sciences and new geological and geophysical investigations at existing NPP sites. PRP aims at reducing the uncertainty range of the former PEGASOS results. The PRP was completed and submitted by the end of 2013. At the end of 2015, ENSI defined new hazard assumptions, based on PRP, known as ENSI-2015.

Because of the insights resulting from the Fukushima Daiichi accident, ENSI asked the licensees to re-assess what constituted adequate protection against external flooding for their NPPs, taking into account the upgraded site-specific flooding hazard. The results identified some necessary backfits (e.g. improving the system for protecting the water intake against blockage on one site). After implementing these measures, ENSI concluded that all Swiss plants have sufficient margins over their design basis.

Finally, with regard to extreme weather conditions, ENSI set out the requirements for probabilistic hazard analyses and safety cases in greater detail. At the end of 2012, in compliance with an ENSI request to this effect, the plant operators submitted a document illustrating how they intend to build their safety case. The probabilistic hazard analyses and the proof of adequate protection of the plant against extreme weather conditions were submitted to ENSI in 2014. The hazard analyses were reviewed by ENSI in 2015. As a result of ENSI's review, the Swiss NPPs were required to update their hazard analyses. Some provisional hazard values were identified for use in proving adequate protection.

Article 18 – Design and construction

The Swiss NPPs were designed, constructed and backfitted in accordance with the concept of defence in depth. To enhance robustness against extreme external events, all Swiss NPPs have a special independent, bunkered system for shutdown and residual heat removal. The various levels of defence that exist ensure that safety criteria and dose limits for the public are met during normal operation of the NPP and for all design-basis accidents. In addition, appropriate measures are in place to prevent or mitigate the release of radioactive materials into the environment in the event of beyond design-basis accidents. Design, materials and components are subject to rigorous control and scrutiny and regular testing in order to verify their fitness for service. Safety assessments for the LTO of first-generation NPPs have been performed as part of the periodic safety reviews. Backfitting is carried out when necessary. All Swiss NPPs possess a filtered containment venting system to mitigate radiological effects on the environment in the most severe accident scenarios.

After Fukushima Daiichi, protection of the Swiss NPPs and their spent fuel pools (SFP) against external events was reassessed by the licence holders. Furthermore, the Inspectorate ordered all licence holders to immediately implement two physically separated lines/connections to feed SFPs from outside the buildings as an accident management measure, and to backfit seismically robust SFP cooling systems in the first generation NPPs. In addition, the Inspectorate conducted several inspections to assess the situation in the Swiss NPPs regarding issues that resulted from the accident management actions performed at Fukushima Daiichi.

Furthermore, as specified in Article 5 of the Ordinance on Hazard Assumptions and the Evaluation of Protection against Accidents in Nuclear Plants (SR 732.112.2), the safety of an NPP must be demonstrated for natural hazards with an exceedance frequency of 10^{-4} per annum. At the end of 2015, ENSI defined a new hazard, based on PRP, known as ENSI-2015. According to the Swiss regulations, operators are obliged to verify the nuclear safety of NPPs in the event of significant changes to the hazard definition. The corresponding order was issued by the Inspectorate in 2016. Verifying nuclear safety consists of four phases. In the first phase the license holders worked out and submitted the general concept for a safety assessment. The Inspectorate approved the concepts in 2017. The external flooding analyses were re-assessed in 2011 for flood levels with an exceedance frequency of 10^{-4} per annum. It could be demonstrated that all Swiss NPPs fulfil the requirements. All Swiss NPPs have carried out substantial seismic backfits since commissioning.

To summarise, the Swiss NPPs were designed and constructed on the basis of the IAEA concept of defence in depth. The basic principles regarding redundancy, diversity, physical and functional separation and automation were enshrined in the Nuclear Energy Act, the Nuclear Energy Ordinance and the guidelines issued by the Inspectorate, ensuring that these principles are implemented in the plants as far as is reasonable.

Article 19 – Operation

The requirements for the safe operation of Swiss NPPs are specified in the operating licence granted to each NPP. The operating licence includes commissioning approval. The commissioning programme, which requires the approval of the Inspectorate, comprises pre-operational and start-up tests as well as procedures for testing any equipment that is important for safety. The most important operating procedures are the Technical Specifications, which include the limiting conditions for operation and similarly require the approval of the Inspectorate. The operating procedures for an NPP also cover maintenance, testing and surveillance of equipment. Engineering and technical support in all fields relevant to safety is available to all NPP staff.

The Nuclear Energy Act, the Nuclear Energy Ordinance and regulatory guidelines include requirements for the notification of events and incidents. Under the Ordinance, each NPP must use dedicated emergency operating procedures (EOPs) for operational anomalies and emergency conditions. The ultimate objective of EOPs is to bring the plant into a safe operating state. The legislation also requires an extension to EOPs in the form of severe accident management guidance (SAMG). This is designed to prevent or at least minimise any impact on the environment. SAMG is implemented in all Swiss NPPs and covers all relevant operating states. All NPPs have Accident Management (AM) procedures and a variety of measures to deal with scenarios beyond the plant design basis. All Swiss NPPs are equipped with special bunkered safety systems designed to withstand extreme external events. A flood-proof and earthquake-resistant external storage facility has been in place at Reitnau since June 2011 in order to strengthen the provision for accident mitigation.

The Swiss NPPs have developed their own on-site technical support covering the surveillance test programme, reactor engineering and fuel management, operational experience feedback, plant modifications and safety-related computer applications.

The Nuclear Energy Act, the Nuclear Energy Ordinance and the Inspectorate's guidelines contain requirements for the notification of events and incidents. The process dealing with non-conformance control and remedial action is very important in Swiss NPPs. It is guided by procedures that form part of the management system. Any non-conformance is reported and discussed at the daily morning meeting held by each NPP and follow up action (e.g. work authorisations) is initiated where necessary. Furthermore, each NPP has a process for handling external operating experience, which screens and evaluates information on external events. The Inspectorate has its own process for assessing events in nuclear installations in other countries.

In addition to its general inspection activities, the Inspectorate gains further insight into the operations of an NPP through a system of comprehensive operator reporting. Both the Inspectorate and the operators collect operating experience from domestic and foreign NPPs. In some cases, an analysis of a particular operating experience has resulted in important safety-related backfitting or modifications to Swiss NPPs.

The Nuclear Energy Act includes the principle that those generating radioactive waste are responsible for its safe and permanent management. Thanks to high fuel quality and plant cleanliness, the radioactive waste generated at NPPs is kept to the minimum possible. The resultant waste is collected and separated. As a general rule, radioactive waste is conditioned as soon as practicable. All procedures for conditioning radioactive waste require the approval of the Inspectorate. Each NPP stores spent fuel discharged from reactors on site for several years.

The Nuclear Energy Act prohibits the reprocessing of spent nuclear fuel for a period of ten years with effect from 1 July 2006. This ban has been made permanent as part of the revised Swiss Nuclear Energy Act. At present, spent fuel is also stored in transport and storage casks at the Central Interim Storage Facility (ZZL). All the waste which had been allocated on the basis of reprocessing contracts had been returned to Switzerland by the end of 2016 and is currently stored at the ZZL awaiting final disposal.

Implementation of the Vienna Declaration on Nuclear Safety in Switzerland

1. New nuclear power plants are to be designed, sited, and constructed, consistent with the objective of preventing accidents in the commissioning and operation and, should an accident occur, mitigating possible releases of radionuclides causing long-term off-site contamination and avoiding early radioactive releases or radioactive releases large enough to require long-term protective measures and actions.

The principles regarding design and construction of nuclear power plants are enshrined in the Nuclear Energy Act (NEA) the Nuclear Energy Ordinance (NEO) and ENSI guidelines (for detailed information on the Swiss regulatory system, see Article 7). According to Art. 12, paragraph 1 of the NEA, anyone intending to construct or operate a nuclear installation requires a general licence issued by the Federal Council. With the Swiss energy strategy 2050, several affected acts were revised and the granting of general licenses for the construction of new nuclear power plants has been prohibited since January 2018 (Art. 12a NEA). Nevertheless, the preventive and protective principles for new nuclear power plants are still valid, in particular as a basis for backfitting requirements for existing power plants.

Article 4, paragraph 1 of the NEA stipulates that «Special care must be taken to prevent the release of impermissible quantities of radioactive substances and to protect humans against impermissible levels of radiation during normal operation and accidents.»

Article 5, paragraph 1 of the NEA stipulates that «preventive and protective measures must be taken in accordance with internationally accepted principles» for the design, construction and operation of nuclear installations. These measures include the use of high-quality components, safety barriers, multiple and automated safety systems, the formation of a suitable organisation with qualified personnel, and the fostering of a strong safety awareness.

Furthermore, Article 4, paragraph 3, letter a, entails a dynamic requirement stipulating that precautionary measures «are required in accordance with experience and the state of art in science and technology». The state of the art of science and technology is essentially based on the safety standards set by the IAEA. This means that the Swiss national requirements reflect the IAEA safety standards.

In addition, a so-called precautionary principle enshrined in Article 4, paragraph 3, letter b, requires precautionary measures that «contribute towards an additional reduction of risk insofar as they are appropriate» beyond the minimal requirements and the state of the art of science and technology.

The NEO is legally binding and describes the minimal requirements of Article 5 of the NEA regarding design and construction of nuclear power plants in more detail. These requirements apply for new NPPs and, as far as reasonably achievable, for existing NPPs. Article 10 NEO paragraph 1 specifies the requirements regarding single failure and maintenance criteria, the principles of redundancy, diversity, physical separation, and functional independence. Article 10f paragraph 1 of the NEO, stipulates that safety functions must be initiated automatically, without the need for the operators to take safety-related actions within the first 30 minutes after an initiating event. Furthermore, it states that sufficient margins must be considered in the design and construction of systems and components, that the plant should aim for fail-safe behaviour and that safety functions should preferably be conducted by passive means.

In Article 8 of the NEO, the requirements regarding the protection of NPPs against internal and external hazards are given. The initiating events to be considered in the design are listed in paragraphs 2 and 3. More specific requirements regarding hazard assumptions and assessment of the degree of protection against hazards are given in the «Ordinance on Hazard Assumptions and the Evaluation of Protection against Accidents in Nuclear Power Plants» (SR 732.112.2). One requirement states that the safety of an NPP must be demonstrated for natural hazards with a frequency of 1.0E-4 per year.

The dynamic requirements (cf. Article 4, paragraph 3a of the NEA) are mainly based on the IAEA safety standards. More detailed guidance for special cases is given in the Inspectorate's guidelines.
Due to its dynamic nature, the precautionary principle is only defined in ENSI's regulatory framework in exceptional cases. One of these exceptions is Guideline HSK-R-103 «Measures against the consequences of severe accidents» issued in 1989, which takes into account the lessons learned from the Chernobyl accident. The requirements from that time already include implementing means of RPV pressure relief, hydrogen management, filtered containment venting systems and means of ex-vessel cooling in the event of a molten core.
The dynamic requirements and the precautionary principle enshrined in the Swiss legal framework make sure that new nuclear power plants are designed, sited and constructed consistent with the current international safety requirements (Article 12a of the NEA prohibits construction of new NPPs in Switzerland). This also complies with the principles in the VDNS.

2. Comprehensive and systematic safety assessments are to be carried out periodically and regularly for existing installations throughout their lifetime in order to identify safety improvements that are oriented to meet the above objective. Reasonably practicable or achievable safety improvements are to be implemented in a timely manner.

In Switzerland, a safety assessment is conducted in the course of the periodic safety review (PSR) at least every 10 years. Within these safety evaluation processes, potential improvements are identified and – as appropriate – implemented. Further improvements may be required in the course of the safety assessment for LTO (for more information on PSR, see Article 14). In addition, nuclear safety for each NPP is assessed systematically on the basis of event analyses, inspection results, safety indicator data and information in the periodic licensee reports.
The legal requirement for PSRs is stipulated in Article 22, clause 2e) of the NEA. The licence holder shall: «in the case of nuclear power plants, carry out a comprehensive periodic safety review». The scope of the PSR is defined in Article 34 of the NEO and specified in Guideline ENSI-A03. As part of the PSR, each plant is required to assess its own operating experience and lessons learned from the operation of comparable NPPs. The scope of this assessment is defined in Chapter 5.2 of ENSI Guideline A03. According to Article 34, clause 4 of the NEO, as revised in 2017 to incorporate the period following the fourth operating decade, proof of safety for LTO in accordance with the additional Article 34a must also be submitted as part of the PSR. Proof of safety for LTO shall comprise a) the basic period of operation, b) proof that the design limits for parts of the plant that are technically relevant for safety purposes will not be reached during the planned period of operation, c) the backfitting and technical or organisational improvements planned for the following operating decade, and d) the measures intended to guarantee sufficient numbers of staff with the required expertise for the planned period of operation. The PSRs are assessed by ENSI and the results are recorded in an assessment report, together with any measures that may be imposed. The report is made publicly available.
The Ordinance on the Methodology and the General Conditions for Checking the Criteria for the Provisional Taking out of Service of Nuclear Power Plants (SSR.732.114.5) defines a set of minimal criteria for the existing NPPs to fulfil. If these criteria are not met, the plant has to be taken out of service and backfitted.
There is a dynamic requirement and precautionary principle for existing NPPs. Article 22, clause 2g) of the NEA requires that the licence holder shall: «backfit the installation to the necessary extent that it is in keeping with operational experience and the current state of backfitting technology, and beyond insofar as further upgrading is appropriate and results in a further reduction of risk to humans and the environment».
The Inspectorate is developing Guideline ENSI-G02 «Design principles for existing NPPs» in two parts to record the state of backfitting technology used in Article 22. Clause 2g) of the NEA.

Part 1 of this guideline has been in force since September 2016 and outlines the fundamental safety concepts and design basis requirements. It defines the primary safety goals, the multiple barrier and the defence-in-depth concept in concrete terms. The primary safety function requirements are detailed for safety levels 1–3 and safety level 4. The design basis requirements focus in particular on protection against design basis accidents (level 3) and selected beyond-design basis accidents (level 4a) as outlined in the recent update to guideline ENSI-A01 (September 2018), see Article 14. Part 2 of guideline ENSI-G02 is currently in the final development stages and outlines the design requirements for selected structures, systems and components (SSC) in more detail. All the relevant safety requirements set by the IAEA and WENRA are covered in this guideline.

Furthermore, Article 12 of the DETEC Ordinance on the Hazard Assumptions and the Assessment of the Protection against Accidents in Nuclear Installations SR 732.112.2 and Regulatory Guideline ENSI-A06 define criteria from the risk perspective in order to assess whether measures to reduce risk need to be identified and implemented as appropriate.

The Inspectorate reviews the backfitting projects and in so doing monitors the process closely. The projects and modifications are subject to a four-step procedure, consisting of the concept, detailed design, installation and commissioning of the systems. The Inspectorate grants permissions for every step of the procedure after thorough examination to ensure that they are appropriate and comply with national and international safety requirements.

To conclude, it is clear that the dynamic requirement and the precautionary principle for existing NPPs in the Swiss legal framework ensure that safety improvements according to international good practice are implemented in a timely manner.

There are plenty of examples of backfitting projects in Switzerland. Even back in 1987 the Inspectorate required NPPs to be protected against large-scale external hazards such as aircraft impact, explosion, and third-party actions (HSK-R-101). This requirement led to the construction of bunkered special emergency heat removal systems, which are designed to operate autonomously for at least 10 hours after the initiating event.

The most important backfitting projects and the history of PSRs are outlined in Article 6 of this report. A list of backfitting measure and improvements ordered and performed after Fukushima is given in Article 18.

For more information on PSR and backfitting, see Articles 6, 14 and 18.

3. National requirements and regulations for addressing this objective throughout the lifetime of nuclear power plants are to take into account the relevant IAEA Safety Standards and, as appropriate, other good practices as identified inter alia in the Review Meetings of the CNS.

Article 4, paragraph 1 of the NEA stipulates that «Special care must be taken to prevent the release of impermissible quantities of radioactive substances and to protect humans against impermissible levels of radiation during normal operation and accidents.» Article 5 of the NEA stipulates «When designing, constructing and operating nuclear installations, preventive and protective measures must be taken in accordance with internationally accepted principles.» These measures include the use of high-quality components, safety barriers, multiple and automated safety systems, the formation of a suitable organisation with qualified personnel, and the fostering of strong safety awareness.

Furthermore, Article 4 paragraph 3 a) of the NEA, outlines a dynamic requirement stipulating that precautionary measures «are required in accordance with experience and the state of art in science and technology». The state of the art of science and technology is essentially based on the safety standards set by the IAEA. In addition, a so-called precautionary principle anchored in Article 4, paragraph 3 b) requires precautionary measures throughout the lifetime of nuclear power plants that «contribute towards an additional reduction of risk insofar as they are appropriate» beyond the minimal requirements and the state of the art of science and technology.

Consequently, internationally accepted principles must be taken into account even by the minimal requirements for new NPPs. The relevant IAEA safety standards are incorporated in the Swiss national requirements and regulations through the above-mentioned dynamic requirement, as the IAEA safety standards are essentially used to define the latest state of the art of science and technology. Other good practices are taken into account through the precautionary principle.

Developments and Conclusion

The NEA requires Swiss licensees to perform a PSR at least every 10 years and to backfit the installation to the necessary extent such that it complies with operating experience and the current state of backfitting technology. According to Article 34, clause 4 of the NEO, which also covers the period following the fourth operating decade, proof of safety for LTO must also be submitted as part of the PSR. According to Art. 12a of the NEA, the granting of general licenses for the construction of new nuclear power plants is prohibited.

Switzerland complies with the principles of the Vienna Declaration on Nuclear Safety.

Article 6 – Existing nuclear installations

Each Contracting Party shall take the appropriate steps to ensure that the safety of nuclear installations existing at the time the Convention enters into force for that Contracting Party is reviewed as soon as possible. When necessary in the context of this Convention, the Contracting Party shall ensure that all reasonably practicable improvements are made as a matter of urgency to upgrade the safety of the nuclear installation. If such upgrading cannot be achieved, plans should be implemented to shut down the nuclear installation as soon as practically possible. The timing of the shutdown may take into account the whole energy context and possible alternatives as well as the social, environmental and economic impact.

The general safety of Swiss NPPs was satisfactory at the time the Convention came into force. All NPPs are subject to PSRs at least every 10 years; the safety of all NPPs has been reliably established based on deterministic and probabilistic assessments, operational performance and aspects of safety culture.

PSRs are stipulated in Article 22, clause 2 e) of the NEA. The licence holder shall «in the case of nuclear power plants, carry out a comprehensive periodic safety review». The obligation of backfitting nuclear installations is stipulated in Article 22, clause 2g) of the NEA. The licence holder shall «backfit the installation to the necessary extent that it is in keeping with operational experience and the current state of backfitting technology, and beyond insofar as further upgrading is appropriate and results in a further reduction of risk to humans and the environment». The NEA came into force in 2005. Nevertheless, major backfitting projects have been implemented since the eighties. The most important are outlined below.

The **first generation of NPPs** in Switzerland (Beznau and Mühleberg) started operation between 1969 and 1972. At that time, the Swiss Federal Nuclear Safety Commission was responsible for the review and assessment of applications for site, construction and operating licences. It relied mainly on US regulations and guidance dating from the period as the two reactors came from the USA.

However, certain principles of nuclear safety were not universally acknowledged at that time and so were not taken into account, e.g.:

- separation criteria for electrotechnical and mechanical equipment as a way of protecting an NPP from common cause failures resulting from fire or internal flooding, for example;
- rigorous application of the single failure criterion, including criteria relating to support systems in the event of a loss of offsite power;
- protection of residual heat removal (RHR) systems against external events (e.g. aircraft crashes, earthquakes, floods, lightning and sabotage);
- supplementary shutdown capability in a remote area if the main control room has been lost.

By 1980, the safety authorities had demanded two major backfitting projects in order to improve RHR systems in first generation plants. These projects, which extended over several years, were known as «NANO» for the PWR twin unit at Beznau NPP and «SUSAN» for the BWR at Mühleberg NPP. In addition, a seismic requalification was carried out in the late 1980s. This backfitting project primarily entailed adding one or two fully separated shutdown and RHR systems, including support systems, which addressed the above four issues.

In addition to the NANO feedwater system, an emergency feedwater system was installed in both Beznau units in 1999 and 2000. This was done to improve the reliability and capacity of the auxiliary feedwater system. In both Beznau units, improvements were also made to the reactor protection system and the control systems for separation, redundancy, self-supervision, testability and reliability of power supply by replacing the original systems with a state-of-the-art computerised system in 2000 and 2001. In 2015, a seismically robust emergency diesel generator system was installed in both Beznau units.

Extensive reviews were conducted at both plants following the NANO and SUSAN backfitting projects. The review of Mühleberg NPP was completed in 1992 and in 1994 in the case of Beznau. The two plants were granted new operating licences after this backfitting work. These two NPPs were reviewed extensively in the form of PSRs. In the case of Mühleberg NPP, the PSR assessments were completed in 2002 and 2007, whereas assessments for Beznau NPP were completed in 2004.
The LTO review report of Beznau NPP was published in 2010. There are no fundamental reasons to preclude LTO. Several requirements to be met in order to ensure safe LTO of the plant were defined. The second PSR for Beznau NPP was submitted towards the end of 2012. The Inspectorate's review report was published by the end of 2016. In 2017 the NEO was amended. If an NPP is to be operated for more than 40 years, proof of safety for LTO has to be submitted as part of the PSR. In order to fulfil this new obligation a PSR for Beznau NPP will be submitted to ENSI in 2019.
The most recent PSR for Mühleberg NPP was submitted towards the end of 2010 and the Inspectorate's review report was published in 2013. In December 2012, the Inspectorate published its LTO review report of Mühleberg NPP. In 2013, the owner of Mühleberg NPP, BKW, decided to shut down the plant at the end of 2019. Provisions to increase the safety of the plant during the remaining operating period have been decreed by ENSI (see Article 18). Since the decision to shut down the plant at the end of 2019, the LTO strategy of Mühleberg NPP has become obsolete.
On 18 December 2015, BKW submitted a formal application for the decommissioning order specified in Article 28 of the NEA to the Federal Department of the Environment, Transport, Energy and Communications (DETEC). DETEC issued the decommissioning order requested by BKW on 20 June 2018.

Figure 2:
River view of Mühleberg NPP – Source BKW

The **second generation of NPPs** in Switzerland started operation in 1979 (Gösgen) and 1984 (Leibstadt). They had a higher degree of redundancy and significantly better protection against external events than the first-generation plants. Some further improvements were introduced during licensing and construction (in particular, inclusion of a special emergency heat removal system at Leibstadt NPP).

The analogue control technology in Gösgen NPP is currently being replaced by a modern digital system. A significant proportion of the old control technology has already been replaced. The project is scheduled to end in 2022. Preparations for a similar replacement of the control technology in Leibstadt NPP are under way. Upgrading of the bunkered emergency systems in Gösgen NPP started in 2018. The purpose of backfitting is to cope with a broader spectrum of external hazards.

Both second-generation plants have undergone PSRs. The first review of Leibstadt NPP was performed in 1996, together with a review of the 14.7% power uprate request for the utility. The second PSR for Leibstadt NPP was submitted to ENSI by the end of 2006. ENSI then published its review report in August 2009. The third PSR was submitted by the end of 2016. The publication of the review report is scheduled for 2019. The first PSR for the Gösgen plant was completed in 1999. The second PSR for Gösgen NPP was submitted to ENSI by the end of 2008. ENSI published its corresponding review report in August 2012. The third PSR was submitted by the end of 2018. The publication of the review report is scheduled for 2021.

In 1993, all five plants were backfitted with a filtered containment venting system to mitigate the consequences of severe accidents (e.g. failure of RHR systems).

Additional safety reviews were performed after the Fukushima accident. All Swiss nuclear power plants were required to backfit two additional external feed options to resupply spent fuel pools with coolant. An external storage facility at Reitnau has been in place since June 2011 and contains various operational resources for emergencies that can readily be deployed. If transport by road is not possible, there is the option of air transportation by helicopters. Mobile accident management (AM) equipment stored on-site has been significantly upgraded. For further information on measures taken after the Fukushima accident, see Articles 16–19. (For further information on backfitting projects, see Articles 14 and 18.)

Decommissioning of Mühleberg NPP

BKW announced in late 2013 that Mühleberg NPP will be permanently shut down at the end of 2019. The single 372 MWe boiling water reactor began operating in 1972. Apart from the Lucens experimental plant, it will be the first Swiss nuclear power plant to be decommissioned.

On 18 December 2015, BKW submitted the application documents to decommission its NPP (the final decommissioning plan) to DETEC. The application comprises the main report detailing the conceptual framework for the decommissioning project and three sub-reports: accident analyses and emergency protection measures, the environmental impact report and the nuclear security report.

While preparing to decommission the Mühleberg NPP, the Swiss Confederation set up an inter-institutional monitoring group. All stakeholders are members of this group: The Federal Office of Energy, the Federal Office for the Environment, the Canton of Bern, ENSI and BKW. There are three subgroups on technical aspects, legal procedure and communication. In March 2015, June 2017 and September 2018, the communication sub-group organised six public events concerning Mühleberg NPP. In total more than 1,500 people attended these events and showed a great deal of interest in the decommissioning plan, funding, costs, waste treatment and disposal.

The requirements for the final decommissioning plan are described in the NEA, the NEO and in the technical decommissioning guideline ENSI-G17. ENSI-G17 complies with the WENRA Safety Reference Levels and the respective IAEA Safety Standards on decommissioning.

The documents were reviewed by the authorities. ENSI also wrote an advisory opinion. Based on the authority's advisory opinions, DETEC issued the decommissioning order regulating the decommissioning process in June 2018 – more than one year before final shutdown. The Federal Administrative Court did not receive any objections to the order. The decommissioning order is legally binding. This ensures that any necessary preparations can be finalised before the plant's planned shutdown on 20 December 2019.

The decommissioning of Mühleberg NPP is the first project of its kind in Switzerland. Immediately after final shutdown, BKW plans to begin some preparatory dismantling activities with spent fuel still on site. In the first phase the planned activities include the clearing out of the turbine building and installing decontamination facilities as well as removing the RPV internals. According to BKW's plans, the project will be completed within 11 years.

Developments and Conclusion

Backfitting required in response to technical progress, or analysis of hazards in the light of the Fukushima accident have been tracked continuously in all NPPs. Where the shutdown of NPPs is concerned, ENSI will not accept any safety compromises during the final years of operation.

Switzerland complies with the obligations of Article 6.

Article 7 – Legislative and regulatory framework

Clause 1: Each Contracting Party shall establish and maintain a legislative and regulatory framework to govern the safety of nuclear installations.

The legislative and regulatory framework in Switzerland for the peaceful use of nuclear energy, the safety of nuclear installations and radiological protection is based on a four-level system:

- Level 1: Federal Constitution of the Swiss Confederation;
- Level 2: Federal Acts;
- Level 3: Ordinances (issued by the Federal Council or a federal department);
- Level 4: Regulatory guidelines.

Federal Constitution of the Swiss Confederation (1st level)

Articles 90 and 118 of the Federal Constitution stipulate that legislation on nuclear energy and on radiological protection are enacted exclusively at federal (national) level. As a result, the authorities of the Confederation have exclusive authority to establish legislation in the field of radiation protection and on nuclear energy.

Federal Acts (2nd level)

The main legal provisions for authorisation and regulation, supervision and inspection are based on the following legislation:

- Nuclear Energy Act (2003);
- Radiological Protection Act (1991);
- Act on the Swiss Federal Nuclear Safety Inspectorate ENSI (ENSI Act, 2007).

Nuclear Energy Act

The NEA regulates the peaceful use of nuclear energy. It applies to nuclear goods, nuclear installations, and radioactive waste generated in nuclear installations or surrendered to the federal collection centre. The most important provisions of the NEA are:

- basic principles of nuclear safety, including the precautionary principle, the protection of people and the environment, and measures to prevent sabotage or the proliferation of nuclear material. The provisions set out the obligation to take preventive and protective measures in accordance with internationally accepted principles when designing, constructing and operating nuclear installations;
- a licensing procedure describing authorisations (licences) for the siting, construction (including design), operation (including commissioning) and decommissioning of nuclear installations;
- the general responsibilities of the licensee, including responsibility for the safety of the installation, the obligation on NPPs to conduct systematic and periodic safety reviews and to backfit installations to the necessary extent that is in keeping with operational experience and the current state of backfitting technology, and beyond insofar as further upgrading is appropriate and results in a further reduction of risk to humans and the environment;
- regulations on decommissioning and on the disposal of radioactive waste, including the licensee's obligation to decommission and dispose of waste at its own cost, and special provisions relating to deep geological repositories;
- the designation of ENSI as the supervisory authority for nuclear safety and security;
- provisions regarding the authority and powers of the supervisory authorities, including the right to (i) access all relevant information and documentation to perform comprehensive assessments and carry out effective controls, (ii) enter nuclear installations without prior notification, and (iii) order the application of any measure necessary and appropriate to maintain nuclear safety and security;
- the funding of the supervisory authorities by fees collected from the licence holders and applicants;
- criminal sanctions.

Radiological Protection Act[3]

The Radiological Protection Act has a comprehensive scope: it applies to all activities, installations, events and situations that may involve an ionising radiation hazard. It includes the following:

- fundamental principles of radiation protection (justification and limitation of exposure, dose limits);
- licensing obligation for the handling (including use, storage, transport, disposal, import, export) of radioactive substances;
- protection for persons who are occupationally exposed to radiation and for the general population;
- permanent monitoring of the environment;
- protection of the population in the event of increased radioactivity (emergency response organisation and emergency measures).

ENSI Act

The Act on the Swiss Federal Nuclear Safety Inspectorate ENSI came into force on 1 January 2009, when the Inspectorate was separated from SFOE in order to comply with the international requirement of independence. The Inspectorate was founded as a new organisation, taking over the staff and responsibilities of its predecessor, which had been part of SFOE (see Article 8 (2)). The ENSI Act asks ENSI to implement a quality control system and sets an obligation for ENSI to have periodic quality checks by external parties on how it carries out its duties and services and to provide long-term quality assurance. In this context the Ordinance on the Swiss Federal Nuclear Safety Inspectorate from 2008 stipulates that ENSI should periodically undergo a review by external experts to assess how it complies with the requirements of the International Atomic Energy Agency (IAEA).

Ordinances (3rd level)

All significant provisions that establish binding legal rules must be enacted in the form of a federal act. Ordinances require a legal basis in a federal act, although this basis may be of a rather general nature. In the field of nuclear energy and radiation protection, there are a number of highly relevant federal ordinances issued by the Federal Council or a department (Ministry). The following are the most important:

- Nuclear Energy Ordinance[4];
- Radiological Protection Ordinance[5] (revised in 2018);
- Ordinance on Safety-Classified Vessels and Piping in Nuclear Installations;
- Ordinance on the Qualifications of Personnel in Nuclear Installations;
- Ordinance on Hazard Assumptions and Evaluation of Protection Measures against Accidents in Nuclear Installations;
- Ordinance on the Methodology and Boundary Conditions for the Evaluation of the Criteria for the Provisional Taking-out-of-Service of Nuclear Power Plants;
- Ordinance on the Federal Nuclear Safety Commission;
- Ordinance on the Swiss Federal Nuclear Safety Inspectorate;
- Several ordinances on emergency preparedness, emergency organisation, iodine prophylactics, alerts to the authorities and public etc. (see Article 16);
- Several ordinances on nuclear security issues that are not the subject of this report, e.g. security guards, trustworthiness checks for employees, protection of information or threat assumptions and security measures for nuclear installations and nuclear materials.

---

[3] The English translation of the Radiological Protection Act is available on the Swiss Confederation website (www.admin.ch/opc/en/classified-compilation/19910045/index.html).

[4] The English translation of the NEO is available on the Swiss Confederation website (https://www.admin.ch/opc/en/classified-compilation/20042217/index.html).

[5] The English translation of the Radiological Protection Ordinance is available on the Swiss Confederation website (www.admin.ch/opc/en/classified-compilation/20163016/index.html).

Regulatory guidelines (4th level)

The Inspectorate either issues guidelines in its capacity as a regulatory authority or based on an explicit stipulation in an ordinance. Most of the stipulations to issue guidelines can be found in the NEO and in the Radiological Protection Ordinance. Guidelines are support documents that formalise the implementation of legal requirements and facilitate uniformity of implementation practices. They also embody the state of the art in science and technology. Whereas acts and ordinances have legal force, guidelines are semi-mandatory. The Inspectorate may allow deviations from the guidelines in individual cases provided that the suggested solution ensures at least an equivalent level of nuclear safety or security.

International Conventions

Switzerland has ratified various international conventions, in particular the following:

- Convention on Nuclear Safety;
- Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management;
- Convention on Early Notification of a Nuclear Accident;
- Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency.

In addition, Switzerland has agreed various bilateral agreements with different countries, including all neighbouring countries.

Clause 2(i): The legislative and regulatory framework shall provide for the establishment of applicable national safety requirements and regulations.

National requirements

Safety requirements and regulations are specified in acts, ordinances and regulatory guidelines. After the NEA and the NEO entered into force in February 2005, ENSI started a special project to ensure that its guidelines were complete. The guidelines were divided into three categories based on the classification introduced by ENSI for its oversight activities, which distinguishes between assessment of facilities and surveillance of operations:

- Series A: Guidelines covering the assessment of facilities;
- Series B: Guidelines covering the surveillance of operations;
- Series G: Guidelines with general requirements (covering both the assessment of facilities and surveillance of operations).

In this process, ENSI was able to identify gaps in the previous regulations, especially in its own guidelines. Consistency and comprehensiveness are characteristic features of the ENSI guideline system.

Appendix 2 contains a list of the regulatory guidelines currently in force. The status of the guidelines is available on the Inspectorate's website.[6]

With respect to regulatory guidelines, the Inspectorate has established a Committee for Regulatory Basis which meets monthly to examine and survey the guidelines, and review draft guidelines to ensure the accuracy of the content and that they are consistent with the regulatory framework. The specification of a guideline lists all relevant IAEA safety requirements and guides as well as the relevant WENRA Safety Reference Levels. Once the draft guideline including the explanatory report has undergone an internal hearing, it is subject to an external consultation round. All interested parties, including all existing nuclear facilities, the Federal Offices of Energy and of Public Health, Federal Commissions, the Swiss cantons, as well as non-governmental organisations, may submit comments. The comments are carefully evaluated, and the corresponding ENSI decisions are documented in a «public consultation report». Comments not considered in the final version of the guideline must be justified. The final draft is examined closely by the Committee for Regulatory Basis. Finally, the guideline is put into effect by ENSI's Director.

[6] https://www.ensi.ch/en/documents/document-category/guidelines/

When it becomes apparent that some aspects of a guideline no longer reflect the state of the art or the underlying legislation, ENSI initiates a revision of the guideline. Moreover, the Committee for Regulatory Basis systematically reviews the guidelines on a regular basis, at least every ten years. However, most guidelines are reviewed earlier than this.

International harmonisation

In addition to the IAEA and the OECD Nuclear Energy Agency, WENRA is a major driving force in efforts to harmonise nuclear safety requirements at European level. Switzerland was one of its founding members and has held the chair of WENRA since 2011. WENRA provides regulatory authorities with a single forum at which they can share their years of experience in regulating a range of nuclear facilities as well as in drawing up and implementing standards. So-called Safety Reference Levels (SRLs), which are based on the IAEA Safety Standards, are issued on the basis of this expertise. As a WENRA member, Switzerland is committed to adopting and incorporating the SRLs into its national legal and regulatory framework. This implementation process is monitored by the corresponding WENRA working group.

The Inspectorate participates in the two standing WENRA working groups: «Reactor Harmonisation Working Group» and «Working Group on Waste and Decommissioning», as well as various ad-hoc groups and task forces. The Swiss self-assessment in the area of «Reactor Harmonisation» identified a number of SRLs to be incorporated into the Swiss regulatory framework. The corresponding WENRA peer review showed that implementation in Switzerland is well under way. All WENRA SRLs for spent fuel and waste storage as well as for decommissioning are implemented in the Swiss regulatory framework, the latter by guideline ENSI-G17 «Decommissioning of Nuclear Installations», which was published in April 2014. In addition to complying with the WENRA SRLs, guideline ENSI-G17 also respects the IAEA Safety Standards for decommissioning.

The Inspectorate participates in all IAEA Safety Standard Committees, the Commission on Safety Standards and the Nuclear Security Guidance Committee to promote high international standards in nuclear safety and security. The Inspectorate also harmonises its guidelines with IAEA Safety Standards. Therefore, when issuing a new guideline or revising an existing one, the Inspectorate analyses the IAEA Safety Fundamentals and Safety Requirements relevant to the topic of the guideline. Every guideline is accompanied by an explanatory report. For each IAEA Safety Requirement, this report also shows where in the Swiss legislation or the Inspectorate's guidelines it is implemented.

In addition, the Inspectorate is committed to implementing all SRLs issued by WENRA. The explanatory reports show if and how each safety reference level is implemented for each guideline.

In 2015, the Inspectorate published its Regulatory Framework Strategy consisting of five guiding principles:

1. ENSI's has a comprehensive regulatory framework harmonised with the relevant international requirements.
2. ENSI's regulatory framework is based on existing, tried-and-tested regulations, insofar as they are suitable for application within its supervisory scope.
3. ENSI issues its own guidelines only when it is necessary to do so.
4. ENSI's guidelines are drawn up transparently, with the involvement of all stakeholders.
5. The level of detail of ENSI's regulatory framework is based on the hazard potential and the risk.

Clause (2) (ii): The legislative and regulatory framework shall provide for a system of licensing with regard to nuclear installations and the prohibition of the operation of a nuclear installation without a licence.

The system of licensing results from the NEA and the Radiological Protection Act described above in Clause (1) of this Article. The complex licensing procedures affect the responsibilities of many authorities. An important instrument for coordination is the so-called «concentrated decision-making procedure»: the authority which is primarily responsible acts as a «lead authority» and decides on all relevant aspects. The other authorities that could claim jurisdiction refrain from taking their own decisions. Instead, their opinions are submitted for consideration to the lead authority.

In Switzerland, there are three main types of licences:

- general licence;
- construction licence;
- operating licence.

With the exception of the general licence, every licensing decision can be challenged in court. Constructing or operating a nuclear installation without a licence is a criminal offence according to the NEA.

Figure 3: *Diplomatic Conference – Source ENSI*

Licensing procedure

The **general licence** is required for the siting of a nuclear facility and defines the site, the purpose and essential features of the planned facility, and the maximum permissible radiation dose to the public due to the facility. The licence also specifies a time frame within which the licence holder must submit an application for a construction licence.

The application must contain detailed information on the site characteristics, purpose and outline of the project, the expected radiation exposure in the area surrounding the plant, important information on organisation and personnel, an environmental impact report, a report on compliance with spatial planning requirements and a concept for decommissioning or, in the case of deep geological repositories, for the monitoring period and closure.

The process of granting a general licence starts with the review and assessment of the application by ENSI. The result of the regulatory review and assessment is documented in a Safety Evaluation Report (SER). ENSI may suggest licence conditions. The SER may then be evaluated by the Federal Nuclear Safety Commission NSC.

As the licensing process comes under the responsibility of other federal authorities as well as cantons and neighbouring countries, the concentrated decision-making procedure set out above applies. The opinions of the other authorities must be included, especially those responsible for environmental protection and land use, planning and construction. The application and the corresponding reviews by the federal and cantonal authorities are published as official documents and are subject to a three-month consultation period during which everyone can raise objections. The process ends with a decision by the Federal Council, which must be ratified by Parliament. Eventually, the decision may be subject to a nationwide popular vote, a so-called (optional) referendum.

The **construction licence** specifies the licence holder, the location of the installation, the planned reactor thermal power output or capacity of the installation, the main technical implementation elements, a brief outline of emergency protection measures and especially a list identifying all structures, systems and components of the installation that may only be constructed or installed after a permit has been issued by the relevant supervisory authority (i.e. ENSI). Further conditions may be attached to the licence as proposed by the competent authorities (e.g. by ENSI). The licence also specifies a time frame within which the licence holder must start the construction works.

The application for a construction licence must contain a Safety Analysis Report (SAR), an environmental impact report, a report on compliance with spatial planning requirements, a quality management programme for the planning and construction phase, an emergency preparedness concept and a decommissioning plan or, in the case of deep geological repositories, a plan for the monitoring period and a plan for closure of the installation. It must include a report showing how the project complies with the general licence conditions.

The concentrated decision-making procedure applies again. As with the review of the application for a general licence, several Federal offices are involved in evaluating those issues relating to their specific responsibilities. With the exception of environmental impact and spatial planning, the ENSI Safety Evaluation Report for a construction licence application covers all areas mentioned above.

The licensing process also involves the canton where the facility is to be constructed and the public. The application and the assessment reports are made public and those entitled may file an objection. The construction licence is drafted by SFOE and eventually issued by DETEC.

The **operating licence** specifies the licence holder, the permitted reactor thermal power output or capacity of the facility, the limits for release of radioactive substances into the environment, environmental surveillance measures, plus safety, security and emergency measures to be taken by the licence holder during operation of the installation and the start-up levels that require a permit from the relevant supervisory authority (i.e. ENSI) before the installation can start operating. Further conditions may be attached to the licence as proposed by the competent authorities (e.g. by ENSI).

The application for a construction licence must contain the Final Safety Analysis Report, technical documentation necessary for operation (as defined in Annex 3 of the NEO), and evidence of insurance cover. It must include a report on how the project complies with the general and construction licence conditions.

With the exception of insurance cover, the ENSI Safety Evaluation Report for an operating licence application addresses all areas mentioned above.

The procedure for granting an operating licence is essentially the same as for granting a construction licence.

The owner of a nuclear installation is obliged to decommission the installation if it has been definitively taken out of operation or if the operating licence has not been granted, has been withdrawn, or has expired. The **decommissioning order** is based on the owner's decommissioning project, which must describe the various project phases and overall timetable, each step in the process of dismantling and demolition, protective measures, personnel requirements and organisation, the management of radioactive waste and the overall costs, plus measures taken by the operator to secure the necessary financing. It must also contain an environmental impact report.

DETEC issues the decommissioning order. The procedure is essentially the same as for granting a construction licence. After the decommissioning activities have been completed in accordance with the applicable regulations, the Department verifies that the installation no longer represents a radiological risk and is thus no longer subject to the provisions of nuclear energy legislation.

To control the conditions of the licence and the decommissioning order, a «permit procedure» has been set up. The permits granted by the supervisory authorities as part of a valid licence and the decommissioning order are defined in the NEO or in the licence, and the decommissioning order respectively. They include selected elements of the construction work, the manufacture of important components, assembly and wiring on site, sets of commissioning tests as well as any safety-relevant changes to the installation during operation, and the decommissioning itself. This permit procedure can therefore be considered as an enforcement tool (see Clause 2(iv) of this Article).

Clause (2)(iii): The legislative and regulatory framework shall provide for a system of regulatory inspection and assessment of nuclear installations to ascertain compliance with applicable regulations and the terms of licences.

The legal basis for inspections by the Inspectorate is provided in the NEA. It grants the Inspectorate a right of access to all relevant information and documentation, including documentation located in the offices of supplier companies, to perform comprehensive assessments and carry out effective controls, to enter nuclear installations without prior notification, and to order the application of any measure necessary and appropriate to maintain nuclear safety and security.

The aim of regulatory inspections is to ensure that the licensee complies with its primary responsibility for safety. The Inspectorate, with the help of experts working on its behalf, reviews the licensee's programmes and independently assesses the performance of the licensee by (i) observing specific activities, and by (ii) carrying out its own inspections and taking its own measurements.

Clause 2(iv): The legislative and regulatory framework shall provide for the enforcement of applicable regulations and of the terms of the licences, including suspension, modification or revocation.

The licensing and regulatory authorities have enforcement powers based on the NEA. They can order any measure necessary to protect persons, property and other important rights, to safeguard Switzerland's national security, to ensure compliance with its international commitments and check that measures have been implemented.

In terms of licences, the licensing authorities (Federal Council, DETEC) will not grant a licence (general licence, licence for construction, commissioning, operation, modification of NPPs) or a decommissioning order unless the legal requirements are met. The licensing authority shall withdraw a licence if the prerequisites for granting it are not or are no longer met or if the licence holder fails to comply with a condition or ordered measure despite having been reminded to do so. The withdrawal of a general licence also results in the withdrawal of the construction and operating licences. The Inspectorate has the authority to suspend or withdraw permits.

The supervisory authorities order necessary and reasonable measures to maintain nuclear safety and security. The NEA provides provisions for the special case of an immediate threat. An immediate threat is defined as an objective situation that, if not addressed as it arises, could pose a high probability of damage. In the event of an immediate threat, the Inspectorate may impose immediate measures that deviate from the issued licence or an order. In particular, ENSI may order an immediate plant shutdown and allow the plant to restart only when the licence holder has implemented the necessary corrective actions. If necessary, the supervisory authorities may seize nuclear goods or radioactive waste, eliminate potential threats, and charge the cost to the owner. They may seek intervention by cantonal and local police forces, including the investigating arm of the customs authorities. If the provisions of the Act are breached, the supervisory authorities may call in the relevant federal police authority. The Federal Council may order the precautionary shutdown of a nuclear power plant if an extraordinary situation arises.

Stakeholder consultation

Stakeholder consultation is an important instrument in the Swiss legislative process, in the decision-making process with regard to granting licences for nuclear installations and in the procedure for issuing guidelines. In the Swiss legislative process, the relevant stakeholders are consulted before the law is submitted to Parliament for decision or, in the case of an ordinance, to the Federal Council. With regard to licensing procedures (general, construction and operating licenses), stakeholder consultations have to be carried out by the authority preparing the decision. In the procedure for issuing guidelines, the draft guideline and the explanatory report are subject to an internal hearing and an external consultation round. Stakeholder consultation provides transparency and can lead to more appropriate and balanced solutions.

Developments and Conclusion

The NEA and the NEO came into force in 2005 and are well established. New ordinances and guidelines issued by the Inspectorate have been introduced. Since then, the NEA as well the Ordinance and some of the guidelines have been subject to specific changes.
Switzerland complies with the obligations of Article 7.

Article 8 – Regulatory body

Clause 1: Each Contracting Party shall establish or designate a regulatory body entrusted with the implementation of the legislative and regulatory framework referred to in Article 7, and provided with adequate authority, competence and financial and human resources to fulfil its assigned responsibilities.

Organisation and competence of the regulatory body

Licensing

The **Federal Council** is the authority that grants general licences. **DETEC** grants construction licences and operating licences for nuclear facilities (see Article 7). For the three kinds of licences mentioned, SFOE is responsible for coordinating the application procedure. In addition, SFOE issues licences for handling nuclear material and radioactive waste.

Supervision

ENSI is the supervisory authority for nuclear safety including radiological protection and nuclear security. Its responsibilities and duties are as follows:

- to establish safety and security criteria and requirements that reflect operational experience and the state of the art of science and technology;
- to prepare safety and security evaluation reports (SER) to support decisions by the licensing authority;
- to monitor compliance with regulations including inspections and reports and to request documentation on aspects of nuclear safety, nuclear security and radiological protection;
- to grant, suspend or withdraw permits;
- to order the application of measures necessary and appropriate to maintain nuclear safety and security, including the precautionary and active protection of personnel in NPPs, the public and the environment against radiation hazards;
- to ensure on-site and off-site emergency planning and the dissemination of appropriate information in an emergency according to Article 16.

Advisory committee

The federal **Nuclear Safety Commission NSC** is designated as an advisory committee to the Federal Council and DETEC. It is involved in the licensing process as it reviews and comments on the SER prepared by the supervisory authorities.

The NSC consists of five to seven part-time members, supported by a secretariat with three employees representing 2.5 full-time equivalents and, if necessary, temporarily supplemented by external experts in specific disciplines. NSC members are appointed by the Federal Council on a personal basis. Members have a broad range of expertise including most, if not all, of the disciplines relating to reactor safety, radiation protection, emergency preparedness, waste management, human and organisational factors and transport safety.

The NSC focuses on fundamental aspects of nuclear safety and suggests necessary measures. The responsibilities of the NSC are defined in the Ordinance on the Federal Nuclear Safety Commission. They include the following:

- The NSC comments on new legislation or amendments and the development of regulations relating to nuclear safety. The Commission may recommend additions or amendments to regulations.
- The NSC may recommend measures to improve the safety of nuclear installations.
- The NSC may issue position statements on expert opinion regarding general licences, construction licences, operating licences and decommissioning orders.
- The NSC may suggest research projects in the field of nuclear safety.

Others

The authorities listed below have responsibilities associated with the operation of NPPs. However, they are not involved in the licensing process and have no authority over the plants:

- the **National Emergency Operations Centre** (NEOC) – part of the Federal Office of Civil Protection (FOCP) in the Federal Department of Defence, Civil Protection and Sports – in charge of all emergency situations, including those arising from events at NPPs and relating to the protection of the public and the environment;
- the **Division of Radiological Protection** at the Federal Office of Public Health (FOPH) in the Federal Department of Home Affairs – in charge of radiological monitoring of the environment;
- the **Supervision and Safety Division (ASI) of the SFOE** is responsible for the State System of Accounting for and Control of nuclear materials (SSAC) as well as further supervisory activity incumbent on Switzerland from bilateral and multilateral agreements and export control relating to the non-proliferation of nuclear weapons and the nuclear fuel cycle
- several advisory committees to the government or government departments covering aspects of radiological protection, emergency planning and waste disposal.

Financial and human resources

Costs incurred by the safety authorities (with the exception of the legal framework and information to the public) totalling some 60 million Swiss Francs per year, are mainly covered by fees from licensees. Nuclear safety research promoted and endorsed by the regulatory body has a budget of about 6 million Swiss Francs: some 2 million Swiss Francs is from public funds and 3 million Swiss Francs from NPPs.

Supervisory authorities

ENSI is a stand-alone organisation (separated from the SFOE) controlled by its own management board (ENSI Board) and with its own budget. This gives the Inspectorate complete flexibility over budget decisions and independence when recruiting personnel.

The Inspectorate currently has a staff of some 150 specialists covering the following fields:

- Division K: reactor safety including site inspection (40);
- Division S: radiation protection, emergency preparedness, human and organisational factors and nuclear security (30);
- Division E: waste management and transport safety (20);
- Division A: safety analysis including human and organisational factors (25);
- Division DS: communication, regulatory framework, legal and international affairs (15)
- Division R: resources including human resources, IT and finance (20).

The number of employees has remained constant over the past few years. In January 2019, the Inspectorate had 151 employees representing 138 FTEs.

While the additional workload caused by the accident in Fukushima has decreased significantly, public interest in ENSI's work has grown and the number of requests under the Federal Act on Freedom of Information increases year by year. Since 2011, legal affairs have become more and more important as several stakeholders have appealed against decisions by the Inspectorate.

In order to maintain the necessary staff numbers over the coming years, a human capital management concept was developed in 2012 and implemented by 2015. The concept deals with seven topics: recruitment, training, career planning, resource planning, succession planning, salary system and fringe benefits. Different projects in this field are ongoing, focussing on maintaining staff competencies and productivity (e.g. job stress analysis).

Independent consultants are commissioned to advise the Inspectorate in specific technical areas (e.g. civil engineering). The Swiss Association for Technical Inspections, an independent private company is responsible for monitoring the manufacture, repair, replacement, modification and in-service inspection of pressure-boundary components.

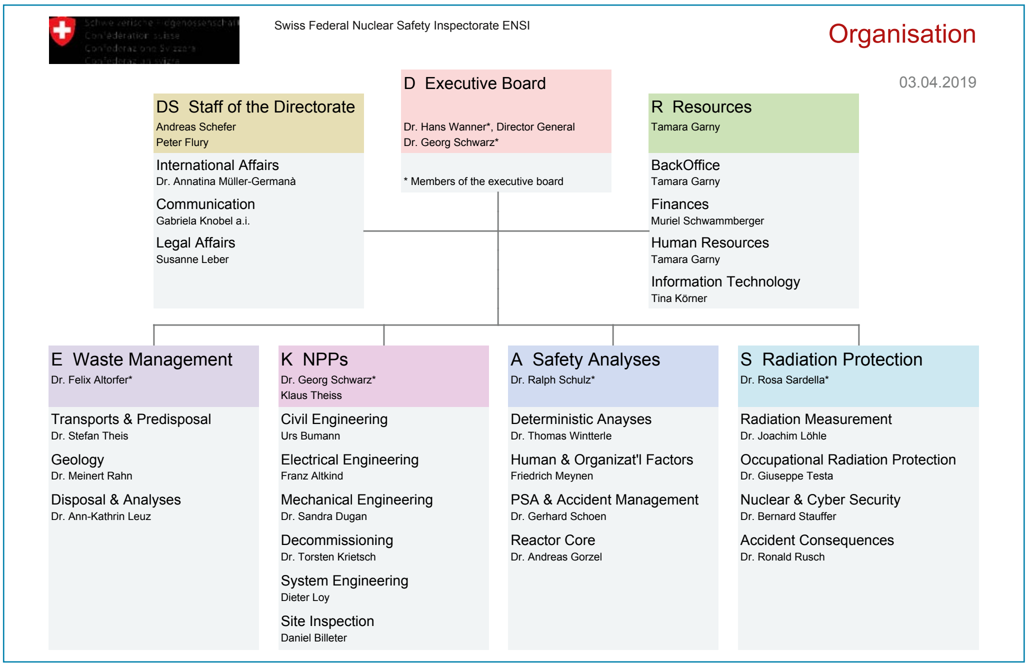


Figure 4:
ENSI Organisational Chart as of January 2019 - Source ENSI

Quality management

The Inspectorate uses a process-oriented management system, which was awarded ISO 9001 certification (quality management) in December 2001 and ISO 14001 certification (environmental management) in November 2007. The current ISO 9001 certificate is valid until December 2019. Taking into consideration the costs and benefits, certification of the environmental management system was abandoned in 2017. The project to obtain ISO 45001 certification (health&safety management) was suspended for the same reason. The radiation measurement laboratory has been accredited in accordance with ISO 17025 since 2005, and the Inspectorate was accredited as an inspection body according to ISO 17020 in 2015.

The management system is applied to all relevant activities and includes the Inspectorate's safety, quality and environmental policies as well as the performance agreement between the ENSI Board and the Inspectorate. The performance agreement includes strategic and operational goals as well as budget allowances for the Inspectorate for one year. All system documents can be accessed quickly by all staff members using user-friendly IT tools.

The management system is subject to continuous improvement ranging from self-evaluation to internal audits, management reviews, evaluation of performance indicators and routine checks by the certification agency.

- Internal audits: ISO 9001 requires institutions to conduct an audit of their activities at appropriate intervals to verify that operations still comply with the requirements of the quality system. A team of around 10 staff members, assigned to this function and trained as quality auditors, carry out internal audits based on an annual audit plan. All processes are subject to an internal audit at least once every three to five years.
- Management review: this is carried out yearly by senior management at the Inspectorate in order to assess staff performance quality (e.g. by appraising performance indicators) and to reflect changes that have occurred (or are expected to occur) in the organisation, risks, staffing, procedures, activities and workload. Senior management are also responsible for ensuring implementation within a specified period of actions identified by an internal audit, surveillance or reassessment visit by IRRS or the certification body together with complaints from customers and internal suggestions for improvements. This process is supported and managed by a sophisticated but user-friendly IT tool.

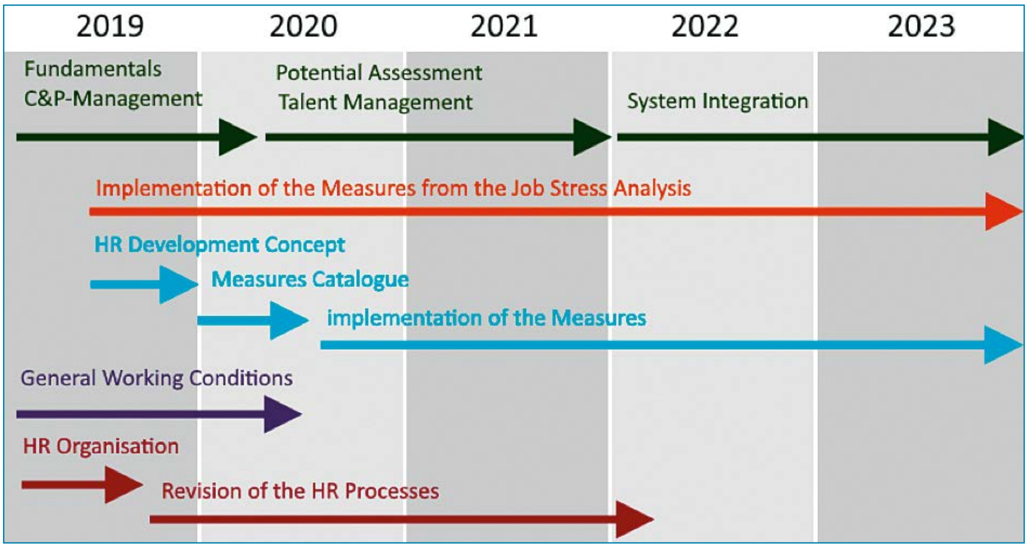
- Performance indicators: performance indicators are defined for each process, including the indicators contained in the performance mandate. The results are evaluated by the owners of the process and reviewed in conjunction with the management review mentioned above.
- External audits: in 2018, an International Review Team carried out an IPPAS mission. In addition, the annual supervisory and renewal audits required for ISO 9001 certification were performed by the certification company SQS, the accreditation audits for ISO 17020 and 17025, and the annual financial audits were carried out by KPMG. Periodic external audits, including IAEA missions, are required by the ENSI Act and the ENSI Ordinance.

These mechanisms and measures provide the means for continuous assessment and opportunities for improvements to the management system. They also facilitate the introduction of new public management elements and generally strengthen the Inspectorate's regulatory effectiveness.

Knowledge management and training

Some activities relating to knowledge management and training measures are integrated in the Inspectorate's management system. However, there is currently no systematic approach either to knowledge management or to individual training. Therefore, the Inspectorate has decided to launch a new project concerning Human Resources Management. It consists of several topics including Competence&Performance Management and will be completed – according to the current schedule – by autumn 2023:

Figure 5:
ENSI Project for Human Resources Development - Source ENSI



The Inspectorate has increased its involvement and participation in nuclear safety assistance programmes at many levels. This includes participation in international working groups and IAEA services, such as the IRRS and OSART missions, staff exchanges with foreign regulators and inspection workshops in other countries. There is also close collaboration with the Swiss Federal Institute of Technology (ETH).

Cooperation with neighbouring countries

Switzerland has concluded agreements on the bilateral exchange of information on nuclear safety and radiation protection issues with its counterparts in many countries, in particular with its neighbours Germany and France. As a minimum, the agreements include early notification of nuclear accidents or extraordinary radiological situations. Collaboration with France, Germany, Italy and Austria also includes standing binational committees.

The German-Swiss and French-Swiss committees are the most comprehensive because both these countries have sizeable nuclear power programmes. They go well beyond early notification and include the exchange of information on all relevant aspects of nuclear safety and radiation protection. Each has at least one permanent technical working group that meets at least once a year. Collaboration with France includes inspections of nuclear installations in both countries conducted jointly by members of the French and Swiss safety authorities. Both the German-Swiss and French-Swiss committees have proved instrumental in harmonising and coordinating cross-border emergency management.

Openness and transparency of regulatory activities

Acting in the politically sensitive field of nuclear energy, ENSI is constantly under the scrutiny of the media, the public and non-governmental organisations (NGOs). ENSI therefore has a vital interest in maintaining its independent status (see clause 2) and in resisting any undue interference from third parties.

After the accident in Fukushima, ENSI created a section responsible for communication. The four staff members are responsible for organising information activities and work closely with the management team.

Under the NEA (Article 74), the Inspectorate «shall regularly inform the public of any special occurrences». In addition, the Inspectorate is obliged to respond to questions from Parliament on nuclear safety and the work of the regulatory body. As a federal authority, ENSI is subject to the Federal Act on Freedom of Information in the administration. All ENSI documents generated after July 1 2006 are made public with a few exceptions relating to nuclear security, personal data or proprietary information.

The information services of the Inspectorate go well beyond these legal requirements. The Inspectorate's website www.ensi.ch is an important information tool covering all aspects of nuclear safety in Switzerland. It is available in the national languages German and French as well as Italian and English to a lesser degree. It is accompanied by activities on social media – e.g. Twitter, LinkedIn etc. In addition to annual reporting (consisting of the Regulatory Oversight Report, the Research and Operational Experience Report, the Radiation Protection Report and the Business Report), it publishes reports on current topics – e.g. ENSI decisions on nuclear safety, disposal of radioactive waste, etc. After the Fukushima accident, an interdisciplinary team of ENSI experts (the «Japan Analysis Team») reconstructed the events of the accident and subjected them to in-depth analysis. The results were presented to the public in four reports between August and December 2011. The final report, including a summary on all measures taken based on the lessons learned, was published in December 2016. In addition, the National EU Stress Test Report, the subsequent Peer Review Report and Action Plans following the analysis were made public, as well as the results of the Topical Peer Review on ageing management of NPPs.

ENSI informed the public about the 2011 IRRS mission and the follow-up mission in 2015 and their findings. As soon as the final report was finalised, it was published on the Inspectorate's website. ENSI also informed the public about the OSART mission to Mühleberg NPP and implementation of the recommendations.

Other communication activities include responses to questions from NGOs and individuals as well as participating in public hearings, symposiums and panel discussions on nuclear safety. ENSI regularly organises meetings with its stakeholders irrespective of their stance on nuclear energy. Media activities include press conferences and press releases as well as interviews on nuclear safety issues that are the subject of current media discussion and background discussions with journalists.

A crisis communication concept and handbook were developed in 2016. This document, along with the communication strategy, defines the rules and responsibilities for communication in different crisis situations. The main aims of this concept are that all relevant stakeholders are addressed in time and that information is provided at the appropriate level.

In 2009, in connection with the search for sites for deep geological repositories, SFOE set up the Technical Forum on Safety, which is led by ENSI. The Technical Forum on Safety discusses and answers technical and scientific questions asked by the public, municipalities, potential siting regions, organisations, cantons and authorities in neighbouring countries. The forum comprises experts from the body leading the process (SFOE), other bodies with supervisory or support roles (ENSI, Swiss Federal Office of Topography (swisstopo)), commissions (NSC), the National Cooperative for the Disposal of Radioactive Waste (Nagra) and the cantons, and includes one representative from each of the potential siting regions.
A similar panel was created by ENSI in 2012 for topics relating to the safety of NPPs. The Technical Forum on NPPs is led by ENSI and discusses and answers technical and scientific questions posed by the public, communities, organisations, cantons and authorities in neighbouring countries. The forum consists of representatives of the NPPs, NGOs, municipalities near NPP sites, cantons and authorities in neighbouring countries as well as experts.

Safety and Oversight Culture

In 2012, an ENSI-wide project was initiated to assess the safety culture within ENSI, to identify shortcomings between the current and the target status and to define any necessary corrective actions. The target status was developed over the course of several workshops covering all staff members. Finally, the project team submitted a list of 15 proposed measures and about the same amount of recommendations to the management team. In the meantime, most measures have been implemented. One of the project's major achievements was a new Mission Statement. In combination with the code of conduct, this document sets the guidelines for all kinds of activities within the Inspectorate. For more on this issue, see Article 12.

Clause 2: Each Contracting Party shall take the appropriate steps to ensure an effective separation between the functions of the regulatory body and those of any other body or organisation concerned with the promotion or utilisation of nuclear energy.

Swiss nuclear power plants

Swiss NPPs are operated by private companies, with cantons and municipalities as the most important shareholders. The federal government does not hold shares in the nuclear industry. The regulatory body is therefore not directly linked to any person or organisation with a commercial interest in nuclear power.

Separation of the supervisory authority for nuclear safety from other governmental bodies concerned with the use and promotion of nuclear energy

The NEA requires the supervisory authorities to be independent of technical directives and formally independent of the licensing authorities. It also clarifies and expands the position, duties and responsibilities of the Inspectorate as the supervisory authority for nuclear safety in terms of the development of safety criteria and the maintenance of nuclear safety. SFOE deals with questions of energy economics and politics and considers issues relating to the security of energy supply. The NEA (Art. 70) stipulates that supervisory bodies are not bound by instructions in technical matters and are formally separated from the licensing authorities.
The Act on the Swiss Federal Nuclear Safety Inspectorate ENSI grants the Inspectorate regulatory independence and ensures separation between the Inspectorate and the licensing authorities. In passing this Act on 22 June 2007, the two parliamentary chambers in Switzerland resolved to convert the Inspectorate into a body constituted under public law to be formally, institutionally and financially independent. The ENSI Act (Art. 18) stipulates that ENSI shall exercise its supervisory activity autonomously and independently.

The Act on the Swiss Federal Nuclear Safety Inspectorate ENSI came into force on 1 January 2009. The Inspectorate is supervised by the ENSI Board whose members are elected by the Federal Council and report directly to it.

Developments and Conclusion

The Inspectorate's management system is well established and provides effective support for both management and daily operations. The entire system was considered a Good Practice in the IRRS mission of 2011. The follow-up mission in 2015 demonstrated that some minor gaps compared with the IAEA requirements had been closed. The management system is actively maintained and subject to regular minor modifications for further development and improvement. About one quarter to one third of the documentation is updated every year. However, the basic structure of the system remains the same and still covers the requirements set down in the related ISO and IAEA standards.

The Inspectorate is the legally, institutionally, politically and financially independent national regulatory body, responsible for supervising nuclear safety and security of the Swiss nuclear facilities. The Inspectorate is supervised by the ENSI Board whose members are elected by the Federal Council and report directly to it.

Switzerland complies with the obligations of Article 8.

Article 9 – Responsibility of the licence holder

Each Contracting Party shall ensure that prime responsibility for the safety of a nuclear installation rests with the holder of the relevant licence and shall take the appropriate steps to ensure that each such licence holder meets its responsibility.

Article 22 of the NEA sets out the general obligations on the part of the licence holder. It expressly states that the licence holder is responsible for the safety of the installation and its operation. It further details the most important duties of licence holders as follows:

- to accord nuclear safety sufficient priority at all times when operating the nuclear installation and in particular to comply with prescribed limits and conditions;
- to establish a suitable organisation and employ an adequate number of appropriately qualified personnel;
- to take measures to ensure that the installation is kept in good condition;
- to carry out inspections and systematic safety and security evaluations throughout the entire life of the installation;
- to conduct a comprehensive periodic safety review in the NPPs[7];
- to report periodically to the regulatory authorities about the condition and operation of the installation and notify them without delay about any reportable events;
- to backfit the installation to the necessary extent on the basis of operational experience and the current state of backfitting technology, and beyond insofar as further upgrading is appropriate and results in a further reduction of risk to humans and the environment;
- to monitor scientific and technological developments, and compare operating experience and findings with those of other installations of a similar nature;
- to keep complete documentation on technical installation and on the operation of the installation, and amend the safety analysis report and security analysis report as necessary;
- to carry out appropriate measures to secure quality assurance for all activities conducted within the installation;
- to keep the decommissioning plan or the project for the monitoring period and the plan for the closure of the installation up to date.

During daily oversight activities (e.g. inspections, document reviews, safety reviews, regulatory meetings), reviews of modifications that require a permit and safety expert reports, the Inspectorate verifies that decisions taken by the licensee meet the above-stated general obligations concerning safety, i.e. that the licence holder retains responsibility for the safety of the installation and its operation.

The licence holder must designate the holder of the position for technical operation of the installation (Article 30 paragraph 4 of the NEO). The holder of this position is responsible for decisions regarding safety. Guideline ENSI-G07 stipulates that neither the responsibility of the licence holder nor the responsibility of the holder of the position for technical operation of the installation can be transferred to third parties. By their very nature, these legal statements concerning responsibility for safety are formulated in a very general manner. The Inspectorate therefore conducted a specialists' discussion on safety culture with the senior management of all the Swiss NPPs in 2015 to discuss and reflect on their understanding of responsibility and the arrangements made to fulfil their responsibility for safety. During these discussions, the participants reflected upon their understanding of responsibility and shared their views on the role of leadership and the management system in assuming responsibility for safety.

The Swiss nuclear industry has undergone drastic changes in recent years. The political decision by Switzerland and other countries to phase out nuclear energy (in the medium term) has led to restructuring among suppliers of Swiss nuclear power plants. This has also led to the Swiss nuclear industry being confronted with loosing nuclear competencies. In addition, the liberalization of the European electricity market has been completed in the meantime. Among other things, this has led to electricity prices falling

[7] Art. 34 para. 1 of the NEO also obliges the license holder to conduct periodic safety reviews every 10 years

sharply. This has forced the energy companies and thus the nuclear power plants to introduce unprecedented austerity measures. The Inspectorate addressed the challenges associated with these changes and their safety implications as part of a specialists' discussion on safety culture in 2018. These discussions also covered the assumption of responsibility for safety at a time of such large-scale changes. All NPPs have a well-established network of contractors and good relationships with their vendors. In the case of changes due to restructuring, for example (see above), the NPPs consider remedial actions. One such action may entail insourcing specific skills in order to keep specific nuclear competencies in-house. The responsibilities of contracted organisations that carry out safety-relevant duties are laid down in contracts between the licensees and the corresponding external companies. The procedure for drawing up these contracts is part of the plants' management system and is inspected by the Inspectorate in accordance with the regulatory guidelines on the organisation of NPPs. Contracted personnel who carry out safety-relevant tasks in a nuclear installation are required to comply with the NPP's policies and procedures regarding safety. The regulatory guideline on organisation (ENSI-G07) stipulates that the licence holder cannot transfer its responsibility for the safety of the installation and its operation to third parties or external organisations.

All Swiss NPPs are members of the World Association of Nuclear Operators (WANO) and benefit from extensive information exchanges on operational experience within this network. In addition, WANO serves as an adviser to the operators in several operational areas. In fact, many of the programmes to enhance human performance in nuclear installations recommended by WANO (e.g. managers in the field, operational decision-making, and pre-job-briefing) are implemented in the Swiss NPPs.

A safety controlling function is established in the Leibstadt and Beznau NPPs. In each plant safety controlling is carried out by a senior member of staff (safety controller) who is critical and retains an open mind in respect of safety issues. The safety controlling function is a voluntary initiative. It forms part of the NPP's commitment to continually improve safety. The safety controller independently reviews a whole range of safety aspects, e.g. safety awareness and provision in daily work processes, safety provision in decision-making and in management system processes, and resource allocation in respect of safety. The safety controller notifies the plant manager of issues relating to safety and reports to the plant CEO. The safety controller's mandate lasts for about 3 years.

The licence holders also participate in two technical safety forums chaired by ENSI (see Article 8). Their main purposes are to receive, discuss and answer questions from the public about technical safety aspects of nuclear power plants and geological repositories.

The Inspectorate's senior management team meet periodically with the licensees' senior management staff to address technical, financial and human aspects. Nuclear energy's changed perception in Swiss society and associated debate concerning the use of nuclear energy in Switzerland has not noticeably affected the staff turnover rate in NPPs. However, the NPPs have started adopting a more long-term approach to human resource planning as a means of preserving and further developing the necessary competencies in nuclear technology. In addition, Beznau and Leibstadt NPPs have arranged employee workshops on the subject of «Perspectives in the Nuclear Industry». During these workshops, the employees were informed about job prospects in connection with LTO and dismantling. The workshops can be considered as an employee retention measure and also as a means of maintaining nuclear competencies in-house. Mühleberg NPP has introduced a large number of measures (workshops, individual interviews, etc.) with a view to achieving the best possible employee retention in the light of the forthcoming decommissioning project.

At the outset of the nuclear industry in Switzerland, the Swiss NPPs founded the «Group of Swiss NPP Managers» (Directors). The group itself and sub-groups in the areas of Operation, Training, Management Systems, Human System Interface, etc., meet regularly several times a year to exchange experience and develop new concepts.

Developments and Conclusion

Switzerland complies with the obligations of Article 9.

Article 10 – Priority to safety

Each Contracting Party shall take the appropriate steps to ensure that all organisations engaged in activities directly related to nuclear installations shall establish policies that give due priority to nuclear safety.

The NEA stipulates that each licence holder engaged in activities concerning nuclear facilities has a general obligation to give the necessary priority to safety. All licensees have implemented this obligation in their management system and have established an operating policy that gives due priority to nuclear safety. This operating policy is communicated to all staff in the NPP and submitted to the Inspectorate with other documents. Modifications to the operating policy of an NPP require a permit in accordance with the NEO.

The obligation to give the necessary priority to safety is also demonstrated by these organisations' commitment to external comparison, peer review and improvement. Every Swiss NPP is also a member of WANO and all Swiss NPPs have been involved in the WANO peer review process since 2005. The cycle for WANO peer reviews and WANO follow-up missions is about six years, i.e. the NPPs are involved either in a WANO peer review or in a WANO follow-up mission every two to three years. In 2016 – 2019, the following WANO peer reviews and WANO follow-up missions took place in Switzerland:

- 2016: WANO peer review in Beznau NPP; WANO follow-up mission in Gösgen NPP, WANO peer review in Leibstadt NPP
- 2017: WANO follow-up mission in Mühleberg
- 2018 WANO peer review in Gösgen NPP, WANO follow-up mission in Leibstadt NPP, WANO follow-up mission in Mühleberg NPP
- 2019: WANO follow-up mission in Beznau NPP

The Swiss NPPs also took initiatives to participate in WANO member support missions. Examples of the topics covered include fire load management, risk management and low-level events. WANO implemented several improvements after the accident at Fukushima. Among other measures, licence holders now have to undergo a peer review to examine how decisions taken at headquarters can affect nuclear safety across the company. Meanwhile, all the Swiss licence holders have conducted these so-called Corporate Peer Reviews (CPR) for the first time: Axpo AG with Beznau and Leibstadt NPPs in 2016, BKW with Mühleberg NPP, also in 2016, and Alpiq AG with Gösgen NPP in 2017.

All Swiss NPPs underwent OSART missions, including follow-up missions. No further OSART missions are planned in Switzerland for the time being. This is also because the Swiss NPPs are regularly involved in the WANO peer review process (see above). From a technical standpoint (i.e. design and construction), Swiss NPPs comply with the current state of the art in science and technology by virtue of the fact that their original design has been strengthened through backfitting (see Article 18). Personnel in all plants are well aware of the safety implications of their activities, and safety-related training (see Article 11) continuously reinforces this level of awareness. The safety culture in all Swiss NPPs is an important means of fostering high levels of safety (see Article 12).

Developments and Conclusion

All Swiss organisations engaged in activities relating to nuclear facilities comply with the obligation to give the highest priority to safety. All licensees have implemented this obligation in their management systems. This is also demonstrated by their commitment to external comparison, peer review and improvements.

Switzerland complies with the obligations of Article 10.

Article 11 – Financial and human resources

Clause 1: Each Contracting Party shall take the appropriate steps to ensure that adequate financial resources are available to support the safety of each nuclear installation throughout its life.

Swiss nuclear legislation stipulates that nuclear installations must be kept in good condition and the licensee must provide persons with responsibility for safe operation of a nuclear installation with the necessary resources.

The Swiss licensees are mainly owned by cantons (states) or municipalities. This public ownership ensures that the licensees are in a solid financial position. To date, they have covered all costs associated with the construction, operation and maintenance (including replacement of obsolete or worn components) of their NPP. They have also paid fees to the regulatory body (see Article 8). They have voluntarily implemented many modifications or backfitting measures shown to be necessary by virtue of developments in science and technology. These voluntary upgrades are in addition to those required by the safety authorities (see Articles 6 and 18). The licensees also cover the costs of radiological emergency protection.

If, for any reason (e.g. inadequate financial resources), the licensee could not or refused to implement any future backfitting measures deemed necessary by the safety authorities, the licensing authority would suspend or revoke its operating licence. An NPP facing such a suspension or withdrawal of a licence would have an interest in ensuring that the requirements are met if it wished to continue normal operations.

A decommissioning fund has been established as required by the NEA. This covers the cost of decommissioning, including dismantling. It is financed by regular contributions from the licence holder. If, after final shutdown, the resources paid into the fund during operation of the plant are insufficient to cover the cost of decommissioning an NPP, the licensee is still required to pay the difference. If the licensee were financially incapable of doing so, the licensees of the other NPPs would be required to intervene and cover the deficit. Decommissioning cost studies are reviewed every 5 years and were last updated in 2016 to comply with the heightened requirements of the revised ordinance on decommissioning and waste disposal funds.

Clause 2: Each Contracting Party shall take the appropriate steps to ensure that sufficient numbers of qualified staff with appropriate education, training and retraining are available for all safety-related activities in or for each nuclear installation, throughout its life.

Requirements regarding qualified staff

Under the NEA, there must be a sufficient number of qualified staff with the expertise required to manage and control a nuclear installation during all phases of its life cycle. A minimum level of staffing with qualified personnel is stipulated for the plants on a 24-hour basis. This ensures that adequate staff are present in the plant at all times to operate under normal conditions, to initiate alarms and to take the first measures required in case of an emergency. Moreover, all employees of Swiss NPPs are members of the respective Emergency Response Organisation (ERO), so the plants can always draw on a sufficiently large pool of specialists for their ERO.

The specific minimum qualifications and training of specialist staff are laid down in the relevant ordinances (NEO, the Ordinance governing the requirements for personnel in nuclear installations, the Ordinance relating to checks on the trustworthiness of personnel and the Ordinance on security guards). In addition to technical qualification, the Ordinance governing the requirements for personnel in nuclear installations stipulates that NPP personnel must be medically and psychologically fit for their functions. In this context, NPPs conduct tests for psychotropic substances.

Staffing

The NEO and related guidelines issued by the Inspectorate define the organisational arrangements required for operation of nuclear installations. The NEO stipulates that the facility must be structured in a way that ensures internal responsibility for at least the following activities and areas:

- operation of the installation in all operating modes;
- maintenance, material technology and testing methods, technical support;
- design and monitoring of the reactor core;
- radiation protection and radioactive waste;
- water chemistry and use of chemical additives;
- emergency planning and preparedness;
- supervision and assessment of nuclear safety;
- nuclear security;
- quality assurance for services provided by contractors;
- initial and continuing training of personnel;
- fostering of safety awareness.

There are no specific requirements with regard to staffing levels in NPPs. At the end of 2018, Mühleberg NPP had a workforce of 312, the twin-unit Beznau NPP had a workforce of 496, Gösgen NPP had a workforce of 548 and Leibstadt NPP had a workforce of 509.

All Swiss plants have long been implementing programmes to ensure early replacement of retiring staff to guarantee that sufficient time is available for the transfer of know-how to new employees. In addition to these programmes, the NPPs have increasingly started to introduce personnel development measures, personnel retainment measures and personnel recruitment measures. These measures must be seen primarily as accompanying measures to compensate for the change in the perception and reputation of the engineering professions, which is leading to a lack of skilled workers and problems finding new recruits. At present, the changed perception in society and the associated discussions about the use of nuclear energy in Switzerland have not had a noticeable impact on the personnel turnover rate in NPPs.

In addition to employing their own personnel, licensees use contractors, particularly for maintenance during the annual refuelling outages and plant modifications. These include specialists from the manufacturer or supplier of major components or systems and other external experts for specific tasks. During these outages, the Inspectorate oversees the qualification and reliability of the contractors' personnel.

Figure 6: *Workers in Gösgen NPP – Source KKW Gösgen Däniken AG*

Methods used for the analysis of competence, availability and sufficiency of additional staff required for severe accident management, including contracted personnel or personnel from other nuclear installations;

The requirements for knowledge, skills and competence of the staff in NPPs are established in the «Ordinance on the Requirements for the Personnel of Nuclear Installations», in the «Ordinance about Education and Training in Radiation Protection», in guideline ENSI-B10 «Education, Qualification and Re-qualification of Personnel», in guideline ENSI-B11 «Emergency Exercises» and in guideline ENSI-B13 «Training and Continuing Education of Radiation Protection Personnel», which covers radiation protection actions in incidents and accidents. The Inspectorate examines how these requirements are met by recognition of education and training courses and/or the recognition of individual competencies. Furthermore, the availability and competence of professionals for management of severe accidents are checked annually by inspecting emergency preparedness exercises at all NPPs. These inspections prove that the radiation protection personnel are able to act in an appropriate manner in accident situations, for example. Investigations concerning necessary improvements to staff adequacy have been initiated with expert discussions between the Inspectorate and NPPs based on international exchanges of experience, e.g. in the ISOE Expert Group on «Occupational Radiation Protection in Severe Accident Management and post-accident Recovery» and in the WGHOF of the OECD/NEA, CSNI on «Human Performance under Extreme Conditions». Finally, guideline ENSI-B11 requires plant emergency exercises to be carried out with the emphasis on involving the plant fire brigade. Such exercises should be organised on a regular basis and fire brigades from outside the plant are now intended to be involved too. Such exercises primarily serve the purpose of training and checking the operational readiness of the plant fire brigade.

Licensing of operators

Control room operators, shift supervisors and standby safety engineers working in NPPs require a licence. Licences are granted by the NPP to specialists who satisfy the conditions in the Ordinance governing the requirements for personnel in nuclear installations. The licensee can only grant a licence to an operator if the candidate passes the examinations specified in the above-mentioned Ordinance. The examination board consists of representatives from the licensee and the Inspectorate. To pass an examination, the candidate must meet with the unanimous approval of both parties.

Education and training

The Ordinance governing the requirements for personnel in nuclear installations specifies the education, knowledge and experience required by personnel who perform safety-relevant activities in nuclear installations (e.g. plant managers, licensed operators, personnel carrying out maintenance duties).
The personnel selected as potential candidates to obtain a licence, i.e. reactor operators, shift supervisors and radiation protection experts, must have successfully completed 3–4 years' vocational training in a technical profession and have a minimum of two years' experience in their profession (the latter is not compulsory for radiation protection experts) before starting their operator's and radiation protection expert training respectively. Standby safety engineers must be in possession of a shift supervisor's licence as well as a degree from an engineering school or university.
The Reactor School at the PSI provides specific training in nuclear fundamentals, the basics of electrical and mechanical engineering, water chemistry, safety concepts and radiation protection. The selection procedure for all licensed control room personnel includes aptitude tests. Under the Ordinance governing the requirements for personnel in nuclear installations, plant managers must have an engineering or science degree, basic knowledge of nuclear engineering and the specific knowledge required for the individual function together with management experience and experience in the relevant NPP.

The education and training required for control room personnel to obtain a licence is given in summary form below:

- **Field operators:** employees wishing to become licensed control room personnel must start as field operators. There is no licensing at this level. However, it is common for such operators to have passed an officially recognised examination. Courses and on-the-job training provide them with a good understanding of the NPP and a basic understanding of radiation protection, physics and nuclear engineering.
- **Reactor operators:** this function requires a formal licence. Candidates for positions as reactor operators must have worked for one or two years as a field operator. They must complete a detailed theory course at the Reactor School at the PSI or an equivalent institution. On completion of this basic education, candidates' complete plant-specific training. This takes the form of various courses at the NPP, on-the-job training and simulator training.
- **Shift supervisors:** applicants for this function must be experienced reactor operators (one to three years' experience). They receive additional education and training in leadership, specific plant behaviour, procedures and undergo full-scope simulator training with their team.
- **Standby safety engineers:** shift supervisors with a degree from an engineering school or university can become standby safety engineers. In particular, they need further training in leadership under unfavourable conditions plus an extensive and detailed knowledge of emergency procedures.

Radiation protection specialists and radiation protection technicians are trained at the Radiation Protection School at the PSI or an equivalent institution abroad. The Inspectorate supervises the final examinations of candidates for both functions.

Adequate recurrent training exists for all of the above functions. It comprises simulator training (except for radiation protection experts), plant-specific courses and theoretical courses, usually at the Reactor School and the Radiation Protection School at the PSI. Members of the training section of the relevant operational department provide training for licensed control room personnel. They are professionals and have training in adult education.

All Swiss NPPs have full-scope replica simulators on site. Thus, each NPP has its own site-specific simulator training, which is also used for requalification purposes. The Inspectorate supervises training activities.

Non-licensed personnel in NPPs are also well educated and trained. Regular retraining is provided to ensure that personnel are up to date with advances in science and technology and plant modifications.

The financial resources allocated to training are defined in the annual budget produced by the NPP. The annual management meeting between NPPs and the Inspectorate includes an overview of this budget.

In order to maintain specific expertise in nuclear technology within Switzerland, Swiss NPPs sponsor a dedicated professorship at ETH Zurich.

Developments and Conclusion

The existing nuclear installations have adequate financial resources to support the safety of each nuclear installation. They also have sufficient qualified staff with appropriate education and training for all safety-related activities together with adequate retraining opportunities.

Switzerland complies with the obligations of Article 11.

Article 12 – Human factors

Each Contracting Party shall take the appropriate steps to ensure that the capabilities and limitations of human performance are taken into account throughout the life of a nuclear installation.

Human and Organisational Factors Understanding and Oversight Approach

In nuclear facilities, in addition to technical aspects, human and organisational factors (HOF) also influence plant safety. In 2013–2015, the Inspectorate (i.e. its team of HOF specialists) jointly worked to achieve a common understanding of the term «human and organisational factors» as well as an approach for overseeing human and organisational factors. ENSI has continued to work continuously on the latter topic. It also takes into account findings from further development of the supervisory culture, i.e. the safety culture of the regulatory body.

Organisation and Safety Culture

The licensee's obligation to establish a suitable organisation (i.e. organisational structures and processes) is firmly anchored at several points in the Swiss legislative framework. The NEO sets out requirements concerning the organisation that are specified in detail in the guideline «Organisation of Nuclear Power Installations». The guideline describes the Inspectorate's requirements in terms of NPP organisational structure and work processes, together with the requirements to be taken into account by the operating organisation to ensure that both technical and organisational changes are managed safely. The guideline also stipulates that the operating organisation must give top priority to safety in all plant activities.

As already mentioned (see Article 9), Swiss NPPs are faced with the loss of nuclear competencies in the supply industry. This is happening at a time when the NPPs are planning and executing, or have recently completed major backfitting projects (see Article 18). This has brought to light supply management problems as a result. The inspectorate was therefore keen to examine how the NPPs cope with this situation and whether and how they learn from the experiences gained in backfitting projects. It therefore conducted a technical discussion on «Learning from Project Experience» in all NPPs in 2018. The technical discussion was conceived and carried out as an interdisciplinary meeting. The ENSI delegation consisted of a system engineer, a mechanical engineer, an electrical engineer, an analysis specialist and a human factors specialist. During the discussion, the NPPs had to demonstrate how learning from experience in the context of projects is anchored in the organizational structure and in the management system. Further, they also needed to explain the means (e.g. instruments) available at the plant for learning from project experience. Finally, ENSI required the NPPs to set out their experience in terms of possibilities and limitations associated with project experience learning. To further develop its supervisory culture, ENSI also asked the licensees to provide feedback on its oversight of projects that are conducted by NPPs or have already taken place.

In Switzerland, the concept of safety culture is also considered. The guideline on organisation of nuclear power plants stipulates that the licensee must permanently incorporate measures in its management system to observe, assess, and strengthen its safety culture. Furthermore, the licensee must also define the meaning of the term as well as the principles and prominent features of safety culture in a document that is considered binding for all employees. ENSI also worked on a mutual understanding of nuclear safety and security culture. Its approach to safety and security culture is based on an integrated understanding of the culture of a (nuclear) organisation, where safety is understood in the sense of «protecting people and the environment from the harmful effects of ionising radiation» (IAEA SF-1). Nuclear safety and security both serve the same purpose of protecting people and the environment. In other words, ENSI explicitly refrains from drawing a distinction between safety and security culture in its supervisory activities, although it does consider the specific requirements for security and nuclear safety. The themes of safety and security are dealt with under the generic term safety culture. The operators of the Swiss nuclear power plants share this same approach. ENSI's report on «Oversight of Safety Culture in Nuclear Installations» was updated in 2016 to explicitly address this issue and to clarify ENSI's understanding and approach regarding safety and security culture (https://www.ensi.ch/en/2017/03/13/security-and-safety-as-parts-of-the-overall-culture-for-the-protection-of-man-and-the-environment/).

The Inspectorate has conducted a series of oversight activities, e.g. inspections and technical discussions in the field of organisation as well as safety culture. In addition to these ordinary oversight instruments for organisational and plant engineering issues, the Inspectorate employs a specific method to oversee safety culture: specialist discussions on safety culture issues. The aim of these discussions is to establish a platform where the licensees can reflect on safety culture topics previously set by the Inspectorate. The Inspectorate facilitates these discussions in an open and constructive way. In 2018, the Inspectorate conducted such a discussion on the subject of «coping with the altered conditions in the nuclear industry» (see chapter 9).

Due to a series of events at Leibstadt NPP with significant human and organisational aspects, the Inspectorate has reinforced its oversight and increased its scrutiny of the safety culture at Leibstadt NPP.

In the aftermath of Fukushima, the Inspectorate created an interdisciplinary analysis team to attempt to understand the scope and complexity of the accident at Fukushima. The analysis team also included experts in the field of human and organisational factors. In 2011, the Inspectorate published its analysis of the accident. One of these reports was dedicated to analysis in the field of human and organisational factors. Since this first early publication on the human and organisational aspects of the Fukushima accident was based on the sparse information initially available, a team of experts in the human and organisational factor field pursued and deepened their analysis on the basis of numerous accident reports published after the accident by several official and authoritative investigation committees. A first new report on the events and the organisations involved in the response to the accident was published in German and French in 2015 (see: https://www.ensi.ch/de/dokumente/fukushima-daiichi-menschliche-und-organisatorische-faktoren-teil-1/). A second report describing the accident chronology from the point of view of the people who were involved in the accident response on the site of the Fukushima Daiichi NPP was published in German in 2018 (with a French translation under way) (see: https://www.ensi.ch/de/dokumente/fukushima-daiichi-menschliche-und-organisatorische-faktoren-teil-2/) (an English translation of the reports is under consideration).

Human Factors Engineering

The NEO lays down a series of design principles for NPPs, including a principle relating to human factors engineering: «Workstations and processes for operation and maintenance of the installation must be designed so that they take account of human capabilities and their limits». The Inspectorate pays particular attention to this principle when it oversees modifications that affect human-machine interfaces. Since 2007, the Inspectorate has required a human factors engineering programme in conjunction with the initial concept of modernisation projects. Within the human factors engineering programme, the licensee must describe how human and organisational factors (e.g. a human-centred design process, integration of operating experience from predecessor or similar systems, multidisciplinary project management) are integrated continuously and systematically throughout the entire modification project. Article 18 lists activities in this area. The human factors engineering programme adopts a graded approach. This ensures that appropriate resources are allocated in accordance with requirement 7 «Application of the graded approach to the management system» of IAEA Safety Standard GSR Part 2.

Event Analysis

All NPPs conduct thorough investigations of human and organisational factors whenever they are identified as the root cause or a contributing factor in safety-relevant events. If these investigations identify weaknesses in these areas, this triggers an assessment of similar situations in other NPPs.

The NEO states that all NPPs must appoint a committee to analyse events and outcomes attributable to human and organisational factors. All NPPs have appointed such committees, who receive adequate education and training on a regular basis.

Developments and Conclusion

The Inspectorate has continued to develop its understanding of the term «Human and Organisational Factors (HOF)» as well as methods to oversee the organisation of NPPs. It has also pursued its efforts to oversee human and organisational factors in plant modernisation projects and in event analysis.

Switzerland complies with the obligations of Article 12.

Article 13 – Quality assurance

Each Contracting Party shall take the appropriate steps to ensure that quality assurance programmes are established and implemented with a view to providing confidence that specified requirements for all activities important to nuclear safety are satisfied throughout the life of a nuclear installation.

All Swiss NPPs have an integrated management system and are certified under ISO 9001 (Quality Management), OHSAS 18001 (Occupational Health and Safety) and ISO 14001 (Environmental Management) standards. According to the certification requirements, the management systems are audited periodically by the certification institute and the certificates are renewed on a regular basis. NPPs apply well-established methods for self-assessment of their management system.

The Inspectorate concentrates its supervisory activities on the aspects of the licensee's management system that are relevant to nuclear safety. These safety-relevant processes need to ensure appropriate quality assurance for the output. They are supervised as part of ENSI's event analysis, the approvals for plant modifications and during outages, but also by a series of inspections for the management system which are dedicated to current topics. Major changes in the management system must be reported to the Inspectorate.

Due to ageing issues and the Swiss regulatory requirement to ensure that the plant always uses state-of-the-art technology, there is a continuing need for plant modifications. According to the NEO, the licensees must take full responsibility for quality assurance of the products supplied by their contractors. This quality assurance is a particular challenge due to the need to provide the required internal and external resources with adequate competency levels. ENSI decided to perform the management system inspections in all NPPs and the PSI research facility on a range of different topics, e. g. change management, work task management and supply chain management (see below). These management system topics play a part in ensuring proper quality assurance of the work performed in maintenance and plant modifications.

Due to several international incidents involving the use of unclassified components in the classified area, a supply chain management inspection was designed and carried out as the focal inspection for 2017. Its scope was «Verification of processes regarding warehousing, sourcing spare parts and completeness of its qualifications». International events show that the number of incidents increases in difficult market conditions. ENSI representatives from the Electrical Engineering, Mechanical Engineering and Human and Organizational Factors sections carried out the inspection. The scope of the inspection included the procurement process (in particular goods receipt), sampling inspections of 1E classified components and mechanically classified components in safety classes 1 (SK1) to 3 (SK3). The inspected components included electric (1E) motors, RP electronic cards and contactors/relays, mechanical valves (SK3), screws (SK1) and seals (SK3). In the first part of the inspection, the licensees introduced the topic of sourcing electrical and mechanical components and their quality requirements. ENSI inspected the processes that should guarantee the licensee's sourcing of qualified components. In the second part of the inspection, ENSI carried out random checks on a number of electrical and mechanical spare parts in the warehouse as well as in the workshop. The third part of the inspection entailed examining documents for randomly selected spare parts from the warehouse. The inspection was conducted in one day; this meant that the licensee's relevant counterparts were at ENSI's disposal throughout. A follow-up inspection was necessary in two NPPs, as ENSI observed a deviation from the process (i.e. labelling of components) during the inspection. The follow-up inspections gave rise to satisfactory results. ENSI had already carried out inspections in the supply chain management field in previous years (e.g. supplier evaluation, warehousing, procurement and intelligent customer competencies).

A series of management system inspections have also been performed on the subject of operational experience feedback (OEF). This also includes learning from experience in the quality assurance process.

Overall, ENSI was able to confirm that the regulatory requirements were satisfied for all topics. ENSI made suggestions for continuous improvement of the corresponding processes and shared the identified best practices with all inspected licensees.

All NPP activities other than normal operation, e.g. backfitting, replacement and modifications to systems and components, require a permit. In order to achieve regulatory approval, the Inspectorate assesses the quality assurance programme, paying particular attention to the performance of independent checks on all safety-relevant information as part of the quality assurance process.

Developments and Conclusion

All Swiss NPPs have an integrated management system that is certified under ISO 9001. The management systems are audited periodically by the certification institute and the certificates are renewed on a periodic basis.

The NPPs carry out internal and external audits and use established self-assessment methods to ensure the continuous improvement of their management systems.

The Inspectorate performs regular inspections to assess the effectiveness of quality assurance measures within the management system. As part of the continuous improvement of management systems, ENSI pays particular attention to incorporating feedback from internal and external operating experience regarding quality assurance processes.

Switzerland complies with the obligations of Article 13.

Article 14 – Assessment and verification of safety

Clause 1: Each Contracting Party shall take the appropriate steps to ensure that comprehensive and systematic safety assessments are carried out before the construction and commissioning of a nuclear installation and throughout its life. Such assessments shall be well documented, subsequently updated in the light of operating experience and significant new safety information, and reviewed under the authority of the regulatory body.

Overview of the Contracting Party's arrangements and regulatory requirements to perform comprehensive and systematic safety assessments

For existing plants, a PSR is required at least every ten years. Important elements of a PSR include updating the Safety Analysis Report (SAR), assessing design basis accidents, assessing the ageing surveillance programme, updating the Probabilistic Safety Assessment (PSA) and evaluating operating experience over the last 10 years. The details (scope and process) of a PSR are defined in guideline ENSI-A03.

Changes in the organisation, modifications or backfitting of components and documents (e.g. Technical Specifications) relating to safety must be approved by the Inspectorate. The Inspectorate's associated review may involve inspections (see Clause 2). Data from inspections, event assessments and safety indicators provide a foundation for ENSI's systematic assessment of operating safety, which is carried out annually (see Clause 2). In addition, the licensees must perform annual safety assessments in line with the requirements set out in the guideline ENSI-G08 and probabilistic evaluations of their operating experience according to the guideline ENSI-A06.

The above safety analyses are explicitly specified in the NEO as requirements for the analysis and reports to be submitted for decommissioning projects. The following paragraphs provide further information on certain safety analyses.

Further reviews and assessments of the design basis are mandatory if events classified INES 2 or higher have occurred in a national or international NPP. As a direct consequence of the major accident in Japan, the Inspectorate issued three formal orders in which the operators of Swiss nuclear power plants were required to implement immediate measures and to conduct additional reassessments. The Inspectorate ordered immediate measures comprising the establishment of an external emergency storage facility for Swiss NPPs, including the necessary plant-specific connections, and backfitting measures to ensure the provision of external means of injecting coolant into the spent fuel pools. The additional re-assessments, which were to be carried out immediately, focused on the design basis for Swiss NPPs to withstand earthquakes, external flooding, extreme weather conditions and combinations thereof. Investigations were also requested regarding the coolant supply for the safety systems and spent fuel pool cooling, taking into account the lessons learned from the accident in Japan.

The seismic hazard assumptions to be used in the re-assessment after the major accident in Japan had to be derived from the available PRP interim results (see Articles 17 and 18). The DETEC Ordinance on Hazard Assumptions and Assessment of Protection against Accidents in Nuclear Installations (SR 732.112.2) stipulates that, in the case of new or changed hazard assumptions, the deterministic and probabilistic safety assessments must be updated. Accordingly, after defining the new earthquake hazard (ENSI-2015, see Article 17) in May 2016, ENSI issued a formal order to the operators of Swiss nuclear power plants to update the earthquake safety assessment: a) by the end of 2018: the safety case originally required by the Inspectorate after the Fukushima reactor catastrophe in March 2011, b) by mid-2019: the probabilistic safety analysis, and c) by the end of September 2020: a detailed and refined deterministic safety analysis. While the safety case in a) is restricted to the 10^{-4} per year earthquake, the full deterministic safety analysis in c) requires a 10^{-3} per year earthquake and the 10^{-4} per year earthquake hazard proof (see section on deterministic analysis in this article).

Extreme weather conditions which are increasingly relevant for Swiss nuclear plants such as extreme wind, tornados, heavy rain, extreme air and water temperatures in winter and summer and extreme snowfall have been examined as part of the EU stress test. The evaluation is based on the IAEA Specific Safety Guide SSG-18 on Meteorological and Hydrological Hazards in Site Evaluation for Nuclear Installations to the greatest possible extent.

As a part of the Fukushima Action Plan, an additional safety margin analysis was performed for Swiss NPPs. The safety margin analysis is a follow up of the analysis carried out in the EU stress tests. The safety objective of the safety margin analysis was to systematically evaluate the plant's robustness with respect to earthquakes and external flooding. Possible improvements had to be identified and implemented based on the results. The recent update of guideline ENSI-A01 (September 2018) explicitly stipulates that a safety margin analysis must be performed for natural hazards.

Safety assessments within the licensing process and safety analysis reports for different stages in the lifetime of nuclear installations

As a result of the accident at the Fukushima Daiichi NPP, the Swiss government has suspended plans for new-builds. Ongoing safety assessment activities for the different stages in the lifetime of nuclear installations consist of

- periodic assessments as described in the next topic and
- assessments of LTO.

Long-Term Operation

ENSI started to develop an approach for assessing LTO of nuclear power plants in Switzerland in around 2004. ENSI's approach is based on international recommendations, IAEA Safety Guides NS G 2.6 and SSG-48, IAEA-SALTO guidelines, WENRA Reactor Safety Reference Levels (Issues K and I) and the Swiss legal basis, NEA, SR 732.1, NEO, SR 732.11, DETEC Ordinance on the Methodology and the General Conditions for Checking the Criteria for the Provisional Taking out of Service of Nuclear Power Plants, SR 732.114.5, the guidelines ENSI-B01 and ENSI-B06 and the guideline issued by the Swiss Association for Technical Inspections (SVTI), SVTI-NE-14. According to Article 34, clause 4 of the NEO, SR 732.11, which has been in force since June 2017, additional proof of safety for LTO must be submitted as part of the PSR for the period following the fourth operating decade. According to Article 34a, which has also been in force since June 2017, proof must be provided that the design limits for the parts of the plant that are technically safety-relevant will not be reached during the planned period of operation, and backfitting and organisational improvements planned for the next operating decade must be shown. Furthermore, the LTO safety case shall cover two main areas: material ageing and conceptual ageing. In the first area the focus is on ageing management programmes (e.g. maintenance, in-service inspection, in-service testing) and on the status of major plant components (e.g. RPV, containment, selected reactor coolant piping) in the light of the relevant ageing mechanisms, including forecast analyses over the next reporting period. With regard to conceptual considerations on ageing, the focus is on the plant safety concept (updated deterministic and probabilistic analyses) and on backfitting (according to the state-of-the-art in backfitting technology). In particular, the licensee is required to demonstrate that the limits described in the recently updated DETEC Ordinance on the Methodology and Conditions for the Assessment of the Criteria for Provisional Shutdown of Nuclear Power Plants (SR 732.114.5) are adhered to. If these limits are breached, this means that the NPP must be provisionally shut down.

The licensees of the following Swiss NPPs have submitted the required proof of LTO safety. Beznau NPP submitted its documents in 2008 and 2018, Mühleberg NPP in 2010, and Gösgen NPP in 2018. The LTO safety proof for Leibstadt NPP is required in 2024. Results of the ENSI review are described in the LTO safety evaluation reports dated November 2010 for Beznau NPP and December 2012 for Mühleberg NPP, while the 2018 Beznau and Gösgen documents are currently being reviewed by ENSI.

As a result of the LTO review of the 2008 and 2010 documents, ENSI confirmed that Beznau NPP and Mühleberg NPP meet the Swiss safety objectives for at least an additional 10-year operating period. There is no indication that the terms and conditions for a provisional shutdown (DETEC Ordinance SR 732.112.5) of Beznau NPP and Mühleberg NPP will be fulfilled. In 2013, Mühleberg NPP's licence holder decided to shut down the plant in 2019 for entrepreneurial reasons. ENSI issued a formal order to establish binding conditions for operation until 2019, requesting alternative measures to be implemented. The backfitting measures required by ENSI are listed in Article 18.

Periodic safety assessments of nuclear installations during operation using deterministic and probabilistic methods of analysis, as appropriate and, conducted according to appropriate standards and practices

In addition to the continuous review and evaluation of plant modifications, the PSR is an important control mechanism for both licensees and the Inspectorate. It enables them to identify and assess the actual state of safety in a plant in order to ensure compliance with legal requirements, the provisions of the licenses and the Inspectorate's official stipulations. The current plant status and past operating experience are compared with the current state of the art of science and technology and operating experience from other plants. The licensee carries out the PSR and the Inspectorate evaluates the PSR report submitted by the licensee. The Inspectorate adds its own experience from previous inspections, assessments and reviews.

The concept of defence in depth as described in the IAEA Specific Safety Requirements SSR-2/1 (Rev. 1) plays a central role in the PSR and its evaluation. In its report, the licensee is required:

- to explain how the safety policy is implemented on a plant-specific basis;
- to assess the operating performance and management of the plant;
- to perform a deterministic safety status evaluation;
- to perform a probabilistic safety analysis.

Based on the above-mentioned evaluation, the licensee must demonstrate that the fundamental safety functions specified in SSR-2/1 (Rev. 1) and the radiological protection measures are effective in both normal and abnormal plant operation. The licensee must also demonstrate how the evolving state of science and technology is taken into account in the plant's design and operation and how experience gained from similar plants worldwide is integrated. In addition, when assessing operating experience over the last 10 years, the licensee must pay particular attention to human and organisational factors and their impact on safety. The Inspectorate's assessment also considers the licensee's safety culture. The PSR includes not only a review of the plant's current safety status, but also an assessment of its future safety status.

Deterministic analysis

The NEO requires Swiss NPPs to implement a Deterministic Safety Status Analysis (DSSA). Deterministic analyses consist of technical analyses to be performed according to guideline ENSI-A01 and radiological analyses according to guideline ENSI-A08. The requirements focus on protection against design basis accidents and selected beyond design basis accidents. The initiating events to be considered in the design are listed in paragraphs 2 and 3 in Article 8 of the NEO. More specific requirements regarding hazard assumptions and assessment of the degree of protection against hazards are given in the Ordinance on Hazard Assumptions and Evaluation of Protection Measures against Accidents in Nuclear Installations (SR 732.112.2). This Ordinance assigns one of three categories to the design basis accidents according to their frequency of occurrence and defines technical criteria for compliance and related technical and radiological safety objectives depending on the assigned accident category. Design Basis Accidents (DBA) with causes other than natural hazards must be considered down to a frequency greater than 10^{-6} per year under the DETEC for NPPs. For accidents arising from natural hazards according to the recent amendment of Article 8 of the NEO (amendment of 1 February 2019), deterministic analyses for design basis accidents with frequencies of 10^{-3} per year and 10^{-4} per year must be performed, and compliance with dose limits of 1 mSv and 100 mSv respectively must be shown. In particular the verification for the 10^{-3} per year natural hazard assumption is new and the dose limit for this accident category (1 mSv) in Switzerland is very strict compared to international standards.

The DSSA review aims to verify the expected behaviour of the plant under assumed accident conditions as defined in guideline ENSI-A01. Based on a set of accident scenarios, the licensee must demonstrate that the relevant plant and core-specific parameters remain within safe limits and comply with the technical criteria defined in the DETEC Ordinance on Hazard Assumptions and Assessment of Protection against Accidents in Nuclear Installations (SR 732.112.2). In addition, the licensee must demonstrate that it complies with the individual dose limits for the public, as defined in the Radiological Protection Ordinance. The guideline ENSI-A01 focuses specifically on:

- suitability, validation and compliance with best estimate computer software;
- compatibility of analysis assumptions with system and component design;
- conservatism of simplifications and assumptions in the analysis; and
- adequacy of assumed single failures following initiating events.

The Inspectorate's review also includes independent DBA analyses using appropriate computer codes and own plant models, which are being further developed. In addition, the specific requirements for Safety Level 3 accidents in nuclear installations as distinct from NPPs have been expressed in more detail in the recent amendment of the guideline ENSI-A01 (September 2018).

The requirements for radiological analyses to determine the source term to the environment are given in the guideline ENSI-A08 for both NPPs and other nuclear installations. Radiological inventories, pathways and thermal-hydraulic conditions for the transport of radionuclides within the plant are also considered. The guideline ENSI-G14 sets out the requirements for subsequent calculation of the radiological consequences for the environment in the light of the dispersion of radionuclides and exposure pathways for the population.

Selected beyond design basis accidents (BDBA) must also be considered. Recent amendments of guideline ENSI-A01 distinguish between Safety Level 4a (SL4a) and Safety Level 4b (SL4b) accidents in nuclear power plants. These correspond to the greatest possible extent to the Design Extension Conditions (DEC) A and DEC B from the WENRA RHWG Guidance Document for Issue F: Design Extension of Existing Reactors. For SL4a accidents (e.g. Anticipated Transient Without Scram or Total Station Blackout), prevention of severe fuel damage in the core or in the spent fuel storage can be achieved. The list of SL4a accidents is derived from WENRA Issue F.

According to the latest results of deterministic safety analyses, all Swiss nuclear power plants entirely fulfil the requirements of the current rules and standards.

Probabilistic analysis

The NEO requires the development and use of a PSA for all relevant operating modes in Swiss NPPs. These requirements are also specified in two regulatory guidelines aimed at harmonising the use and development of PSAs:

- Guideline ENSI-A05 defines the quality and scope of requirements for the plant-specific Level 1 and Level 2 PSA for NPPs and other nuclear installations.
- Guideline ENSI-A06 formalises the requirements for applying PSAs to NPPs. It defines general principles for all PSA applications, requirements for periodic maintenance and updates of the PSA and the scope of mandatory PSA applications, and also defines corresponding risk measures and/or evaluation criteria.

All Swiss NPPs perform plant-specific Level 1 and Level 2 studies, including internal and external events such as fire, flooding, earthquakes, aircraft crashes and high winds. Full power, low power and shutdown modes are considered in both the Level 1 and Level 2 PSA.

PSAs for Swiss NPPs also consider the risk of radioactive releases from the spent fuel pool. Consideration of the spent fuel pool in the PSA is mandatory for non-power operation. Consideration of the spent fuel pool in the PSA for power operation depends on the criteria defined in guideline ENSI-A05.

The licensees update PSAs at regular intervals. Every 10 years, as part of the PSR, PSA studies are revised as required to reflect advances in methods and current operating experience. At least once every five years, PSA models are updated to reflect plant modifications and the availability of additional reliability data. Guideline ENSI-A06 also defines the conditions for updating the PSA models at other times for plant modifications not yet incorporated in the PSA models, but which may have a significant impact on PSA results.

The requirements of guideline ENSI-A05 are the main basis of the regulatory review of the PSA studies. The regulatory review aims to develop a thorough understanding of plant attributes, plant-specific operating characteristics, and the plant's vulnerability to potential severe accidents. The review focuses on a general evaluation of PSA models, assumptions, analytical methods, data and numerical results. At the beginning of the review process, ENSI verifies whether the PSA documentation is complete and assesses the PSA approach and analytical methods, as well as the plant design features intended to prevent and mitigate potential severe accidents. Based on the results of this evaluation, the Inspectorate submits requests for additional information to the licensee and its responses are used in the review. Site audits, including plant walk-downs, are also carried out. In particular, a detailed regulatory review of the PSA is conducted as part of the PSR.

Guideline ENSI-A06 formalises the application of PSAs in the regulatory framework with the aim of identifying potential plant improvements, complementing safety assessments within the integrated reactor oversight process and defining relevant risk measures and/or evaluation criteria. Guideline ENSI-A06 specifies the scope of mandatory PSA applications with the aim of meeting these objectives:

- probabilistic evaluation of the safety level;
- evaluation of the balance of risk contributions;
- probabilistic evaluation of technical specifications;
- probabilistic evaluation of changes to structures and systems;
- risk significance of components;
- probabilistic evaluation of operating experience, including reportable events.

In addition, the following analyses and applications are part of or related to PSAs:

- Probabilistic hazard assessment for external events. Hazard curves are used for the PSA itself and as an input for specifying DBAs in the deterministic safety analysis.
- Categorisation of accidents according to their frequency. Based on their frequency, accidents are defined as design basis or beyond design basis accidents. In the case of design basis accidents, different dose limits are set according to their frequencies.
- Analyses of seismic and extreme wind fragilities used for both the PSA and deterministic safety proofs.
- Development of Severe Accident Management Guidelines (SAMGs). The Level 2 PSA is used as a technical basis for developing SAMGs. In particular, the Level 2 PSA provides analyses of severe accident phenomena, indications of the completeness of SAMGs and information to help prioritise measures. SAMGs have been developed for all Swiss nuclear power plants.

According to the latest results of probabilistic safety analyses, all Swiss nuclear power plants meet the IAEA's safety objectives for existing nuclear power plants, which recommend a core damage frequency of less than 10^{-4} per year and a large early release frequency of less than 10^{-5} per year.

Clause 2: Each Contracting Party shall take the appropriate steps to ensure that verification by analysis, surveillance, testing and inspection is carried out to ensure that the physical state and the operation of a nuclear installation continue to be in accordance with its design, applicable national safety requirements, and operational limits and conditions.

As already mentioned in the response to Clause 1, appropriate safety analyses must be submitted to the Inspectorate in support of an application as required, before any modification or backfitting to safety-related systems or components. The following proof is required before any such permit can be granted: evidence of the suitability of the manufacturing process and of the assembly and commissioning processes, evidence of compliance with safety limits, details of dedicated start-up tests as required, procedure for periodic inspections and audits, and finally probabilistic evaluation in respect of the impact on the plant core damage frequency. This proof is required to ensure that each modification or backfitting measure complies with previously approved safety requirements and that the relevant safety margins and operational limits are maintained.

Overview of the Contracting Party's arrangements and regulatory requirements for the verification of safety

The Inspectorate's arrangements and regulatory requirements for the verification of safety address outage activities and refuelling processes, backfitting and replacement programmes, inspections, information meetings and reviews of extraordinary licensee's reports and resulting plant modifications as issued by the Inspectorate in connection with national or international events classified INES 2 and higher.

Fukushima

Swiss nuclear power plant operators submitted their reports as part of the EU stress test performed on the Inspectorate's orders after the Fukushima accident. The results of the Inspectorate's review confirmed that Swiss NPPs display a high level of protection against the impact of earthquakes, flooding and other natural hazards, as well as loss of electrical power and ultimate heat sink.

A complete summary of backfitting measures initiated after Fukushima is given in Article 18.

Periodic Safety Reviews

As part of the PSRs carried out every ten years, the condition of the NPPs and their operational management are reviewed to ensure compliance with legal requirements, license provisions and the Inspectorate's official stipulations. Finally, compliance of the plant condition with the underlying approval requirements is examined in the course of ongoing supervision and during inspections by – and technical discussions with – the supervisory authority.

Main elements of programmes for continued verification of safety (in-service inspection, surveillance, functional testing of systems, etc.)

Outage activities and refuelling

During each refuelling outage, the plant is subjected to a review covering many aspects. A number of examples are listed below:

- The Inspectorate monitors in-service inspections, preventive maintenance and repairs/modifications to safety-related mechanical equipment undertaken by licensees to maintain or enhance plant safety. Its appointed expert, the Swiss Association for Technical Inspections, supervises and verifies many of these activities using a combination of selective supervisory and random checks. In contrast, the Inspectorate focuses on specific issues.
- The licensee carries out a review of mandatory periodic functional testing of systems and components, including switchover tests for the electricity supply. These tests are performed in accordance

with written procedures and all test results are documented. The Inspectorate inspects selected tests and reviews the results of the entire test programme.

- Cycle-specific fuel and core-related issues are reviewed as part of the «Reload Licensing Submittal» submitted by the licensee four weeks before the beginning of the plant refuelling outage. The Inspectorate must approve fuel and core loading before refuelling. The Inspectorate also assesses the state of the fuel assemblies and control rods and attends selected fuel inspection campaigns as well as the start-up measurements.

The Inspectorate issues a letter granting permission to restart plant operation after the maintenance/refuelling outage. In this letter, the Inspectorate gives its assessment of the outage maintenance and refuelling activities, the plant's radiological status and cycle-specific safety analyses. The permit may also include conditions for plant operation or requirements and recommendations for maintaining and improving plant safety. The Inspectorate documents its own activities during the outage in a separate outage report.

Backfitting and replacement

Backfitting and replacement of safety-related equipment are necessary when existing equipment no longer satisfies current standards or when it becomes difficult to maintain. The Inspectorate may also require backfitting or replacement of equipment, e.g. following a PSR. In addition, a backfitting programme is required when the NPPs enter LTO (i.e. after 40 years of operation). New equipment is mainly installed and commissioned during plant outages. The Inspectorate reviews the process for such activities and monitors the process closely. In most cases, the Inspectorate must approve the design, installation, modification and commissioning of the equipment.

A list of backfitting measures and improvements is given in Article 18.

Inspection

Inspections in nuclear installations are primarily performed by the Inspectorate. In the field of mechanical engineering, some aspects of inspections are delegated to external experts who act exclusively on behalf of the Inspectorate.

The regulatory inspections by the Inspectorate serve to provide the basis for independent judgements on safety-related issues such as:

- quality measures during plant modifications and operation;
- availability of documentation (e.g. operating instructions, technical specifications, emergency instructions and emergency plans);
- adherence to operating instructions and technical specifications;
- plant operation and recording of safety performance;
- adequacy of PSA models in representing the current plant configuration and operational characteristics;
- housekeeping practices designed to prevent or mitigate fire and the effects of seismic hazards;
- availability and training of operating personnel;
- radiation protection;
- human factors engineering (e.g. human-system interface);
- organisation and safety culture;
- protection against sabotage and malicious acts.

The inspections cover all aspects of engineering relevant to safety (e.g. fire or flood protection), the relevant natural science (e.g. reactor physics, water chemistry) and social science (e.g. work and occupational psychology) disciplines.

In 2015, ENSI was accredited by the Swiss Accreditation Service (SAS). Inspections in the following fields are covered by the accreditation:

- operational radiation protection

- radiation measurements
- transportation of radioactive substances

The Inspectorate plans inspections in accordance with its Basic Inspection Programme, which provides a systematic basis for **periodic inspections.** The inspection intervals are based on the extent to which the items (components, systems, processes) to be inspected are relevant to safety and on operating experience.

In addition to the above periodic inspections, the Inspectorate management team defines **issue-based inspections**. These focus on specific issues identified in the annual systematic safety assessment described below. If necessary, **reactive inspections** are carried out, e.g. in response to international experience, events or plant modifications proposed by the licensee. After the shutdown on 20 December 2019, inspections in Mühleberg NPP will be planned and performed in line with decommissioning progress.

Inspections are performed at any time and are more frequent during outages than during normal operation. In most cases, the licensee is given advance notice of inspections. This ensures that activities to be addressed by the inspection are compatible with the inspection, that components are accessible and that the relevant staff are available for discussions. Inspections by the site inspector are usually unannounced.

Most inspections are performed during operation of nuclear installations, although a few inspections cover other nuclear installations, such as research reactors, which have been shut down.

A full-time site inspector is appointed for each NPP. Other nuclear installations have been assigned to part-time installation inspectors. As the Inspectorate's offices in Brugg and the NPP sites are in relatively close proximity, regional offices are not required. For the same reason, there are no resident inspectors, but regular unannounced visits occur.

During normal operation, the site inspector is present on the site one day per week on average. During outages, the site inspector is present for four or five days. After the shutdown of Mühleberg NPP, the presence of the site inspector will be determined by progress with decommissioning. Inspections by specialists focus on specific issues, whereas site inspectors take a more general view of the NPP. Findings of potential interest are reported by the site inspector to the specialists at the Inspectorate. The duties of site inspectors are not limited to inspections. They also act as a vital link between the licensee and the Inspectorate. Site inspectors take the lead role in systematic safety assessments (see below), which are part of the integrated oversight process.

Figure 7:
Clearance – Source ENSI

Information meetings

Each site inspector (see above) conducts monthly meetings with the respective licensee in order to obtain the latest information on plant status and performance. Further members of the Inspectorate management team and the licensee meet annually for an information meeting at which the licensee reports on plant operation. The meetings also discuss special issues and ongoing or planned projects. The Inspectorate then gives its views on the various topics and clarifies current or future requirements (safety-related requirements are normally presented to the licensee before they are enforced).

In addition, there is an annual meeting between senior managers from the Inspectorate and the NPP in order to discuss current safety issues. There are also annual management meetings between the Inspectorate's senior management team and senior managers from ZWILAG, PSI, Nagra and the TSO SVTI.

In addition to these regular information meetings, the Inspectorate may arrange meetings on specific issues at any time it deems appropriate.

Elements of the ageing management programme(s)

Review of Ageing Surveillance Programme

The safety-relevant aspects of material ageing must be taken into account for all classified systems, structures and components (SSCs). Switzerland was one of the first countries to introduce systematic ageing management programmes (AMPs). All licensees started their plant-specific AMPs in 1992. The regulatory expectations for the AMP in Switzerland are provided within the current guideline ENSI-B01 (issued 2011), which superseded guideline HSK-R51 (issued in 2004). The guideline ENSI-B01 is based on the legal framework in Switzerland (NEO and NEA) and in the guideline makes reference to the requirements in IAEA Safety Guide NS-G-2.12 concerning material ageing issues. The Inspectorate has checked IAEA Safety Guide SSG-48, published in November 2018 to supersede Safety Guide NS-G-2.12, to assess its implications for the existing AMPs. No need for immediate action to implement new requirements has been identified as yet. References to the new IAEA Safety Guide will be updated in the next revision of guideline ENSI-B01.

Information from manufacturers, knowledge gained from maintenance, operating experience, root cause analyses of international reportable events and the current state of the art of science and technology must be considered when implementing and maintaining the ageing monitoring programme. The AMP covers the areas of mechanical, electrical and civil engineering and SSCs. There are specific requirements for individual implementation of AMPs for electrical and I&C systems, mechanical systems and civil structures. This reflects individual needs based on the various physical ageing mechanisms and the respective maintenance strategy, and also follows the approach outlined in IAEA TEC-DOC-1736. AMP documentation in Switzerland comprises:

- Technology-specific assessment of potential ageing mechanisms;
- Plant-specific or generic guidelines;
- Fact sheets on ageing management with structural element-specific/component part-specific or component-specific categorisation of the relevant ageing mechanisms and their compliance with the respective maintenance programmes. The guideline requires fact sheets to be updated to reflect any new safety-related results, or at least once every ten years;
- Annual status reports which include a compilation of: updated fact sheets and complementary measures; evaluation of ageing-relevant internal and external operating experience and current state of science and technology; assessment of the effectiveness of the applied AMP and the complementary measures taken.

AMPs provide essential information concerning the scope and qualification process of the respective in-service inspection programmes (ISIs) for mechanical components and are used to check the maintenance programmes already in place. The AMP maintenance (updating) process ensures that the relevant ageing mechanisms for all safety-relevant components and structures are identified and that appropriate complementary measures are initiated if any deviations or gaps are discovered.

The initiated complementary measures are a key issue of the AMP. They cover the following topics, for example:

- Studies for specific material degradation issues (e.g. susceptibility to material degradation under specific conditions, root cause analysis of flaws);
- Modification/adjustment of in-service inspection programmes (temporary or permanent);
- Mitigation techniques;

Switzerland took part, on a voluntary basis, in the first ENSREG Topical Peer Review (TPR) process which started in 2017 based on the EU Nuclear Safety Directive 2014/87/EURATOM. This first Topical Peer Review focused on the overall ageing management programme as well as some specific ageing supervision programmes implemented in Nuclear Power Plants (NPPs) and in Research Reactors (RRs) above 1 MWth (not relevant for Switzerland). In the first phase of the review, national self-assessments comprising a description and assessment of AMPs were conducted and the results were documented in National Assessment Reports (NARs), published at the end of 2017. The second phase started in January 2018 when the National Assessment Reports were made available for questions and comments from stakeholders. The self-assessments, questions from stakeholders and the participating countries' responses were discussed during a one-week workshop in May 2018. The identified generic and country-specific findings on AMPs were compiled by ENSREG and published in October 2018 to provide input for national action plans. The TPR report confirmed that the Swiss NPPs have implemented effective AMPs. The TPR Board defined categories for evaluating different aspects within AMPs: «good practice» (an aspect of ageing management which is considered to go beyond what is required in meeting the appropriate international standard), «good performance/TPR expected level of performance» (level of performance that should be reached to ensure consistent and acceptable management of ageing throughout Europe), and «area for improvement.» In addition, challenges which are common to many or all countries were identified. Switzerland was issued a number of good practices for:

- Application of a method for inspection, monitoring and assessment of inaccessible structures
- Use of hydrogen water chemistry and noble metal injection in BWRs (Leibstadt and Mühleberg NPPs) as mitigation measures to prevent or delay stress corrosion cracking
- External peer review services to provide independent advice and assessment of licensees' ageing management programmes
- Performance checks for the behaviour of new types of materials by inspection of original material samples aged under realistic operating conditions.

Another six aspects were considered to be good performance:

- Participation in international projects and groups and use of existing international databases
- Adaptation of AMPs during extended shutdown
- Inspection of safety-related pipe penetrations through concrete structures
- Volumetric inspection of nickel base alloy penetrations which are susceptible to primary water stress corrosion cracking (PWSCC)
- Non-destructive inspections of RPV base material
- Fatigue analyses taking into account the environmental effect of the coolant.

The following three aspects were identified as areas for improvement:

- Checks to establish the scope of existing AMPs against new IAEA requirements and implement modifications if necessary
- Include non-safety-related inaccessible pipework, which, if it failed, might impact SSCs performing safety functions in AMPs
- Application of opportunistic inspections of inaccessible pipework when they become accessible for other purposes.

In 2018, the Inspectorate conducted a set of topical inspections on AMPs for inaccessible structures and piping in all Swiss NPPs. These inspections showed that most inaccessible areas are included in either AMPs or maintenance programmes. Opportunistic inspections of inaccessible structures and pipes have been carried out by some NPPs and are planned for all Swiss NPPs.

Arrangements for internal review by the licence holder of safety cases to be submitted to the regulatory body

Reporting

Article 37 and Annex 5 of the NEO specify the periodic reports to be submitted to the regulatory body in order to assess the status and operation of the facility. Article 38 and Annex 6 address reporting of planned activities, events and safety-relevant findings. Article 39 covers reporting obligations in the field of nuclear security. The NEO delegates detailed requirements in terms of the content of the report to the Inspectorate. These aspects are covered in guidelines ENSI-B02 and ENSI-B03, both of which came into force in 2009. Guideline ENSI-B02 deals with periodic reporting, e.g. monthly reports, annual safety reports and outage reports. Guideline ENSI-B03 is concerned with reporting planned activities, events and safety-relevant findings. Data relating to general plant performance, including radiological characteristics and plant modifications for which a permit is not required, must be reported periodically (monthly or yearly). However, events such as equipment failures, scrams and failure of mandatory tests must be reported immediately or within 24 hours if they relate to nuclear safety aspects (see Annex 6 of the NEO).

The licensee also must review information on international events available through various channels such as WANO, IAEA and supplier information letters. The insights gained from these reviews must be reported on a monthly basis. A set of safety indicators has been defined and the raw data for these indicators must be included in the monthly reports.

Reports by licensees may trigger regulatory requirements or recommendations for improvement. The Inspectorate also reviews information from international events as well as insights from safety research. These reviews may also trigger regulatory action and, if appropriate, requirements or recommendations to the licensee.

Quality requirements concerning internal reviews by the licence holder of safety cases to be submitted to the regulatory body (e.g. by means of independent verification) are defined in ENSI-G07.

Regulatory review and control activities

Integrated Oversight: ENSI's Annual Systematic Safety Assessment

Under the Inspectorate's integrated oversight approach, all aspects of relevance to nuclear safety are integrated into a single comprehensive oversight strategy. The aim is twofold: firstly, the Inspectorate must ensure that it has sufficient information on the design, state and effectiveness of all safety provisions so that it can provide a realistic assessment of the safety of each nuclear installation. Secondly, the Inspectorate must ensure that it takes adequate and effective measures if it detects a weakness in a safety provision. Every assessment and action must be justified and traceable.

In order to obtain a realistic picture of the safety of each installation, the Inspectorate operates a systematic safety assessment system. Firstly, safety information is structured based on the following key issues:

- requirements are sub-divided into design and operational requirements;
- operating experience is sub-divided into state and behaviour of the plant and behaviour of man and organisation.

Secondly, information is structured based on the following safety goals:

- safety functions;
- levels of defence in depth and barrier integrity.

For each NPP, data is collected as shown in Figure 8 and Figure 9.

Inspection findings, operator licensing results, event analysis results, safety indicator data and information in the periodic licensee reports are evaluated annually as part of the integrated oversight process.

Each finding identified during an inspection is assigned to one or more cells in each table (defence in depth and fundamental safety function). The same process is used for the event analysis results, and each direct or indirect cause, along with each safety-relevant effect, is detailed. Finally, operator licensing results and the safety indicator assessments are given.

Findings are rated on a scale based on the International Nuclear Event Scale (INES). The scale is designed to assess all levels of safety performance ranging from good practice to a severe accident on an identical scale. The categories are defined as follows:

- Category G: Good practice – All requirements are fulfilled and the practice of other NPPs is clearly exceeded.
- Category N: Normality – All requirements are fulfilled

Subject / Goals		Requirements		Operational experience	
		Design requirements	Operational requirements	State and behaviour of the plant	State and behaviour of man and organisation
Levels of defence in depth	Level 1				
	Level 2				
	Level 3				
	Level 4				
	Level 5				
Barrier integrity	Fuel integrity				
	Integrity of the primary cooling system boundary				
	Containment integrity				
overall defence in depth aspects					

Figure 8: *Safety Assessment Table – Defence in Depth*

Subject / Goals		Requirements		Operational experience	
		Design requirements	Operational requirements	State and behaviour of the plant	State and behaviour of man and organisation
Safety functions	Controlling reactivity				
	Cooling the fuel				
	Confining radioactive materials				
	Limiting exposure to radiation				
	overall aspects				

Figure 9: *Safety Assessment Table – Safety Functions*

- Category V: Need for Improvement – Deviations from requirements in documents not requiring formal authorisation by the Inspectorate fall into this category
- Category A: Deviation – Deviations from normal operation within operational limits and conditions
- Categories 1 to 7 - Rating based on the INES Manual

Categories V and A correspond to INES 0. Findings from inspections rated INES 1 or higher are classified as events. Findings rated A are checked to see whether they must be classified as events. Any finding in category V or higher requires action.

Inspection data, operator licensing data, event analysis data, safety indicator data and periodic licensee report data are entered in a database. A software tool allows safety assessment data to be displayed and the ratings can also be displayed in a table for any period and any installation. Each rating is linked to a source document. The ratings for each NPP are evaluated annually. The result of this evaluation influences the focus of future inspections. Insights gained from the annual safety assessment of each plant are included in the annual regulatory oversight report published by the Inspectorate.

Developments and Conclusions

Switzerland complies with the obligations of Article 14.

Article 15 – Radiation protection

Each Contracting Party shall take the appropriate steps to ensure that in all operational states the radiation exposure to the workers and the public caused by a nuclear installation shall be kept as low as reasonably achievable and that no individual shall be exposed to radiation doses which exceed prescribed national dose limits.

The Radiological Protection Act was partly revised in October 2007. Based on the recommendations of the International Commission on Radiological Protection (ICRP) (e.g. Publication No. 103), the Radiological Protection Ordinance was completely revised and came into effect in 2018. The Ordinance's contents are arranged according to the recommended structure into planned, emergency and existing exposure situations. Relevant changes, amongst others, included the distinction of dose factors for infants (1 y), children (10 y) and adults as well as dose factors for irradiation from an airborne plume and on the ground. The purpose of the latest revision of the Ordinance was to ensure compatibility with the new European Safety Directive, Version 24 from February 2010 (final) and the IAEA Basic Safety Standard, GSR Part 3, from July 2014.

The Inspectorate revises and adapts most of its guidelines relating to radiation protection in an ongoing process:

- HSK-R-07: Guideline for radiation protection zones in nuclear installations and in the Paul Scherrer Institute (will be replaced in 2020);
- ENSI-B04: Clearance of materials and zones from controlled areas (revised and issued in November 2018);
- ENSI-B09: Determining and reporting of doses from occupationally radiation exposed personnel (revised and issued in July 2018);
- ENSI-G13: Radiation protection measuring instruments in nuclear facilities, basic concepts, standards and testing (revised and issued in July 2018);
- ENSI-G14: Calculation of radiation exposure in the vicinity of nuclear installations due to emissions of radioactive materials (revision planned);
- ENSI-G15: Radiation protection objectives of nuclear installations (revision planned).

A further guideline, ENSI-G12 «Nuclear Facility-specific Radiation Protection Measures» (provisional working title) is currently being drafted. It covers all aspects concerning «source term reduction», «enclosure of radioactivity by barriers from the Radiological Controlled Area», «limiting and optimisation of external exposure» as well as «preventing incorporation and contamination of personnel». This guideline will replace the above-mentioned HSK-R-07 guideline and specifies the Radiation Protection Ordinance for application in nuclear facilities.

Dose limits

The Radiological Protection Ordinance limits the general maximum individual total dose for NPP personnel (plant personnel and contractors) to 20 mSv per year. Exceptionally, a limit of 50 mSv in one year, but not exceeding 100 mSv over five consecutive years, may be authorised by the Inspectorate. The Inspectorate has not received such requests to date.

The total number of plant personnel and contractors who are occupationally exposed to ionising radiation in all Swiss nuclear facilities is around 6,000. Since 1996, all annual collective doses have remained around 2 man-Sv or less per unit. The annual collective doses over the last 20 years are illustrated in Figure 10.

Beznau NPP: The steam generators in Beznau NPP II were replaced in 1999, leading to a collective dose of 0.64 man-Sv. The low dose for this work can largely be attributed to «lessons learned» from the 1993 steam generator replacement in Beznau NNP 1 (collective dose 1.2 man-Sv) and to the optimisation of radiation protection. Long outage periods in Beznau NPP I and II led to a high collective dose in 2015. Over this time, major projects were completed, including the installation of new reactor vessel heads by opening the containment in both units.

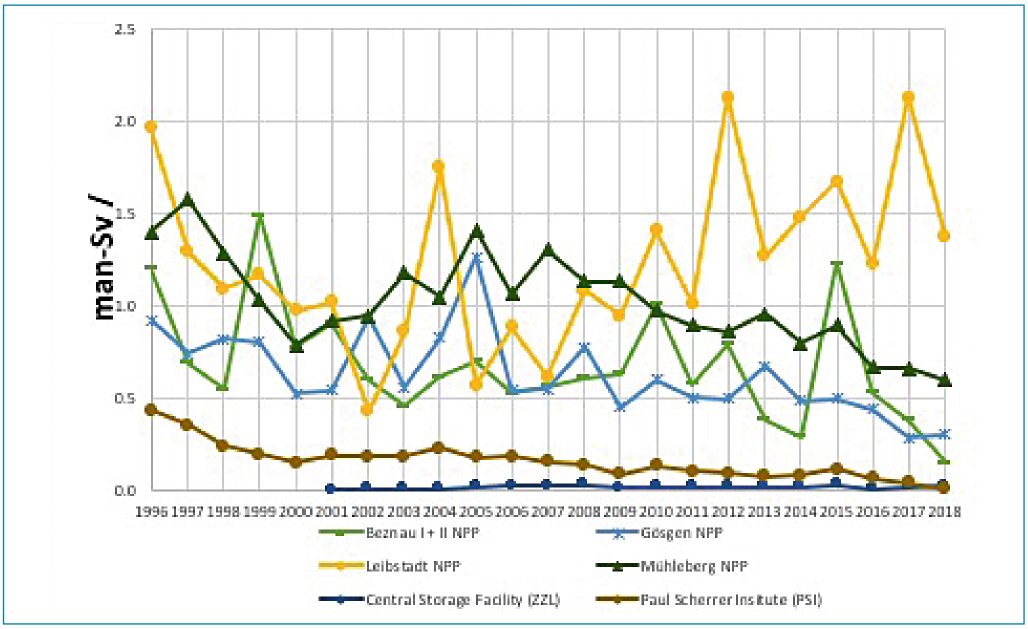


Figure 10: *Annual collective doses for personnel in Swiss NPPs, the Central Interim Storage Facility (ZZL) and the PSI Research Institute. All peaks are related to extraordinary work performed. (note: Beznau NPP has two units, both located on the same site)*

Leibstadt NPP: Extensive structural alteration works relating to the planned power upgrade resulted in higher collective doses in 1994 and 1996. In 2004, additional inspections for maintenance and repair of recirculation pumps resulted in a higher collective dose. The unplanned repair of a crack in a weld seam of a reactor pressure vessel nozzle resulted in an increased accumulated dose in 2012. The increasing amount of maintenance work and periodic testing are responsible for the rise in annual collective doses since 2013.

Gösgen NPP: As part of the PISA project, replacement of the primary safety valve in 2005 led to an increase in the collective dose.

The dose due to non-natural sources is limited by the Radiological Protection Ordinance to 1 mSv per year for members of the public. Guideline ENSI-G15 defines a source-related dose constraint of 0.3 mSv per year, representing the maximum allowed dose resulting from emission and direct radiation from each nuclear site (irrespective of the number of reactors) for population groups living nearby. In addition, the contribution from direct radiation may not exceed 0.1 mSv per year.

A nuclear facility must be designed in such a way that the source-related dose constraints are not exceeded as a result of incidents with an occurrence greater than 0.01 per year and the dose limit for members of the public (1 mSv, as mentioned above) is not exceeded by incidents with an occurrence greater than 0.0001 per year.

The maximum allowed emissions are defined in the operating licences, based on the characteristics of the NPP and the results of the dose calculations, taking the ALARA principle into consideration. The Inspectorate's guideline ENSI-G14 defines the rules used to calculate doses due to emissions and discharges. Doses calculated on the basis of annual emissions for a virtual most exposed population group, including the contribution from deposition from previous years, have always been well below 0.2 mSv per year. Contributions due to annual releases have been below 0.01 mSv per year for all Swiss NPPs since 2015. These facts are illustrated below in Figure 11. Doses due to direct radiation have always been below 0.1 mSv per year for all Swiss NPPs. In conclusion, the data shows that the sum of the annual dose caused by direct radiation and emission has always been below the source-related dose constraint.

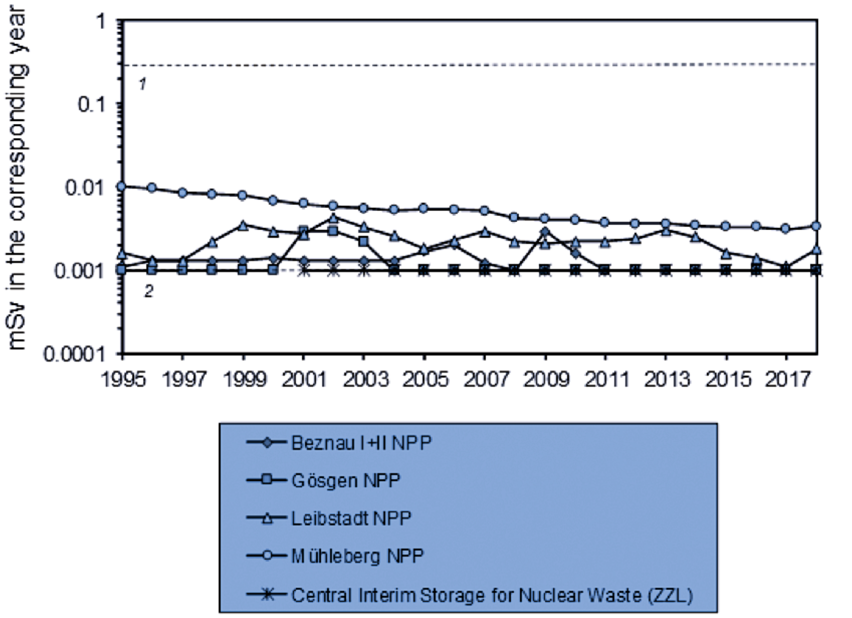


Figure 11: *Doses calculated on the base of annual emissions from the Swiss NPPs and the Central Interim Storage Facility (ZZL) without the contribution of direct radiation.*[8]

Steps taken to ensure as low as reasonably achievable radiation exposure

Over the years, NPP-specific measures have been used to keep radiation exposure resulting from the operation and maintenance of NPPs as low as reasonably achievable. In 1994 the new annual dose limit for individuals of 20 mSv per year was introduced. This limit was only exceeded by two incidents: at Beznau NPP I in 2009 and Leibstadt NPP in 2010. In both cases, the individual doses did not exceed 50 mSv. The mean individual doses for plant personnel and contractors (see Figures 12–15) show a stable progression in all NPPs over the past few years. The significant efforts to reduce doses, particularly between 1988 and 1995, are noteworthy. Since 2013 there has been a slight increase in the annual collective doses as well as the mean individual doses recorded in Leibstadt NPP due to extended maintenance works. The increase in mean individual doses in Beznau NPP can be explained by extended outage periods in both units, during which various projects were performed with the assistance of numerous contractors on site.

The most significant dose reduction measures undertaken in Swiss NPPs during recent years, are shown below in Table 3.

In its publication 75, the ICRP recommends using operational dose constraints based on good practice, including optimisation. In this sense, guideline ENSI-G15 requires the NPP to determine dose planning objectives (e.g. max. individual doses or collective job doses) for the respective activities based on: empirical values from comparable activities in its own or in a comparable installation;

---

[8] The annual doses are calculated for a virtual most exposed population group (3), including exposure due to deposition from previous years. The higher value for the Mühleberg NPP relates to an emission of radioactive particles in 1986 due to a malfunction of the dry resin waste treatment system.

1. 0.2 mSv per year value (source-related dose constraint minus direct radiation constraint).
2. Values below 0.001 mSv per year are shown at the level of 0.001 mSv per year.
3. Virtual person, permanently located at the main plume area, consuming all food produced locally and all drinking water from the river downstream of the NPP in question.

- current radiological situation;
- international experience;
- optimisation processes.

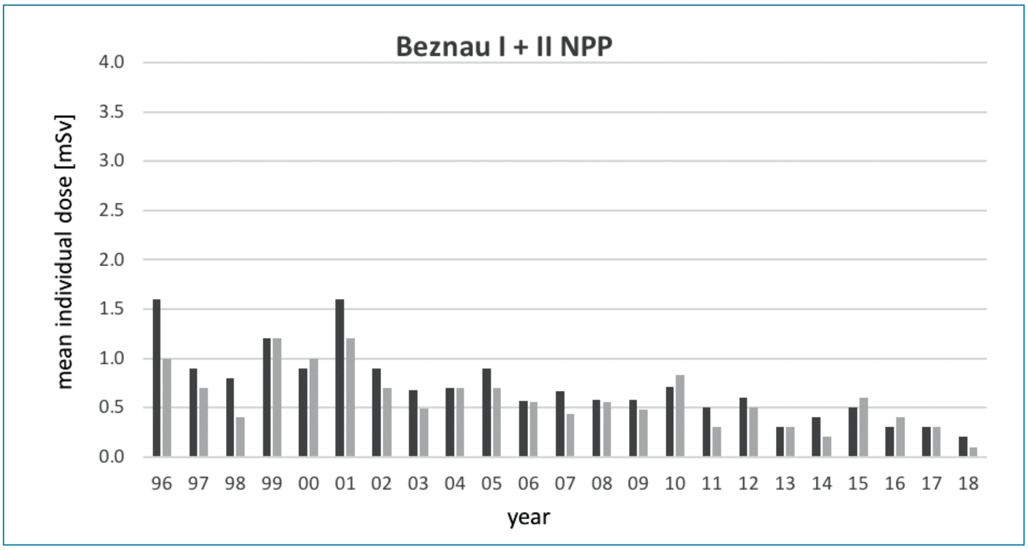


Figure 12: *Mean individual dose to plant personnel (dark-coloured bars) and contractors (light-coloured bars) in Beznau NPP.*

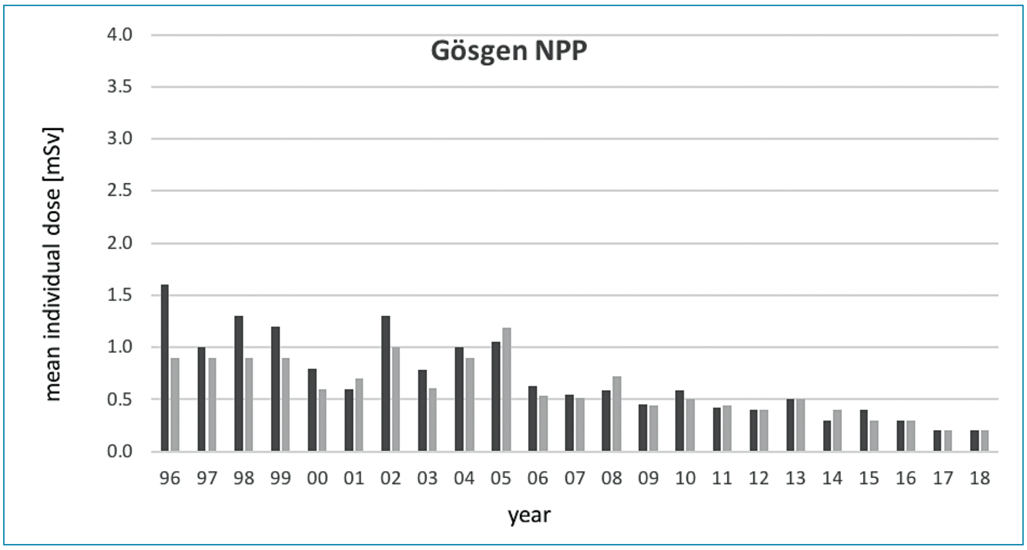


Figure 13: *Mean individual dose to plant personnel (dark-coloured bars) and contractors (light-coloured bars) in Gösgen NPP.*

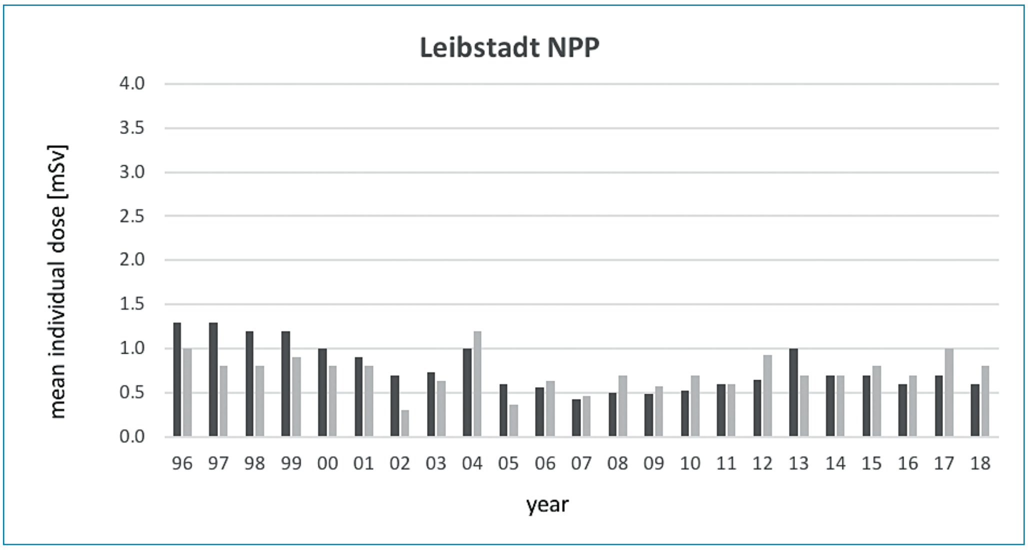


Figure 14: *Mean individual dose to plant personnel (dark-coloured bars) and contractors (light-coloured bars) in Leibstadt NPP.*

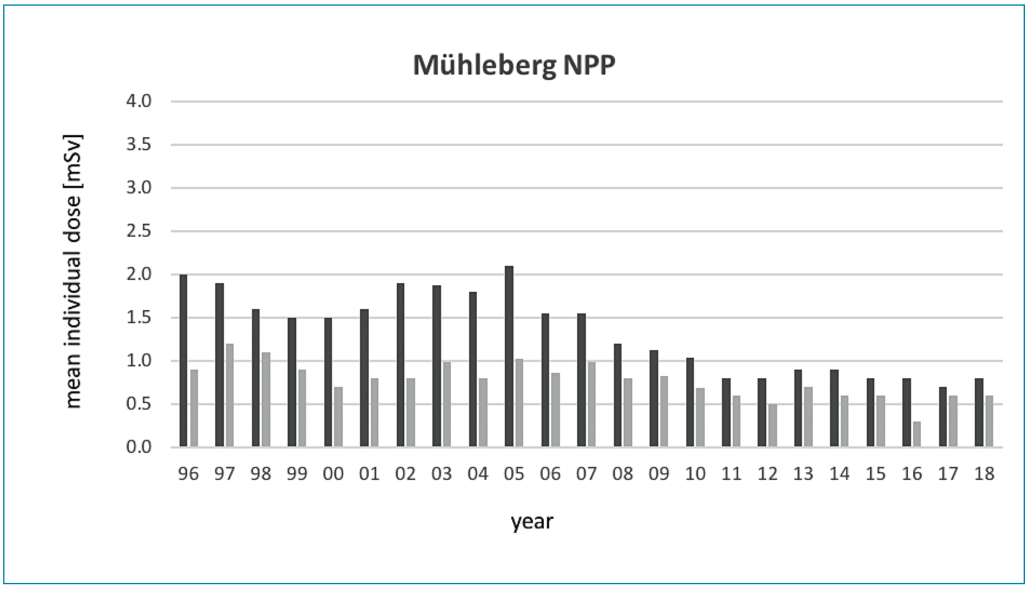


Figure 15:
Mean individual dose to plant personnel (dark-coloured bars) and contractors (light-coloured bars) in Mühleberg NPP.

Table 3:
Main dose reduction measures in Swiss NPPs

Plant	Average collective dose during outages over the last five years [man-mSv]	Main dose reduction measures
Beznau I and Beznau II NPPs	581	Temporary lead shielding (70 tons) Low dose rate areas (< 0.005 mSv/h) for personnel Individual acoustic dose and dose rate warnings Strong emphasis on training and motivation Daily job-specific follow-up of doses vs. planning including interventions if necessary to maintain the NPP-internal dose constraint of 10 mSv p.a. for workers Remote tools for primary system inspections Improved water chemistry, reducing colloid fixation on primary system surfaces Radiological risk analyses and improvement of infrequent or high dose tasks/works
Mühleberg NPP	606	Temporary lead shielding (85 tons) Permanent racks for supporting removable lead shielding Replacement of components with «Stellite» parts with components made from a cobalt-free alloy Daily follow up of job-specific actual doses vs. planning doses Zn-64-depleted zinc feed in primary water Online noble chemistry (OLNC) primary water operation mode leading to a reduction in the dose rates for the recirculation pipes Stopping hydrogen injection into the primary water system some hours before the reactor is shut down for the outage Use of wireless dosimeters for special kinds of operations to control the dose and dose rate online

Plant	Average collective dose during outages over the last five years [man-mSv]	Main dose reduction measures
Gösgen NPP	444	Temporary lead shielding (up to 40 tons) Highly compartmentalised containment with compartments made from concrete. Replacement of the old isolation system with new isolation cassettes on the primary coolant pipes Daily follow-up of total and selected job-specific actual doses vs. planning doses Extensive mock-up training Zn-64-depleted zinc feed in primary water Shutdown procedure individually adjusted to the current activity of the primary coolant water Chemical decontamination of all three reactor coolant pumps Wireless telephone system with noise-cancelling features used for work in noisy areas to improve communication Intensive surveillance of high-dose or high-risk works on site Work planning includes reasonable system conditions (filled pipes or compounds, closed systems etc.)
Leibstadt NPP	1121	Temporary lead shielding (32 tons) Temporary shielding with water bags Job dosimetry (bar code) with online follow-up. Job planning for jobs entailing collective radiation exposure > 10 man-mSv Replacement of components with «Stellite» parts with components made from a cobalt-free alloy Zn-64-depleted zinc injection in primary water Extensive mock-up training Stopping hydrogen injection into the primary water system some hours before the reactor is shut down for the outage Extensive camera system in the turbine building to reduce the number of operator walkdowns in steam-affected areas Chemical decontamination of components and systems as required Application of tele-dosimetry for specific jobs to control the dose and dose rate online Soft shutdown and optimised RHR operation during refuelling outage

According to the Radiological Protection Ordinance, radiation protection is deemed to be optimised if the following conditions are met:

- Various possible solutions have been individually assessed and compared.
- The sequence of decisions that led to the particular solution is comprehensible.
- Due consideration has been given to the possible occurrence of incidents and safe storage of radioactive sources that are no longer in use is provided.

The Inspectorate has issued the following detailed requirements:

- Special quality management rules for the radiation protection department as part of an NPP's QM system (see Article 13), including procedures defining how dose planning objectives are determined, the optimisation process, documentation as well as the relevant regulations regarding responsibilities.

- Radiation protection planning (including determining dose planning objectives) in accordance with internal procedures if the anticipated collective dose for a planned activity in a nuclear installation leads to higher collective doses than the planning thresholds specified in-house (typically 5, 10 or 20 man-mSv).
- A report sent to the Inspectorate if planning an activity results in an anticipated collective dose in excess of 50 man-mSv.
- Radiation protection planning presentation several weeks before shutdown for a planned outage, including a description of major jobs, radiation protection measures, monitoring concept and the radiation protection organisation.

The Inspectorate examines the dose planning objectives of an NPP in detail if the expected annual collective dose exceeds 1.5 man-Sv. In this case, the Inspectorate requests optimisation measures and, if appropriate, immediate comparison of the monitored doses with the dose planning objectives. If relevant deviations come to light, the activity must be stopped, plans must be revised and improvements must be implemented.

Contaminated wastewater in all Swiss NPPs is collected and treated in batches. However, every power plant uses customised reduction techniques to treat this wastewater. In Beznau NPP the radioactivity in the wastewater is reduced by nanofiltration, chemical precipitation, centrifugation and evaporation in some cases. In Gösgen NPP an evaporation technique is used to reduce the amount of contaminated wastewater and to produce a concentrated slurry. Leibstadt NPP uses a centrifugation or evaporation technique which is sometimes combined with ion exchange to treat contaminated wastewater and Mühleberg NPP uses filtration and ion exchange methods plus evaporation to handle its wastewater.

Three of the Swiss NPPs – Gösgen, Leibstadt and Mühleberg – have conventional off-gas treatment systems, which consist of catalytic recombiners, off-gas condensers, hold-up lines, activated carbon filter columns, HEPA filters and off-gas pumps. Beznau NPP has a slightly different system, which uses three pressurised hold-up tanks and the volume compensation tank in the chemical and volume control system. Each NPP has formulated site-specific targets for liquid and gaseous discharges with the intention of keeping doses as low as possible – and well under the statutory limits – for members of the public by using reasonable, justifiable effort.

Every ten years each licensee of a Swiss NPP is required to perform a PSR. As part of this review, the licensee must assess liquid and gaseous discharges from his plant and compare these with corresponding discharges from similar European reactors. Several individual improvements to the Swiss NPPs have emerged from this process, e.g. liquid discharges less than 1 GBq for Beznau NPP since 2007 due to the introduction of nanofiltration, or Mühleberg NPP, which in 2017 achieved the lowest ever liquid discharge figure of 0.11 GBq in its operating history after installing an evaporator in the contaminated wastewater treatment system.

RCA boundary review in Swiss NPPs

In 2004 ENSI requested all Swiss NPPs to examine their entire radiological controlled area (RCA) to identify potentially uncontrolled pathways between radioactive media and materials from inside the RCA and the environment. The integrity of barriers including the outside boundaries of the RCA (walls, ceilings, floors, windows, doors, feedthroughs with blank flanges or valves, locks, joints etc.) and interfaces between systems with potential radioactive media and systems open to the environment (tubes, tanks, valves, filters etc.) was examined in each NPP. The results of the investigations performed and suitable countermeasures were presented to ENSI on a regular basis. Meanwhile the last corrective actions performed were concerned with preventing unlicensed discharge paths. Summary reports were submitted to ENSI by each NPP. The integrity of RCA boundaries represents a relevant checkpoint in approval procedures for facility modifications, which are ongoing processes.

Operating radiation protection organisation

To ensure the independence and professional competence of the facility's radiation protection organisation, the licensee is required to implement three requirements based on the provisions of the Radiation Protection Act.

- The licensee must provide a direct communication link between the authorised radiation protection expert and the licensee's management representative.
- The licensee must delegate authority to the radiation protection experts enabling them to intervene in the operation of the NPP if radiation protection rules are violated.
- The licensee must provide adequate personnel resources within the radiation protection organisation. The plant staff must be made up of professionals with approved education and training. Tasks relating to radiation protectionare reserved for these professionals.

Detailed descriptions of these rules form part of each NPP's documentation as required for an operating licence to be granted. Modifications to the NPP's radiation protection rules must be authorised by the Inspectorate.

Regulatory control activities

As mentioned above, the Inspectorate reviews NPP radiation protection planning processes as part of its supervisory duties. Typically, these reviews are performed in conjunction with radiation protection planning for forthcoming outages.

Most inspections concerning radiation protection matters focus on the outage phases in every NPP. These inspections are usually planned several weeks in advance, on the basis of the plant's radiation protection planning. Other routine inspections are performed during operation in addition to specific inspections covering special topics, such as radiation monitoring instrumentation, contamination management, dosimetry, resources/presence of radiation protection staff, etc.

In addition, the Inspectorate reviews all NPP periodic reports relating to radiation protection measures. The Inspectorate operates a computerised database for radiological and chemical plant data which is submitted monthly by the licensees.

Environmental radiological surveillance

The Radiological Protection Act establishes the legal basis for radiological surveillance of the environment. More detailed requirements are laid down in the Radiological Protection Ordinance and in the legislation for foodstuffs. The discharge and environmental monitoring regulations issued by the Inspectorate are based on the above-mentioned legislation. These regulations include constraints on the control of discharges, plus a complete programme for environmental monitoring of radioactivity and direct radiation in the vicinity of the facility. The programme is drawn up by the Federal Office of Public Health in cooperation with the Inspectorate, the NEOC and the cantons. The programme is reviewed annually and modified as necessary.

The Inspectorate defines requirements for measuring devices as well as describing how the measurements should be performed. It checks that the devices are maintained properly and audits measurement bookkeeping during annual inspections. It also performs its own quarterly benchmark tests with laboratory measurement of environmental probes from each plant.

The environmental surveillance programme has three main aspects:

- Measuring emissions from the plant and comparing the actual emissions with the limits defined in the NPP's operating licence: the limits are chosen in such a way that the dose for people living in the vicinity of the plant remains well below the source-related dose constraint (see section on dose limits above).
- Calculating the dose from the measured emissions for the most exposed population group living in the vicinity of the NPP: the calculated values are compared directly with the source-related dose constraint. The models and parameters used for the calculation are defined in the Inspectorate's guideline ENSI-G14.

- Radiological emission surveillance programme: the environment is monitored nationwide by the Federal Office of Public Health. The areas surrounding NPPs are also monitored by the NPP and the Inspectorate independently. The programme includes online measurements of dose rates near the plants (MADUK, see Article 16), as well as regular sampling and measurement of air, aerosol fallout, water, soil, plants and foodstuffs.

The results are published in annual reports issued by the Inspectorate. A summary of the results of the entire environmental radiological surveillance programme is also published in the Federal Office of Public Health's annual report.

Developments and Conclusion

Switzerland complies with the obligations of Article 15.

Article 16 – Emergency Preparedness

Clause 1: Each Contracting Party shall take the appropriate steps to ensure that there are on-site and off-site emergency plans that are routinely tested for nuclear installations and cover the activities to be carried out in the event of an emergency. For any new nuclear installation, such plans shall be prepared and tested before it commences operation above a low power level agreed by the regulatory body.

Before a new NPP is started up, on-site and off-site emergency plans must be established and approved by the Inspectorate. The general requirements for emergency preparedness are based on the following acts, ordinances, Inspectorate guidelines and concepts:

Acts:

- Nuclear Energy Act;
- Radiological Protection Act.

Ordinances:

- Nuclear Energy Ordinance;
- Radiological Protection Ordinance;
- Ordinance on Emergency Preparedness in the Vicinity of Nuclear Installations (Emergency Preparedness Ordinance);
- Ordinance on the Federal Civil Protection Crisis Management Board;
- Ordinance on Iodine Prophylactics in the Case of a Nuclear Accident;
- Ordinance on Alerting, Alarming and the Security Radio Network;
- Ordinance on Maximum Levels for Contaminants.

Guidelines:

- Emergency exercises (guideline ENSI-B11)
- Emergency preparedness in nuclear installations (guideline ENSI-B12)
- Organisation of nuclear installations (guideline ENSI-G07)

Concepts

- Emergency protection concept in case of a nuclear power plant accident in Switzerland, Federal Office for Civil Protection FOCP (2015).
- National Planning and Measures Concept: large-scale evacuation in case of a nuclear power plant accident (2016)

A working group was set up by the Federal Council (IDA NOMEX) [9] in May 2011 to review emergency preparedness measures in the case of extreme events in Switzerland. The group's report entitled «Review of Emergency Preparedness Measures in Switzerland», which is available on the Inspectorate's website (www.ensi.ch), was adopted by the Federal Council in July 2012 and describes a series of organisational and legislative measures which have proven to be necessary as a result of the review carried out. These include, for example, measures in the field of equipment and material, emergency planning zones, scenarios for emergency planning and large-scale evacuations. As a consequence of IDA NOMEX, the legal basis and concepts relating to emergency preparedness and response were revised or are in the process of being updated. The scenario used for emergency planning purposes is now characterised by an unfiltered, substantially higher source term than previously assumed. Consequently, awareness of emergency preparedness and response beyond the outer radius of Zone 2

[9] The Interdepartmental Working Group to Review Emergency Preparedness Measures in case of Extreme Events in Switzerland. In German this is the «Interdepartementalen Arbeitsgruppe zur Überprüfung der Notfallschutzmassnahmen bei Extremereignissen in der Schweiz»

(i.e. 20 km) has been raised and this is reflected in the revised concept for emergency protection in the event of an accident at a nuclear power plant.

Following a recommendation from the IRRS mission in November 2011, the Inspectorate has introduced an IAEA-compatible emergency classification system, extended the scope of inspections with regard to emergency preparedness and response at NPP sites and improved redundancy in emergency communication means. A national nuclear and radiation emergency plan is also being developed under the lead of the Federal Office for Civil Protection (FOCP).

On-site emergency organisation

Each NPP has plant-specific documents on emergency preparedness, which include the following:

- operating procedures for abnormal situations
- emergency operating procedures
- severe accident management guidance (SAMG)
- procedures for reporting to the Inspectorate and to the NEOC
- procedure for reporting to cantonal police in the case of rapidly-evolving accidents
- NPPs' emergency preparedness documentation is reviewed regularly.

SAMG programmes have been implemented at all Swiss NPPs: all plants have appropriate validated guidance for mitigating severe accidents during full-power operation and shutdown. They are validated as a result of emergency exercises which the Inspectorate attends as observer in its role as safety oversight authority. In addition to the full-power SAMG, all plants have developed special guidance for low power/shutdown conditions. Existing strategies to cope with Station Blackout (SBO) scenarios have been extended. As a result, additional equipment has been installed or stored on the plant sites and existing accident management procedures have been adapted.

Since June 2011, extra equipment has been stored at the Reitnau centralised storage facility. Adequate resources such as diesel motor-driven pumps, diesel generators, hoses, cables, borating agents, tools and personal protective equipment should be available from Reitnau within eight hours of request. For situations where transport to the power plant by road is impossible, there is an option for transport by air via military helicopter. Operators test the severe accident equipment stored at Reitnau on a regular basis and during their regular emergency exercises.

Dedicated telephone and fax lines between the NPPs, the Inspectorate and the NEOC are available to ensure communication in an emergency. These communication systems are tested once a month. If the above-mentioned communication equipment is unavailable, it is possible to use a digital radio system. As the IDA NOMEX report emphasised, the importance of redundant and failsafe communication systems, the requirements for redundancy and safety against failure of such systems have been reviewed and defined by the FOCP. Such requirements were also defined for monitoring (plant parameters and environmental dose rate measurement data) and forecasting systems by the Inspectorate in 2012.

Aspects of short-term operability and habitability of emergency control centres during nuclear accidents were assessed during inspections in 2012. Further inspections to ensure that nuclear power plants have suitable emergency rooms and alternative emergency rooms have been carried out in the meantime. All NPP have the option to relocate emergency staff to one of several external emergency facilities.

Off-site emergency organisation

Off-site emergency organisation is based on resources built up as part of the general protection concept developed for the Swiss population as a whole. These resources consist of a well-developed shelter infrastructure and well-trained troops for fire and disaster intervention. Emergency preparedness for events in Swiss nuclear installations where a considerable release of radioactivity cannot be ruled out is regulated under the Emergency Preparedness Ordinance. In the event of a radiological emergency, the Federal Civil Protection Crisis Management Board coordinates the response of all relevant federal offices (ministries) including civil and military support at federal and regional levels.

The Federal Civil Protection Crisis Management Board, the legal basis for which is laid down in the corresponding Ordinance, is responsible for suggesting appropriate measures to the Federal Council (government), which then issues the associated instructions to cantonal authorities and the general public. The Federal Civil Protection Crisis Management Board runs a standby emergency service, the NEOC, which is responsible for alerting and informing the public and for initiating protective actions during the initial phase of an emergency.

The major organisations involved in emergency preparedness have the following responsibilities:

- NPPs are responsible for detecting and assessing an accident, for implementing on-site countermeasures to control this accident and for disseminating information immediately and continuously to the relevant off-site authorities. According to the Emergency Preparedness Ordinance, NPPs are also responsible for determining the source term in a timely manner and communicating this source term to the Inspectorate.
- The Inspectorate is responsible for assessing whether on-site countermeasures implemented by NPP staff are adequate. It makes predictions about the possible dispersion of radioactivity in the environment and about the consequences of such dispersion. The Inspectorate also advises the NEOC and the Federal Civil Protection Crisis Management Board with regard to ordering protective actions for the public. In addition, an automatic dose rate monitoring and emergency response data system (MADUK) has been installed in the vicinity of all NPPs in Switzerland. The system monitors dose rates continuously at 12 to 17 locations in the vicinity of each NPP. The data is transmitted online to the Inspectorate and the NEOC. The Ministry of the Environment of Baden-Württemberg (Germany) receives online data from the dose rate monitors in the vicinity of the Beznau NPP and Leibstadt NPP. All data is also available on the Inspectorate's website (www.ensi.ch). For further information, please refer to Article 15. A second automatic network (NADAM) monitors the external dose rate on national territory. The data is available on the NEOC's website. Every hour, Switzerland transmits the mean value for all stations from the last hour to EURDEP, and this is then transmitted to IRMIS.
- The ANPA system also provides the Inspectorate with online access to measurement data for about 25 important plant parameters. The Inspectorate uses special software – the Accident Diagnostics, Analysis and Management system, ADAM – to display these measurements, diagnose the state of the plant and simulate how an accident may develop. ADAM also includes a module called STEP (Source Term Estimation Program), which allows the source term to be estimated based on actual plant parameters. The Inspectorate set up a new automated system for radiological forecasting in 2015. Calculations are performed hourly using JRODOS (Java-based real-time online decision support system) in combination with LASAT (Lagrangian Simulation of Aerosol Transport) as the dispersion engine, along with forecast meteorological data. The Inspectorate operates a redundant system at its alternate emergency premises, thus ensuring full redundancy. Yet another JRODOS system is operated at the NEOC.
- NEOC is responsible for convening the Federal Civil Protection Crisis Management Board, which has the task of preparing the decisions to be taken by the Federal Council on protective actions after the initial phase of an emergency during an accident. The NEOC is also responsible for overall assessment of an emergency situation and for sending warnings to the cantonal and federal authorities. It must decide on initial protective actions to protect the public and issue alarms (sirens) together with the instructions to be followed, which are issued via radio broadcasts. The NEOC is responsible for coordinating measurement teams, data processing and evaluation, assessing the radiological situation and sharing these results, along with other emergency-related information, with all the relevant response organisations on a secure electronic platform. It is also responsible for exchanging information and communicating with international partners (neighbouring countries and international organisations).

- The Federal Civil Protection Crisis Management Board is responsible for cooperation during events relevant to civil protection on a national level and for coordinating operations. The Federal Civil Protection Crisis Management Board has a committee and a permanent staff unit. The members of the Board are the directors and heads of all major federal offices, including the Director of the FOPH, the Director of the FOCP, the Chief of the Swiss Army Command Staff, the Director of ENSI and representatives of cantonal government conferences. Within their area of responsibility, they take the necessary precautions for dealing with radiological emergency events.
- The cantonal and communal authorities are responsible for preparing and carrying out protective actions for the public. Since 2018 the responsibilities of cantonal and communal authorities have been described in more detail in the updated Emergency Preparedness Ordinance.
- The Swiss Army Medical Service procures iodine tablets for the entire population of Switzerland. It will ensure that the required number of iodine tablets is made available to the authorities who are responsible for the pre-distribution. It also ensures additional storage in drugstores and pharmacies.
- The canton where the NPP is located is responsible for informing its citizens of the potential consequences of an accident in a facility and providing advice on how to respond in an emergency.

In the event of an accident, information is disseminated to the media by the above authorities in line with their individual responsibilities.

Emergency planning zones

According to the updated Emergency Preparedness Ordinance, as released in 2018, each NPP in Switzerland has two distinct emergency planning zones:

- Zone 1 is the area around an NPP where there is a risk of acute danger to the public in the event of an accident and for which immediate protective actions are required. Depending on the NPP's power rating and the discharge height of its vent stack, Zone 1 covers a radius of about 3–5 km.
- Zone 2 adjoins Zone 1 and covers an area with an outer radius of about 20 km. The public can be alerted in individual sectors as appropriate.

The area outside zones 1 and 2 encompasses the rest of Switzerland. So-called planning areas can be defined as a basis for planning and preparing specific measures.

The sectors and outer borders of Zones 1 and 2 generally follow the boundaries of the relevant municipal authorities.

Figure 16: *Storage Facility Reitnau – Source ENSI*

Emergency protective measures

The primary objective of emergency protective measures in the vicinity of NPPs is to prevent acute radiation sickness resulting from the accidental release of radioactive material. In addition to this primary objective, emergency protective measures are designed to minimise the prevalence of long-term, genetic radiation damage.

Protective measures intended for the public are based on the Dose-Measures Concept defined in the Ordinance on the Federal Civil Protection Crisis Management Board. This Concept describes the protective measures to be considered (see Table 4: Intervention levels).

In addition, the Ordinance on Maximum Levels for Contaminants contains limit levels for foodstuffs. The limits correspond to a large extent to the maximum levels set in EU legislation.

The protective measures applied during the cloud phase must be planned so that they can be implemented as a preventive measure in the initial phase of an accident. During the cloud phase, primary measures include sheltering, taking iodine tablets and possibly evacuation before any release. They reflect the following:

- The solid construction of houses in Switzerland and the obligation by the Civil Protection Act to provide shelters for the entire population of Switzerland mean that in most cases sufficient protection is provided against radioactive cloud shine in the cloud phase of an accident by sheltering in houses, cellars or shelters. This is therefore considered to be the most important protective action. In order to prevent infiltration of radioactive material, windows and outside doors should be closed and air-conditioning systems turned off.

Table 4: *Intervention levels*

Protective measures	Dose	Dose intervention level	Integration time
Children, adolescents and pregnant women to remain indoors	Effective dose from external radiation and inhalation (outdoors)	1 mSV	2 days
Seeking shelter, (house, cellar shelter)	Effective dose from external radiation and inhalation (outdoors)	10 mSV	2 days
Precautionary evacuation or sheltering	Effective dose from external radiation and inhalation (outdoors)	100 mSV	2 days
Taking iodine tablets	Thyroidal dose from inhalation of radioactive iodine	50 mSV	2 days
Harvesting and grazing ban	Ordered as a precaution where any of the above measures is ordered as well as for areas downwind of the plant	-	

- Iodine tablets are distributed to all houses, schools and businesses within a radius of around 50 km around the NPPs. The recent extension of the radius from 20 to 50 km for iodine pre-distribution was the result of work by IDA NOMEX. Outside this 50 km radius, tablets are stored by the cantons so that they are available to the public within 12 hours.
- Under the emergency protection concept in case of a nuclear power plant accident, preparations must be made for precautionary evacuation of zone 1 and affected parts of zone 2. Such precautionary evacuations of zone 1 or parts of zone 2 will be ordered by the Federal Council. A basic document containing standard requirements for planning large-scale precautionary evacuations was

issued by the FOCP. Evacuation during the initial phase of an accident will be considered provided that no release of radioactive material is expected during the evacuation period.

Protective actions during the ground phase are based on the actual radiological situation in the environment as indicated by measurement data. Important protective measures include remaining indoors, evacuation after cloud passage, restricted access to certain areas, restrictions on certain foodstuffs, countermeasures relating to agriculture, decontamination and medical support. Under the updated Emergency Preparedness Ordinance, cantons outside zones 1 and 2 have been assigned new duties relating to preparedness and response.

Alert procedures

If an accident occurs, the NPP is required to inform the Inspectorate and the NEOC immediately. If the accident poses a threat to the public and the environment, this triggers a three-stage alerting and alarming procedure. To be effective, measures to protect the public should be taken before any radioactivity is released from the plant. Therefore, the alerting and alarming criteria are based primarily on the situation in the NPP.

- An **alert** is issued at the latest when a high dose rate is detected by monitoring inside the containment. The alert (by a dedicated electronic system) puts federal, cantonal and municipal organisations (within Switzerland) on standby for a possible subsequent alarm. The NEOC informs the IAEA and authorities in neighbouring countries. It also activates the hotline operated by a professional medical call centre.
- The first **alarm** is by siren (along with radio messages broadcast to the public) if an accident develops in such a way that it might lead to a dangerously high release of radioactive materials into the environment. This alarm ensures that the population group at risk is aware of the emergency, so that it can prepare to take protective actions. Instructions are given over the radio. In 2019, in addition to annual testing of the sirens, alarms were also sent to mobile phones via push notification (AlertSwiss App) for testing purposes.
- Further **alarms** by sirens are issued as required to give the public advice on taking iodine tablets, staying indoors, using shelters, etc.

There are special regulations for initiating protective actions in the event of rapidly-evolving accidents. If the annual limit for the release of noble gases is likely to be released in less than 1 hour, which would result in a dose in the immediate vicinity of a plant of about 1 mSv, sirens will alert members of the public located in Emergency Planning Zone 1. The public will be advised to stay indoors for the next few hours. The NPP initiates the action and the cantonal police (responsible for protective actions in Emergency Planning Zone 1) initiate the alert without waiting for an order from the NEOC.

Emergency exercises

Each Swiss NPP conducts an annual emergency exercise observed by the regulatory body. The outcomes of an exercise may lead to new measures to improve how the emergency organisation operates. Such measures are incorporated in training programmes for members of the emergency organisation. According to the Inspectorate's guideline ENSI-B11, each plant's annual emergency exercise takes place in the presence of several representatives of the Inspectorate. This guideline also allows the Inspectorate to require staff emergency exercises lasting up to 24 hours in order to check that Severe Accident Management procedures and organisational measures are adequate, especially for long-term events. A full-scale emergency exercise is conducted every two years. Regular participants of the full-scale exercise include at least one NPP, ENSI, NEOC, the Federal Civil Protection Crisis Management Board, FOPC, the Department of Defence and the canton in which the NPP is located as well as emergency organisations from the surrounding countries.

Clause 2: Each Contracting Party shall take the appropriate steps to ensure that, insofar as they are likely to be affected by a radiological emergency, its own population and the competent authorities of the States in the vicinity of the nuclear installation are provided with appropriate information for emergency planning and response.

The cantonal authorities have issued leaflets to all individuals living in the vicinity of Swiss NPPs describing the potential dangers associated with a nuclear accident. The leaflet also explains existing protective actions to cope with the consequences of such an accident. The procedure for alerting and issuing the alarm to the population in case of accidents is described in Clause 1 of this Article.

Switzerland is party to the Convention on Early Notification and the Convention on Assistance. Switzerland has bilateral agreements covering notification and information exchange in case of a nuclear accident with its neighbours. Although Switzerland is not a member of the European Union, it is part of the European Community Urgent Radiological Information Exchange Network ECURIE. The NEOC is responsible for the notification process and for providing the necessary information. Switzerland also participates in the INES reporting network and has undertaken to report all events rated as Level 2 or higher. If an incident occurs in an NPP, reporting is the responsibility of the Inspectorate. The FOPH is responsible for other radiological incidents.

Since Leibstadt and Beznau NPPs are close to the national border, special plans have been agreed with Germany. These plans are designed to ensure the same level of protection on both sides of the border for the public and the environment. They also seek to harmonise procedures. Dedicated telephone lines have been set up for communication between the authorities. Plans and procedures are updated regularly by bilateral working groups as part of the German-Swiss Commission for the Safety of Nuclear Installations (see Article 17, Clause 4).

Similarly, an expert group on nuclear emergency matters has been set up for France. A yearly exchange of information takes place with Austria. An exchange of information with Italy also takes place on an annual basis. The canton of Geneva has also been represented as part of the «Commission locale d'information» at the Bugey NPP since spring 2016.

Emergency plans are not only tested at national level. German authorities at both local and federal level take part in exercises at the Leibstadt and Beznau NPPs. Switzerland participates in exercises at the French Fessenheim and Bugey NPPs, which are located about 30 km and 70 km from the Swiss border respectively.

Switzerland's preparedness and its response at international level are regularly verified by participating in international exercises conducted by the IAEA or ECURIE. The OECD/NEA INEX exercises are another opportunity to verify certain aspects of emergency management. Switzerland usually participates in these exercises.

Emergency plans and procedures must be regularly improved and adapted to reflect new challenges and changing situations. Experts from several Swiss authorities take an active part in these activities. Switzerland is also a member of HERCA and WENRA working groups on emergency preparedness.

Finally, in order to improve the emergency response system at national and international level, members of the Inspectorate and the NEOC actively support the activities of the OECD/NEA working party on Nuclear Emergency Matters.

Clause 3: Contracting Parties which do not have a nuclear installation on their territory, insofar as they are likely to be affected in the event of a radiological emergency at a nuclear installation in the vicinity, shall take the appropriate steps for the preparation and testing of emergency plans for their territory that cover the activities to be carried out in the event of such an emergency.

This Clause does not apply to Switzerland.

Developments and Conclusions

Since the seventh Swiss report and following the work carried out by IDA NOMEX, several ordinances relating to emergency preparedness are in the process of being revised or have already been revised. The same applies to different concepts relating to emergency preparedness and response in Switzerland. The Emergency Preparedness Ordinance, the Ordinance on the Organisation of Operations in Connection with NBC and Natural Events (now Ordinance on the Federal Civil Protection Crisis Management Board) and the Radiological Protection Ordinance have been updated. The Dose Measures Concept is about to be revised. The lessons learned from the Fukushima accident have led to numerous activities with the aim of improving preparedness and response capabilities both on and off-site. The follow-up to and completion of these activities are still ongoing.
Switzerland complies with the obligations of Article 16.

Article 17 – Siting

Clause 1: Each Contracting Party shall take the appropriate steps to ensure that appropriate procedures are established and implemented for evaluating all relevant site-related factors likely to affect the safety of a nuclear installation for its projected lifetime.

Under the NEA and the NEO, a general licence for a nuclear installation can only be granted if the site is suitable. The procedures for granting a general licence and the associated requirements are discussed in the section on Article 7. The granting of general licences for the construction of new NPPs is prohibited according to the revised NEA which has been in force since January 2018.

The NEA contains a list of conditions governing the issue of a general licence. The first two stipulate that humans and the environment shall be protected and that the granting of a licence does not conflict with other provisions of federal legislation, in particular legislation on environmental protection, preservation of the local natural and cultural heritage and the development plan for the area.

The NEO contains requirements relating to measures designed to prevent accidents initiated either inside or outside the installations. According to the NEO, the following documents shall be submitted with the application for a general licence:

- safety analysis report;
- security report;
- environmental impact report;
- report on compliance with spatial planning requirements;
- concept for decommissioning, or for the monitoring period and closure;
- feasibility demonstration for management and disposal of resulting radioactive waste.

Assessment of external hazards is an integral part of the site evaluation process. Specific requirements are set out in the Ordinance on Hazard Assumptions and Evaluation of Protection Measures against Accidents in Nuclear Installations and include earthquakes, flooding, aircraft crashes, extreme weather conditions (winds, tornados, etc.), lightning, shock waves and fire. The Safety Analysis Report (SAR) must incorporate all relevant factors relating to the site (natural characteristics and human activities), and in particular:

- geology, seismology, hydrology (including flooding and groundwater) and meteorology;
- population distribution, neighbouring industrial plants and installations;
- anticipated exposure to radiation in the vicinity of the installations;
- traffic infrastructure (road, rail, air, water) and transport.

During the licensing procedure, the Inspectorate evaluates the site-related factors likely to affect the safety of a nuclear installation and produces a Safety Evaluation Report (SER) in which additional plant design requirements are defined, if deemed necessary.

The results of the hazard analysis are also incorporated into the PSA for existing NPPs, which is regularly updated (for additional information, see Article 14).

Safety assessments shall be updated whenever relevant new findings or experience is available. For example, relevant safety factors shall be re-evaluated whenever there are plans to build a relevant new facility (e.g. gas pipeline or industrial building) in the vicinity of an NPP.

Site-related factors are re-evaluated every ten years as part of the PSR. In particular, the safety analysis report (including the deterministic safety analysis) and the PSA are updated by the licensee and reviewed by the Inspectorate.

Clause 2: Each Contracting Party shall take the appropriate steps to ensure that appropriate procedures are established and implemented for evaluating the likely safety impact of a proposed nuclear installation on individuals, society and the environment.
As outlined under Clause 1, appropriate steps are implemented in the regulations to ensure appropriate procedures. Switzerland is a small and densely populated country. The concept of safety by distance encounters natural limitations in Switzerland. In 2011, the government decided to phase out the use of nuclear power in Switzerland. According to Art. 12a of the NEA, the granting of general licenses for the construction of nuclear power plants is prohibited.

Clause 3: Each Contracting Party shall take the appropriate steps to ensure that appropriate procedures are established and implemented for re-evaluating as necessary all relevant factors referred to in subparagraphs (1) and (2) so as to ensure the continued safety acceptability of the nuclear installation.
Since the reporting procedures that apply to power plants include the relevant site factors, any modifications to these factors are known (e.g. construction of a new industrial plant in the vicinity of the NPP). If the licensee notifies such modifications, they will include an assessment of their possible consequences. Site-related factors are re-evaluated as part of the PSR. In particular, the SAR (including the deterministic safety analysis) and the PSA are updated by the licensee and reviewed by the Inspectorate. In essence, the re-evaluation processes help to ensure the continued safety acceptability of the NPP as they confirm the validity of earlier assessments or indicate the impact of changes to site-specific safety factors. The applicability and effectiveness of the Inspectorate's re-evaluation process are illustrated by probabilistic reassessments of the hazards posed by earthquakes, external flooding and extreme weather conditions.

Earthquakes

The large-scale PEGASOS project – a German acronym for «Probabilistic Seismic Hazard Analysis for Swiss Nuclear Power Plant Sites» – was carried out by the Swiss licensees between 2001 and 2004 in response to a requirement that originated from the Inspectorate's PSA review process. In 2008, the Swiss licensees launched the PEGASOS Refinement Project (PRP) with the aim of reducing the uncertainty range of the PEGASOS results. As with the PEGASOS project, the PRP primarily sought to characterise seismic sources, ground motion attenuation on rock and the local soil response at the NPP sites. The PRP took advantage of substantial scientific and technical advancements achieved after completion of the PEGASOS project, in particular internationally developed ground motion attenuation equations and new soil investigations at the Swiss NPP sites
In order to ensure a thorough quantification of the uncertainty of seismic hazard estimates, the PEGASOS and PRP projects were designed according to the Senior Seismic Hazard Analysis Committee (SSHAC) Level 4 methodology. The projects involved technical experts, scientific institutions and engineering organisations from several European countries and the USA and made use of an extensive expert elicitation process. The participatory peer review, which is a strongly recommended part of the SSHAC Level 4 approach, was carried out in both projects by the Inspectorate with the help of an experienced team of contracted experts.
The PRP summary report was submitted to the Inspectorate at the end of 2013. In comparison with the PEGASOS project, the level of the computed seismic hazard and the spread of the hazard results turned out to be generally smaller. A breakdown (disaggregation) of the seismic hazard results into partial contributions confirmed the findings of the PEGASOS project, according to which nearby earthquakes with relatively low magnitudes between 5 and 6 have higher hazard contributions than stronger and more distant earthquakes.
In its final review report on PRP, the Inspectorate acknowledged that the project represented a further improvement to the state of the art in probabilistic seismic hazard assessment. The Inspectorate

assessed the refinements achieved in the project's focal points – «ground motion characterisation» (sub-project 2) and «site response characterisation» (sub-project 3) – as well-founded. In contrast, «seismic source characterisation» (sub-project 1) was not investigated in sufficient detail according to the Inspectorate. After it became evident late in the project that the model modifications in sub-project 1 had a significant influence on the computed seismic hazard, the experts did not have any further opportunity to question or confirm their assessments. «Seismic hazard computation» (sub-project 4) was performed in an appropriate manner and the software used complied with the accepted specification. Nevertheless, due to the concerns regarding sub-project 1, the Inspectorate was unable to accept the final results of the PRP.

Due to its reservations concerning PRP sub-project 1, the Inspectorate initiated a sensitivity analysis in which the model for sub-project 1 was replaced by the corresponding model from the Swiss Seismological Service (SED). The results of this combined SED-PRP model were found to be higher than the results of both the PRP and the SED model. In May 2016, the Inspectorate decided that the results of the SED-PRP model should be used, referred to as ENSI-2015 seismic hazard assumptions (known in German as «Erdbebengefährdungsannahmen ENSI-2015»). At the same time, as requested by Swiss regulations in the event of a change in the hazard results, the Inspectorate asked the licensees to assess the consequences on NPP safety and, in particular, on risk (for additional information, see Article 14).

External Flooding

When designing nuclear power plants, protection against flooding was originally determined based on dam and/or weir breach scenarios or on a 1000-year flood. In 2008, the flooding hazards for three sites were reassessed as part of general licence applications for new nuclear power plants, which were intended to be built at existing sites. The new flooding hazards were derived either by considering a 10 000-year flood or, in one case, an extreme flood scenario that actually gives rise to a higher discharge than the 10 000-year flood. The discharge values for 10 000-year floods were calculated by extrapolating river discharge data based on historical flood records, where appropriate. The flood levels were computed using a 2-D model for the flooding scenarios, including a detailed orographic representation. After the severe accident at Fukushima, the Inspectorate ordered the new results to be applied to safety assessments for existing NPPs. In addition, to ensure that the flood risk is evaluated comprehensively, the Inspectorate required the licensees to analyse the effects of total debris blockage of bridges or hydraulic installations near the sites. The licensees' analyses, based on two-dimensional flooding simulations and incorporating sediment transport and appropriate particle size distribution, indicate that total debris blockage does not cause cliff-edge effects for the plants.

A comprehensive reassessment of the external flood hazard was initiated, led by the Federal Office for the Environment along with other regulatory bodies, including ENSI. The Aare river (affecting three of the four NPP sites) will be considered in the first phase. The EXAR project (EXAR being a German acronym standing for «Extremhochwasser an Aare und Rhein») will establish a common base for flood hazard assessment for various regulatory bodies. A Probabilistic Flood Hazard Analysis (PFHA) methodology was developed in order to also assess extremely rare events (with exceedance frequencies even lower than 1E-4/yr).

Extreme weather conditions

For the purpose of designing the plants, the hazard assumptions were defined on the basis of rules and standards that were valid at the time of construction.

During the EU stress test, the Inspectorate identified the need for a re-evaluation of the existing hazard assumptions concerning extreme weather conditions and the associated proof of adequate protection in order to determine whether these elements were up-to-date.

The requirements for re-evaluation of the probabilistic hazard analyses concerning extreme weather conditions were defined in 2012. The probabilistic hazard analyses and proof of adequate protection against extreme weather conditions were submitted to the Inspectorate in 2014. The hazard analyses were reviewed by the Inspectorate in 2015. As a result of the Inspectorate's review, the Swiss NPPs were required to update their hazard analyses. Some provisional hazard values were defined to be used to prove adequate protection. In the meantime, all Swiss NPPs have submitted their updated hazard analyses, which are currently being reviewed by the Inspectorate.

Clause 4: Each Contracting Party shall take the appropriate steps to ensure that appropriate procedures are established and implemented for consulting Contracting Parties in the vicinity of a proposed nuclear installation, insofar as they are likely to be affected by that installation and, upon request providing the necessary information to such Contracting Parties, in order to enable them to evaluate and make their own assessment of the likely safety impact on their own territory of the nuclear installation.

Switzerland has signed agreements on the exchange of information with Austria, France, Germany and Italy. The German-Swiss Commission for the Safety of Nuclear Installations, including its working groups, the Franco-Swiss Nuclear Safety Commission and the Italian-Swiss Commission for cooperation in Nuclear Safety meet annually to consult and exchange information and experience. They also define the terms of reference for individual working groups, e.g. exchange of operational experience, emergency protection planning and exercises, radiation protection, ageing surveillance and waste disposal. In addition, representatives from Austria and Switzerland meet annually to share information on nuclear programmes, operational experience in nuclear installations and the legislative framework for nuclear safety and radiation protection.

Developments and Conclusion

The comments on Clause 3 provide an update on reassessment of the hazards posed by earthquakes, external flooding and extreme weather conditions.

Switzerland complies with the obligations of Article 17.

Article 18 – Design and construction

Clause 1: Each Contracting Party shall take the appropriate steps to ensure that the design and construction of a nuclear installation provides for several reliable levels and methods of protection (defence in depth) against the release of radioactive materials, with a view to preventing the occurrence of accidents and to mitigating their radiological consequences should they occur.

The design and construction of Swiss NPPs are based on US standards (Beznau I and II, Mühleberg, Leibstadt) and German standards (Gösgen) that applied at the time of construction. The standards used are still international and incorporate the principle of defence in depth. The various levels of defence ensure that the NPPs remain within safety limits in the event of a design basis accident and that individual dose limits for the public are not exceeded. In addition, systems, equipment and procedures exist to prevent or mitigate the release of radioactive materials into the environment in the event of a severe accident. Severe Accident Management Guidance (regarded as an element of defence in depth) exists in all Swiss NPPs (see Article 16).

The design and construction of Swiss NPPs were thoroughly assessed as part of the **licensing procedure.** The results of this assessment form part of the SER and play an important role in licensing decisions (see Articles 7 and 14). In compliance with IAEA Safety Standard NS-R-1, Switzerland included design requirements regarding redundancy, diversity, physical and functional separation, automation and other fundamental design principles in Article 10 of the NEO and the Inspectorate's guideline R-101.

After a licence has been granted, the design and construction of existing NPPs are reassessed periodically. An in-depth review comparing the actual design and the current state of science and technology is performed at least every 10 years (PSR, see Article 14).

It is also important to note that Art. 22 of the NEA requires the licence holder of a nuclear power plant to backfit the plant according to the «state of the art of backfitting technology», and beyond, in taking into account whether it is appropriate to implement further measures if these measures allow for further risk reduction.

The **first generation** of Swiss NPPs **(Beznau I, II and Mühleberg)** were constructed using designs from the late 1960s. Beznau NPP consists of two identical units of a Westinghouse 2-loop PWR type with a net electrical output of 365 MW each. Mühleberg NPP is a General Electric BWR/4 type with a net electrical output of 373 MW. They were constructed before the general design criteria (GDC) were established by the former US Atomic Energy Commission in 1972. Comparing the design of first-generation NPPs and the requirements of the GDC revealed that the main design criteria had been recognised and incorporated in the design. These NPPs included several unique design features that were not standard at the time of construction:

- Double containment (free-standing leak-tight steel plus concrete outer shell);
- Load rejection and turbine trip without scram;
- Continuous emergency power supply from a nearby hydroelectric plant;
- Groundwater as emergency feedwater system (Beznau NPP);
- Containment size doubled in relation to reactor power (Mühleberg NPP);
- Hilltop reservoir to flood the core (Mühleberg NPP);
- Outer torus (Mühleberg NPP).

However, a review of the design by the Inspectorate concluded that protection against external events of natural origin, especially earthquakes and flooding, and against man-made external events, e.g. aircraft crash, explosion or intrusion, was not sufficient. A lack of separation of safety-relevant systems was also revealed.

The Inspectorate therefore required backfitting of bunkered special emergency shutdown and residual heat removal systems. The systems had to be redundant and independent from the «normal» or conventional safety systems, including a diverse ultimate heat sink and an independent special emergency power supply, and protected against external events and third-party intervention (SUSAN, NANO, see Article 6). The special emergency buildings include a bunkered emergency control room from which safe shutdown of the plant and residual heat removal can be monitored and controlled. The systems are designed to operate automatically in a special emergency situation, without any operator action required during the first 10 hours after initiation. Backfitting of bunkered special emergency systems was an important measure to strengthen the safety provisions against design basis accidents, as well as beyond design basis accidents.

In this context, another important safety improvement at Beznau NPP was the REQUA seismic requalification programme, which was carried out until 1992 to strengthen the seismic resistance of the plant's vital equipment. Furthermore, in 1989, the existing pressuriser relief valves at Beznau NPP were replaced by pilot-operated pressuriser safety/relief and isolation valves of the SEBIM type. These valves allow primary pressure relief and also enable a feed and bleed operation to be implemented.

In the early nineties, as part of the «Measures against Severe Accidents» developed by the Inspectorate after Chernobyl, hardened filtered containment venting systems were backfitted at Beznau (SIDRENT, 1992) and Mühleberg NPPs (CDS, 1992), allowing active or passive venting of the containment in the case of severe accidents. Also, the Mühleberg NPP containment atmosphere was inertised with nitrogen as early as 1988 to prevent the formation of ignitable gas mixtures. Different means for alternative core cooling and alternative containment cooling were also backfitted in both NPPs. For example, at Mühleberg NPP, a drywell spray system was installed in 1992, to allow the containment to be flooded. In 1999, backfitting of an emergency feedwater system, in addition to the existing auxiliary feedwater system, was completed in Beznau NPP Unit 2. The system is located in a bunkered building which is protected against external hazards. The emergency feedwater system for Unit 1, located in the same building, has been operational since 2000. The feedwater supply to the steam generators is backed up by a third system – the special emergency feedwater system, which is integrated in the bunkered NANO system. The overall feedwater supply system at Beznau NPP is very reliable because of the high degree of redundancy und diversity.

Further measures for improving safety were completed in 2015. In Beznau NPP Unit 2, the hydroelectric emergency power supply was replaced by an additional state-of-the-art, seismically robust emergency diesel generator system. The new emergency diesel generators are air cooled so that they are independent from any cooling water supply. This backfitting project, which was already under way before the Fukushima events, was completed in 2018 (Unit 1). An additional bunkered seal water injection pump and a secured long-term water supply for the emergency feedwater system are also being backfitted as part of this project. The Inspectorate also reviewed Beznau NPP in the light of LTO, as Unit 1 and Unit 2 have been in operation for more than 43 years and 41 years respectively. No further major backfitting measures were identified.

After Fukushima, protection of the Swiss NPPs and their spent fuel pools (SFP) against external events had to be reassessed by the licence holders (see Article 14). Furthermore, the Inspectorate ordered all licence holders to immediately implement two physically separate lines/connections for feeding the SFPs from outside the buildings as an accident management measure, and to backfit the SFPs with qualified accident-proof level and temperature instrumentation with these parameters also being displayed in the main control room as well as in the bunkered emergency control rooms. At Beznau and Mühleberg NPPs, the Inspectorate ordered backfitting of new redundant SFP cooling systems because the existing systems were not qualified as safety systems. The installation of two physically separate lines for feeding the SFP was completed at Mühleberg NPP in 2012 and at Beznau NPP in 2014.

As a result of the reviews regarding earthquake resistance, Beznau NPP was required to improve the earthquake resistance of the SFP storage building, and it installed a venting duct to remove heat and pressure generated by boiling SFP water to protect the building structure in case of beyond design basis accidents. This backfitting project was completed in 2017. The earthquake analyses for the Mühleberg NPP confirmed that the seismic protection measures are adequate, and no additional measures were required.

As a consequence of the flooding analyses, the intake structure of the SUSAN special emergency system at Mühleberg NPP was enhanced to prevent blocking by bedload, sediment and debris transport by the Aare River. This was performed back in 2011, together with the provision of mobile floodwalls. Nevertheless, the cooling water supply for safety and special emergency systems at Mühleberg NPP still relied solely on the Aare River, using diverse intake structures. In the meantime, a diverse cooling water supply, independent of the Aare River, has been constructed. The flooding analyses for Beznau NPP confirmed that flood protection measures are adequate, and no additional measures are required.

The Mühleberg NPP has been operating for more than 40 years. In order to assess the requirements for potential LTO, in 2012 the Inspectorate conducted a thorough safety review of the documents provided by the licence holder as part of the 2010 PSR. Besides the required backfitting measures identified in the Fukushima reassessment process as mentioned above, the Inspectorate addressed deficiencies in the spatial separation of safety systems on the lower floor of the reactor building and improvements with a view to stabilising the core shroud, which is affected by cracks. In 2012, the licence holder planned a backfitting project for LTO including a cooling water supply from a protected well, a qualified redundant SFP cooling system and an additional independent safety injection and residual heat removal system installed in a new building. In 2013, the licence holder decided to end operation in 2019 for entrepreneurial reasons and cancelled the planned LTO backfitting programme. The Inspectorate issued a formal order to establish binding conditions for operation until 2019, requesting that alternative measures be implemented. On this basis, in 2014 the licence holder submitted an alternative backfitting programme, which was evaluated by the Inspectorate. The following main backfitting measures have been installed:

- In 2015, the licence holder finished installing the new emergency system to feed cooling water from a groundwater well to the hilltop reservoir and into the special emergency cooling water system. The backfitting measure also included hose connectors inside the bunkered SUSAN building to ensure an additional cooling water supply for accident management purposes with mobile pumps.
- A new emergency cooling system for the spent fuel pool was installed in 2016. A water supply is guaranteed from the bunkered cooling water system and from the hilltop reservoir. In 2020, the emergency cooling system for the spent fuel pool will be converted into a safety system.
- In 2015, Mühleberg NPP completed backfitting measures to reduce the internal flooding hazard by installing bypass lines with a flow limiter, check valves and orifices into the piping of the RCIC system, the CRD system, the auxiliary condensate system, and the firewater system.
- In 2016, an additional earthquake and flood-resistant single-line emergency water injection system into the reactor pressure vessel was installed. The system is located in a new building which is separated from other safety systems.

In October 2012, an IAEA OSART mission to Mühleberg NPP took place. The review team acknowledged the fast and thorough response to recent significant external operating experience events, including important plant modifications (see Article 19).

In conclusion, all first-generation NPPs have completed or are completing a comprehensive analysis and backfitting programme, and substantial improvements have been made. The results of the EU stress tests on these NPPs confirm this statement.

The Inspectorate monitors activities relating to backfitting measures and plant modifications very closely. The projects and modifications are subject to a four-step procedure, consisting of the concept, the detailed design, installation and commissioning of the systems. The Inspectorate grants permissions for every step of the procedure after thorough examination to ensure that they are appropriate and to ensure compliance with national and international safety requirements.

The **second-generation** NPPs in Switzerland, Gösgen NPP, 1979, and Leibstadt NPP, 1984, were based on German and US design criteria respectively. The bunkered special emergency shutdown and heat removal systems, which provide a very high degree of protection against external events and diversity to the conventional safety systems, including a diversified ultimate heat sink, were integrated in the design from the beginning, which meant that the US design of Leibstadt NPP had to be adapted to the specific Swiss requirements regarding special emergency systems.

The safety status of **Gösgen NPP,** a Siemens/KWU PWR with a gross electrical output of 1035 MW, has been continuously enhanced since it was commissioned. In 1993, a filtered containment venting system was installed, allowing passive or active venting of the containment in the case of beyond design basis accidents.

In 1999, the reliability of SFP cooling was enhanced by installing an additional independent train to the existing redundant trains for SFP cooling.

The structures of several buildings were reinforced with effect from 2001 to improve seismic resistance. Provisions for carrying out primary pressure relief, i.e. installing three pilot-operated pressuriser safety/relief valves, were implemented in 2005. These valves make it possible to carry out primary pressure relief and also a feed and bleed operation in beyond design accident conditions.

During outages in 2006 and 2007, the existing containment sump suction strainers were replaced by new strainers of a filter cartridge type, enlarging the suction area from 10 m^2 to about 110 m^2.

An aircraft crash and flood-proof, earthquake-resistant building for wet storage of spent fuel was commissioned in 2008. The fuel elements are cooled by a completely passive system, i.e. no electrical power or cooling water supply is required to maintain the fuel in a safe state.

The original design of **Leibstadt NPP,** GE BWR/6-238 Mark III, was supplemented by the SEHR special emergency heat removal system to provide increased protection against external hazards, using groundwater from a protected well as an ultimate heat sink.

Several backfitting measures have been realised over the course of time. The alternate rod insertion system (ARI) was introduced in 1988, which provides redundancy and diversity to the existing SCRAM system, significantly reducing the risk of anticipated transients without SCRAM. A redundant safety parameter display system was introduced in the same year.

After the Barsebäck incident in 1992, the existing suction strainers in the emergency cooling systems (measuring 2 m^2) were replaced with strainers measuring 15 m^2. This took place in 1993, as well as backfitting the hardened filtered containment venting system which permits active venting by opening a valve or passive venting via a rupture disc.

Ventilation of the main control room (MCR) was improved in 1996 to ensure that the MCR remains habitable in the event of accidents with a release of radioactive material. The special emergency control room displays were extended by adding neutron flux, important containment data, and stack release parameters to the existing displays. Further enhancements were carried out to improve operational safety and availability.

After Fukushima, reviews of the seismic and flood resistance of the Gösgen and Leibstadt NPPs for the case of a 10 000-year earthquake showed compliance with the current licensing basis, and demonstrated that the fundamental safety functions are ensured (see Article 14). Nevertheless, the safety of Gösgen NPP was further enhanced by several improvements to protection against flooding and earthquakes. The seismic robustness of specific important safety equipment is continuously being improved (especially cable trays and control cabinets). Furthermore, in 2015 the license holder of Gösgen NPP decided to enhance the existing bunkered special emergency shutdown and heat removal system. The aim of the project is to ensure core cooling even in the case of very high peak ground accelerations up to 0.6 g. In addition to the existing protected low-pressure residual heat removal system, new redundant high-pressure coolant injection pumps are to be provided to cover a potential loss of primary cooling water triggered by a very strong earthquake. Other measures as part of this project ensure residual heat removal from the core and spent fuel pool for at least 72 h, including an extended DC power supply. The construction work for the new special emergency feedwater storage tanks at Gösgen NPP started in 2018. These two enlarged storage tanks, which are protected against aircraft crash and other extreme hazards, ensure residual heat removal from the steam generators for an extended period of time. In 2018, a seismic shutdown system was installed at Gösgen NPP. The system is intended to shut down the reactor very quickly in the case of very small peak ground accelerations (0.02 g), thus allowing safe reactor shutdown before higher accelerations impact the core internals.

The assumption of a 10 000-year flood as a new design specification led to several improvements at Gösgen NPP, including the introduction of an automatic advance flood warning system, specification of organisational and administrative measures in emergency procedures, additional sealing for building shells, air inlets and doors, as well as the provision of mobile flood walls to ensure access to important buildings. In 2015, measures to protect against external floods were further enhanced by installing a flood protection wall. No additional enhancements were required for Leibstadt NPP, as the site is flood-proof.

The seismic robustness of the filtered containment venting system (FCVS) was also assessed and revealed that the systems in all Swiss NPPs were sufficiently robust. Nevertheless, Leibstadt NPP is strengthening the existing FCVS in order to increase the existing margins. Gösgen NPP enhanced the existing FCVS in 2018 with an additional filter device, with the aim of reducing the release of organic iodine after severe accidents. In 2014, all plants conducted a re-evaluation of the hydrogen hazard. Passive autocatalytic recombiners (PAR) are already being installed or have been installed in two plants, which means that all Swiss NPPs will have passive measures (inertisation or PAR) to prevent hydrogen combustion.

SFP cooling and SFP instrumentation measures – providing two physically separate lines/connections feeding the SFPs from outside the buildings as an accident management measure, and backfitting the SFPs with qualified accident-proof level and temperature instrumentation with indication of these parameters in the main control room as well as in the bunkered emergency control rooms – have been implemented in Gösgen NPP (2012) and in Leibstadt NPP (2014).

After Fukushima, the Inspectorate conducted several inspections to assess the situation in Swiss NPPs with regard to issues resulting from the accident management actions taken at Fukushima. The Inspectorate verified the design, operability and suitability of the filtered containment venting systems, taking into account possible adverse conditions, e.g. loss of motive power of the valves to be opened, or challenging radiological conditions. They checked that the venting valves can be opened in the case of loss of power by providing nitrogen accumulators that are stored on the spot, or by passive actuation by a rupture disk with defined opening pressure. The condition of the venting filters was also inspected. The suitability and habitability of emergency operations centres was checked in another inspection.

The Inspectorate also carried out inspections to review the ability of Swiss NPPs to cope with a long-lasting SBO. Despite the fact that there are five redundant and diverse safety layers for electrical power supply, additional measures were taken to rule out a potential SBO. Each plant developed an SBO strategy and is sufficiently prepared to cope with an extended SBO of seven days by means of accident management measures, including the provision of nozzles to supply steam generators via mobile pumps or fire trucks, mobile diesel generators, manual means of opening valves, provision of sufficient fuel and lubricants for extended operation, and revision of severe accident management guidelines for SBO.

While the safety assessments performed after Fukushima demonstrated that the existing safety margins are adequate, the Inspectorate decided in 2013 to further strengthen the safety of Swiss NPPs by increasing the safety margins in the case of beyond design basis accidents. Based on the results of probabilistic and deterministic analyses, the objective was to identify areas where backfitting could make an effective contribution to further reducing the hazard, taking into account the principle of adequacy. Accordingly, the licensees carried out the required analyses in 2014. As a result of these investigations, improvements were made to flood protection of the special emergency buildings in Beznau NPP and Mühleberg NPP and the seismic robustness of sensitive components in Gösgen NPP and Mühleberg NPP.

In 2013, the Inspectorate ordered the licensees to conduct studies relating to extreme weather conditions. The Inspectorate defined the requirements for the probabilistic hazard analyses and the safety cases to be applied to demonstrate that the plants are adequately protected against extreme weather conditions. They were required to consider a return period of 10 000 years for extreme weather conditions. More information about this item, and on the earthquake analyses, is given in Article 14.

Electrical systems

The design of electrical systems and components in Swiss NPPs is mainly based on the standards set by the Institute of Electrical and Electronics Engineers (IEEE) or by the Nuclear Safety Standards Commission (KTA) and by the requirements of IAEA NS-R-1. These standards and requirements were also used as a basis for the Inspectorate's respective guidelines. Depending on the safety significance of such equipment, safety class 1E or 0E is applied. Classification 1E is generally applied to all electrical systems forming part of the emergency power supply in the NPP and to the special emergency electrical supply, as well as to electrical components of the safety systems. For equipment classified as 1E, proof of qualification must be available for all components involved in safety functions. This means that the design basis range of the components for ambient conditions is proven for normal operation as well as under adverse conditions such as pressure, humidity, and radiation in the case of an accident. In addition, the components have to withstand earthquake loads in the event of a safe shutdown earthquake (SSE) at the location where they are installed, and the installation locations of such components must be above or protected against the design basis flood levels. Electrical equipment classified as 0E is of lower safety significance. Such equipment is not subject to the qualification criteria applied for 1E equipment, and its seismic resistance is limited to the operating basis earthquake (OBE).

The independence criteria for class 1E equipment and circuits, and the criteria for independence of electrical safety systems, which are defined by IEEE and Reg. Guide 1.75, are also part of the design. KTA 3503, which sets the standards for type testing of electrical modules in the safety instrumentation and control system, is also an accepted and applied standard.

Regarding the importance for safety of a reliable and diversified electrical power supply for NPPs with a view to preventing an SBO, it should be noted that the Swiss NPPs have enhanced protection against the loss of electrical power. In addition to the emergency power supply, which is usually provided by diesel generators, an independent special emergency power supply from dedicated special emergency power diesel generators, which are protected against external events, is also in place. These supplies, which ensure operation of the systems required for safety purposes, can be operated autonomously for several days (exclusively using equipment stored at the NPP site).

The special emergency diesel generators constitute an important «safety layer» of the electrical power supply, but are only one aspect of the provisions in place. The design of the electrical power supply installation complies with the «defence in depth» principle and incorporates several levels of protection, which are referred to in this section as safety layers of the electrical energy supply.

The following safety layers are in place:

- First Safety Layer: external main grid that the generator feeds into
- Second Safety Layer: auxiliary power supply in island mode in case of failure of the main grid
- Third Safety Layer: external reserve grid in case of failure of the external main grid and the auxiliary power supply
- Fourth Safety Layer: emergency electrical power supply from an emergency diesel generator or hydroelectric power plants (HPP) in case of failure of the first three safety layers for supply of conventional safety systems

- Fifth Safety Layer: special emergency electrical power supply from special emergency diesel generators to supply the special emergency systems
- Sixth Safety Layer: local accident management (AM) equipment, such as mobile emergency power units and possible connections to nearby hydroelectric power plants
- Seventh Safety Layer: accident management equipment stored at the central storage facility in Reitnau and other off-site locations (mobile emergency power units)

In order to cope with an SBO, battery-powered DC power supplies and mobile accident management diesel generators are available at all Swiss nuclear power plants. In addition, there is access to further accident management equipment in the central emergency storage facility at Reitnau. ENSI inspected the operators' preparedness to handle an SBO scenario in 2012.

Instrumentation and control

The standards set by the International Electrotechnical Commission (IEC) for instrumentation and control are applied in addition to the classification criteria defined by IEEE documents. Instrumentation and control functions are assigned to safety categories according to ENSI guideline G01, which is based on IEC 61226. These safety categories are assigned to instrumentation and control systems in accordance with IEC 61513.

The PSRs carried out for the Swiss NPPs have demonstrated that the instrumentation for operational and safety systems and the independent accident monitoring instrumentation are designed according to international standards and national requirements, and consider the defence in depth principle. All Swiss NPPs were inspected after the Fukushima accident to confirm that the accident monitoring instrumentation is continuously supplied by batteries and AM diesel generators in the event of an SBO, thus providing the operators with a means of surveying the most important plant parameters.

In general, analogue technology will gradually be replaced with digital control systems. Beznau NPP has replaced the reactor and turbine protection and control system. Gösgen NPP has replaced the reactor control and emergency diesel control system. Replacement of the reactor protection system at Gösgen NPP is ongoing.

Seismic design of nuclear buildings

The nuclear buildings in Swiss NPPs are divided into structural classes I and II according to seismic classes I and II of the equipment in the buildings. Class I equipment and buildings are designed to resist a Safe Shutdown Earthquake (SSE), whereas Class II equipment and buildings are able to resist an Operating Basis Earthquake (OBE). According to previous practice, half of the SSE spectral accelerations were used for the OBE.

Originally the class I structures of the first generation Swiss NPPs (Beznau I and II, Mühleberg) were designed by assuming a horizontal peak ground acceleration (PGA) of 0.12g at rock surface. In the seventies, it was established that an earthquake with an exceedance frequency of 10^{-4}/year or with an exceedance probability of 0.4% in 40 years must be considered for the SSE. This led to seismic requalification and backfitting of the first generation Mühleberg and Beznau NPPs in the eighties under the assumption of a higher PGA of 0.15g at the rock surface. The second generation Gösgen and Leibstadt NPPs were originally designed for a PGA of 0.15 at bedrock level.

Since construction, the Swiss NPP buildings have been backfitted continually. In all NPPs, masonry walls, which can endanger safety-relevant equipment, have been secured with steel structures. In addition, the reinforced concrete structures of various buildings have been strengthened. These include the emergency feedwater system building at Gösgen NPP in 2008 and the auxiliary buildings and SFP storage building at Beznau NPP in 2009 and 2015 respectively. In all three cases, additional heavily reinforced concrete walls were constructed to resist earthquake excitation.

Since 2002, increased earthquake accelerations have been considered for new buildings and when applying reinforcement measures to existing buildings. As a rule, the spectral accelerations assumed

for the SSE are increased by factors of between 1.5 and 2.0. Examples of new buildings where higher seismic accelerations were applied include the new SFP storage building at Gösgen NPP, the diesel generator buildings for the new emergency power supply at Beznau NPP and the new storage building for low level radioactive waste at Leibstadt NPP.
After Fukushima, the Inspectorate ordered seismic safety checks on the Swiss NPPs. In their analyses, the operators were required to consider the seismic hazard derived from the interim results available from the PEGASOS Refinement Project (PRP). The seismic safety of the buildings was verified using a range of different linear and non-linear calculation methods. The analyses and the Inspectorate's review confirmed that the nuclear buildings can withstand the massively increased earthquake impact implied by PRP compared to the present SSE. The calculations have also shown that nuclear buildings still behave in a linear elastic manner in spite of the higher seismic excitation. This means that high seismic margins apply to NPP buildings and only low damage levels are to be expected.
The PRP was completed and submitted to ENSI by the end of 2013. At the end of 2015, ENSI defined a new hazard, based on PRP, known as ENSI-2015 .

Table 5: *Comparison of representative earthquake hazard parameters*

	Beznau NPP	Mühleberg NPP	Gösgen NPP	Leibstadt NPP
Horizontal PGA, bedrock level (SSE)	0.15 g	0.15 g	0.15 g	0.15 g
Horizontal PGA, basement reactor building (SSE)	0.15 g	0.15 g	0.15 g	0.21 g
Horizontal PGA, reference rock level ENSI 2015 (10^{-4}, mean)	0.18 g	0.29 g	0.17 g	0.17 g
Horizontal PGA reactor building basement ENSI 2015 (10^{-4}, mean)	0.30 g	0.36 g	0.39 g	0.36 g

According to the Swiss regulations, the operators are obliged to verify the nuclear safety of NPPs in the event of significant changes to the hazard definition. The corresponding order was issued by the Inspectorate in 2016. The nuclear safety verification consists of four phases. In the first phase the license holders worked out and submitted the general concepts for a safety assessment. The Inspectorate approved the concepts in 2017. The following verifications (update of post-Fukushima verification, probabilistic safety assessment and deterministic verifications) will be submitted in succession up to 2020.
Issues relating to the seismic safety assessment of the existing NPPs have also been discussed in depth and adequate methodology has been developed.

Summary

It is possible to confirm that Swiss NPPs were designed and constructed in full compliance with the IAEA requirements regarding «defence in depth». The basic principles regarding redundancy, diversity, physical and functional separation, and automation were incorporated in the NEA, NEO and the guidelines issued by the Inspectorate, ensuring that these principles are implemented in the plants. Systems and components are classified in safety classes, designed, and manufactured according to proven codes such as ASME and KTA.
The Swiss NPPs are capable of withstanding hazards of natural origin with a return period of 10 000 years. It is worth mentioning that safety margins exist for events beyond this level. The seismic accelerations considered in the analyses are amongst the highest values currently used in Europe. Furthermore, the plants are equipped with a highly reliable power supply, significantly reducing the risk of an SBO.

After commissioning, the Swiss NPPs have been systematically backfitted, taking into account the lessons learned from national and international safety-relevant events. They have undergone several PSRs. The Swiss NPPs were also subject to the ENSREG stress tests that were performed in Europe following the Fukushima accident. The peer review which took place in 2012 confirmed that the degree of protection of Swiss NPPs is very high. Nevertheless, further backfitting measures will be implemented in order to ensure a continual improvement in nuclear safety.

Clause 2: Each Contracting Party shall take the appropriate steps to ensure that the technologies incorporated in the design and construction of a nuclear installation are proven by experience or qualified by testing or analysis.

Systems, structures and components (SSC) are subject to continuous improvement and regular testing to ensure and verify nuclear safety and fitness for service. Swiss NPPs are legally obliged to comply with the current state of science and technology. Therefore, the applied technologies for design and construction modifications as well as backfitting measures are proven by experience or qualified by testing or analysis, which is reviewed by ENSI and/or its TSO.

In Switzerland, the US ASME Code is used for the original design and construction of safety-relevant SSCs as well as for backfitting projects. Recognised non-nuclear codes and standards are used for some SSCs in safety classes 3 and 4. ENSI has implemented guidelines for the approval of design specifications that are used in the case of design modifications or backfitting measures.

The EC-compatible Swiss SIA Code based on the partial safety factors concept was used for civil engineering purposes. For fault events, e.g. loss of coolant accidents, earthquakes and aircraft crashes, the design incorporated special load combinations with appropriate safety factors.

The various SSCs are classified in accordance with internationally recognised Nuclear Safety Classes. These classifications reflect their relevance to safety. Safety-classified components must fulfil stringent requirements in terms of design, materials, fabrication processes, maintenance and inspection. Nevertheless, some material and design deficiencies have appeared over time. The following paragraphs describe major examples of deficiencies, together with the steps taken by the Swiss NPPs to control, eliminate or mitigate them:

- In the late 1960s, the nickel-based material Alloy 600 was used extensively in the primary circuits of NPPs. Its manufacturing, corrosion and mechanical properties appeared favourable for the then operating conditions and service requirements. However, despite earlier experience, this material suffered from stress corrosion cracking in the LWR coolant environment. The steam generators at Beznau NPP I and II were replaced in 1993 and 1999 for that reason.
- In consideration of international operating experience, Beznau NPP decided to replace the reactor pressure heads of Units 1 and 2. It is known that Alloy 600 welding material in the penetration tubes of control rod drive mechanisms is susceptible to stress corrosion cracking under certain material and operating conditions. In 2015, the reactor vessel heads were successfully replaced at Beznau I and Beznau II. To improve the resistivity against stress corrosion cracking in Gösgen NPP, the Alloy 182/82 welding material used for some pressuriser nozzles was replaced by stainless steel in 2013.
- Stainless steel components may suffer from stress corrosion cracking in the event of unfavourable manufacturing conditions such as sensitised material or local cold work. For this reason, the recirculation piping of the Mühleberg NPP was replaced in 1986. A project to replace the recirculation system at Leibstadt NPP is in progress.
- In 1990, the Mühleberg NPP was the first BWR worldwide to report horizontal cracks in the stainless-steel core shroud welds. These were discovered during the annual in-service inspection. The design of the core shroud does not allow for a simple replacement. As a precautionary measure, tie rods have been put in place. Even if there were full circumferential separation of the core shroud welds, these tie rods would hold the core shroud together and in place. In 2000, Mühleberg NPP

introduced hydrogen water chemistry and the addition of noble metal chemicals to protect the reactor internals against stress corrosion cracking. In 2005, the injection method was modified to OnLine NobleChem™. Crack lengths were measured to confirm a considerable reduction in the growth rate of most cracks since then. The newly qualified ultrasonic testing method confirmed that circumferential cracks have not penetrated through the core shroud wall, but have stopped in the middle of the wall in most places. Since 2015, ENSI has required Mühleberg NPP to perform non-destructive inspections on the core shroud welds every year using qualified inspection systems. ENSI has defined thresholds for the stress intensity factor and crack length in general for all core shroud cracks for the residual lifetime of Mühleberg NPP. Mühleberg must check compliance with the ENSI instructions every year using the non-destructive inspection results. The most recent UT inspection performed in 2017 showed no changes in the dimensions of the known cracks in comparison with the 2015 results, confirming that crack growth had essentially stopped. In 2018, visual inspection and measurement of the longest crack in one of the circumferential welds showed no change in crack length.

- After ultrasonic inspections in the Doel 3 and Tihange 2 nuclear power plants in Belgium in 2012 revealed a series of indications in the reactor pressure vessel base material, ENSI requested the Swiss licensees to undertake multiple investigations. Following the corresponding WENRA recommendation, ENSI demanded a reassessment of the quality of the vessel's forged base material. In the first phase of the reassessment, they requested a technical report on material quality, the fabrication process and the inspections performed on the RPV base material. Beznau and Gösgen NPPs (PWR) submitted this document to ENSI in October 2013. In the second phase of the reassessment, ENSI requested an additional ultrasonic inspection of the base material, validated for detection of hydrogen-induced flaws. The ultrasonic inspection of the base material of the reactor pressure vessel in Beznau and Gösgen NPPs was performed in 2015. A large number of indications were found in Beznau Unit 1. The individual UT indications were considerably smaller than the ones detected in Doel 3 and Tihange 2, but nevertheless required justification and a detailed assessment. The safety case (SC) for the Beznau I RPV submitted by Beznau NPP in November 2016 was reviewed by ENSI and by a group of internationally recognised experts, the International Review Panel (IRP) appointed by ENSI. The reviews concluded that the SC contained insufficient supporting data on the effect on material properties as well as incomplete validation of the UT testing method. This resulted in ENSI requesting an extended materials characterisation program and an updated SC. For the detailed investigations, a replica of the forged ring was produced based on original specifications for the fabrication process, with the aim of reproducing the same type of UT indications in sufficient quantities in the same ingot zone as observed in the Beznau RPV shell. The additional assessments and review of the UT validation and the updated SC were completed early in 2018. The IRP and ENSI concluded that the UT indications are caused by agglomerates of alumina inclusions formed during manufacturing, which do not significantly affect the materials properties relevant for structural integrity or irradiation sensitivity. It was possible to confirm that the ultrasonic testing procedures used are reliable and able to detect all relevant flaws. A fracture mechanics assessment of the flaws, using highly conservative assumptions, demonstrated that the case is robust. After ENSI accepted the Beznau Unit 1 RPV SC, the unit went back into operation in March 2018. ENSI has issued a requirement to repeat the UT inspection on the base material of RPV shell C where the indications with the highest UT amplitudes are located.

Article 14 describes the strategies for managing ageing problems as an integral part of a comprehensive ageing surveillance programme.

Clause 3: Each Contracting Party shall take the appropriate steps to ensure that the design of a nuclear installation allows for reliable, stable and easily manageable operation, with specific consideration of human factors and the man-machine interface.

As mentioned in the comments on Clause 1 of this Article, Swiss NPPs were constructed using US or German designs and therefore met these countries' requirements for reliable, stable and easily manageable operation, in addition to requirements in terms of human factors and the man-machine interface.

However, all Swiss NPPs have made improvements compared with the original design in NPP control rooms – the most important element of the man-machine interface. They have introduced computerised process visualisation techniques to facilitate operational control in normal and abnormal conditions. The degree of automation has been increased to reduce the need for manual action for 30 minutes in the event of a design basis accident and for 10 hours in the case of an external event.

The Inspectorate pays particular attention to the consideration of human factors when designing modifications for existing nuclear installations. Since 2007, the Inspectorate has required the licensees to implement a human factors engineering programme (HFE programme) together with the initial concept of a modernisation project for man-machine interfaces (see Article 12). This ensures systematic and continuous consideration of human factors throughout the modernisation project.

Below are some recent modernisation examples that have had an impact on man-machine interfaces and where the Inspectorate closely monitors the human factors engineering process applied by the licensees:

- In the 1990s, Beznau NPP installed two computerised systems to improve the man-machine interface. The first is a computerised alarm system with a prioritisation scheme for displaying important messages with a safety function. The second is a computerised system for emergency operating procedures (EOPs) based on printed EOPs. This system guides the shift supervisor step-by-step through the EOPs. Printed EOPs are available in case of computer failures. These computerised systems were modernised. In 2015, they were validated using the full-scope simulator at Beznau NPP.
- In 2015, Beznau NPP completed a large plant modernisation project to replace the existing hydroelectric power station that forms part of the emergency power supply systems with seismically qualified diesel generators. As a result, changes to the computerised EOPs were necessary. These changes were also validated using the Beznau NPP full-scope simulator.
- In 2009, Gösgen NPP announced that it was planning to replace all instrumentation and control systems. This modification has a major impact on the working conditions for control room operators and maintenance personnel. The project is carried out in several steps. An HFE programme is defined and implemented for each step to address the specific human factor-related aspects of the project. Depending on the impact, a graded approach is applied. Several further projects with HFE-related issues were carried out during the reporting period or are planned for subsequent years (e.g. implementation of adaptive power density control, extension of emergency systems and replacement of fire dampers).
- In 2011, Leibstadt NPP installed the new operational information system, ANIS. A new computerised man-machine interface was created by modernising the systems. The Inspectorate's oversight role included closely monitoring the human factors engineering process and consideration of the new interfaces on the work of the operators applied by the licensees. Since the implementation, Leibstadt NPP stepwise changes the instrumentation to use it for operational systems control. This process is still ongoing and is closely monitored by the Inspectorate.

Developments and Conclusion

Further backfitting measures to be taken depend on the assessments and analyses that are still to be performed as a consequence of the Fukushima events (see Article 14). Proof of the seismic robustness of the Swiss NPPs, which is based on the new ENSI-2015 hazard specification, will probably lead to further enhancements. Further improvements will also be made by implementing the Inspectorate's requirements regarding LTO. The safety requirements for equipment used in design basis and extended design conditions will be implemented in a new guideline (ENSI-G02) laying down updated design rules for existing NPPs.

Switzerland complies with the obligations of Article 18.

Article 19 – Operation

Clause 1: Each Contracting Party shall take the appropriate steps to ensure that the initial authorisation to operate a nuclear installation is based upon an appropriate safety analysis and a commissioning programme demonstrating that the installation, as constructed, is consistent with design and safety requirements.

All five Swiss NPPs have valid operating licences granted in accordance with the law. The initial operating licence includes the commissioning licence. Essentially, the granting of an operating licence is based on the following elements:

- an extensive set of technical and organisational documents as specified in Appendices 3 and 4 of the NEO and submitted by the applicant with the formal application;
- a safety evaluation report by the Inspectorate;
- proof of insurance;
- report to the effect that the plant complies with the general licence and construction licence.

The NSC may comment on the Inspectorate's SER. The licensing procedure is described in Article 7.

The operating licence includes authorisation for commissioning. The commissioning programme must be approved by the Inspectorate and consists of pre-operating and start-up tests as well as procedures for testing all equipment that is important for safety. The licensee conducts a design review to verify that the «as-built state» properly reflects the proposed design in terms of safety requirements (safety criteria and licence conditions). Commissioning itself and all stages of start-up tests are under regulatory control as permits are required from the Inspectorate.

As part of the operating licence, the Inspectorate issues a specialist report for each new operating cycle after outages for maintenance and refuelling. This report is also a substantiated opinion from the regulator confirming that the NPP is safe for the next operating cycle in accordance with specified requirements. It is based on the Inspectorate's assessment of operating performance, including radiation protection, events during the previous cycle, the results of maintenance and refuelling activities during the outage period, and approval of the reload licensing documentation (see Article 14).

Clause 2: Each Contracting Party shall take the appropriate steps to ensure that operational limits and conditions derived from the safety analysis, tests and operational experience are defined and revised as necessary for identifying safe boundaries for operation.

see Clause 3 below

Clause 3: Each Contracting Party shall take the appropriate steps to ensure that operation, maintenance, inspection and testing of a nuclear installation are conducted in accordance with approved procedures.

This Clause is closely linked to Clause 2 and as such they are covered together in the following paragraphs.

Operation of each NPP must comply with an appropriate set of limiting conditions for operation (LCO) approved by the Inspectorate. The LCOs constitute boundary conditions for procedures and instructions for normal operation. They are derived from safety analyses and test results and are included in the Technical Specifications for the plant. The Technical Specifications also contain the plant-specific surveillance requirements. Technical Specifications are based on the Standard Technical Specifications issued by the reactor supplier. The initial Technical Specifications and later modifications require a permit from the Inspectorate. Modifications are required as a result of plant modifications, operational experience and new knowledge. The Technical Specifications must comply with Chapter 6.3 of ENSI guideline G09. Additional procedures implemented by licensees ensure the safe operation of NPPs. They are based on regular verification of the operability of safety-related equipment. These procedures are used in the extensive surveillance programmes for maintenance, inspection and testing. They encompass in-service inspections using non-destructive examination of components, periodic examinations of electronic, electrotechnical and mechanical equipment, periodic functional testing of systems and components, as well as an ageing surveillance programme (see Article 14). Non-destructive testing must comply with ENSI guideline B07.

Regulatory surveillance of plant operation relies on information obtained from the reports submitted by operating organisations (in accordance with ENSI guidelines B02 and B03), information collected during the Inspectorate's inspections and its own measurements. Since the INES classification was introduced in Switzerland in 1992, there have been 17 events in Swiss NPPs rated as Level 1 on the INES scale and 2 events rated as Level 2. The annual number of reportable events as specified in the Inspectorate's guideline B03 (in effect since 2009) is shown in the Figures 17–20 below. Most of the reportable events were rated as Level 0 on the INES scale.

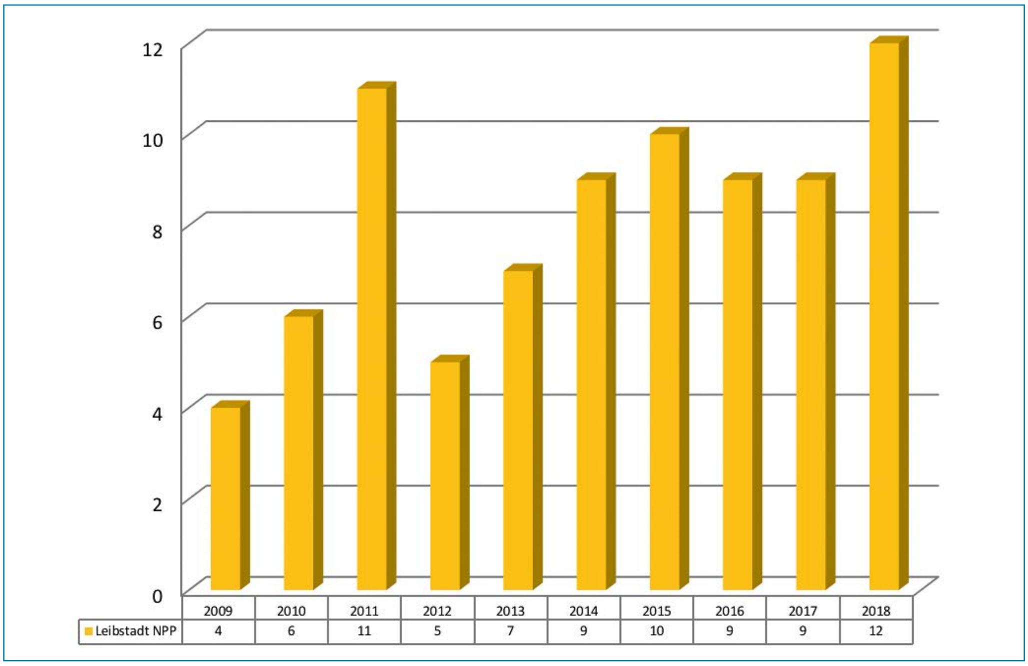


Figure 17:
Annual number of reportable events for Leibstadt NPP

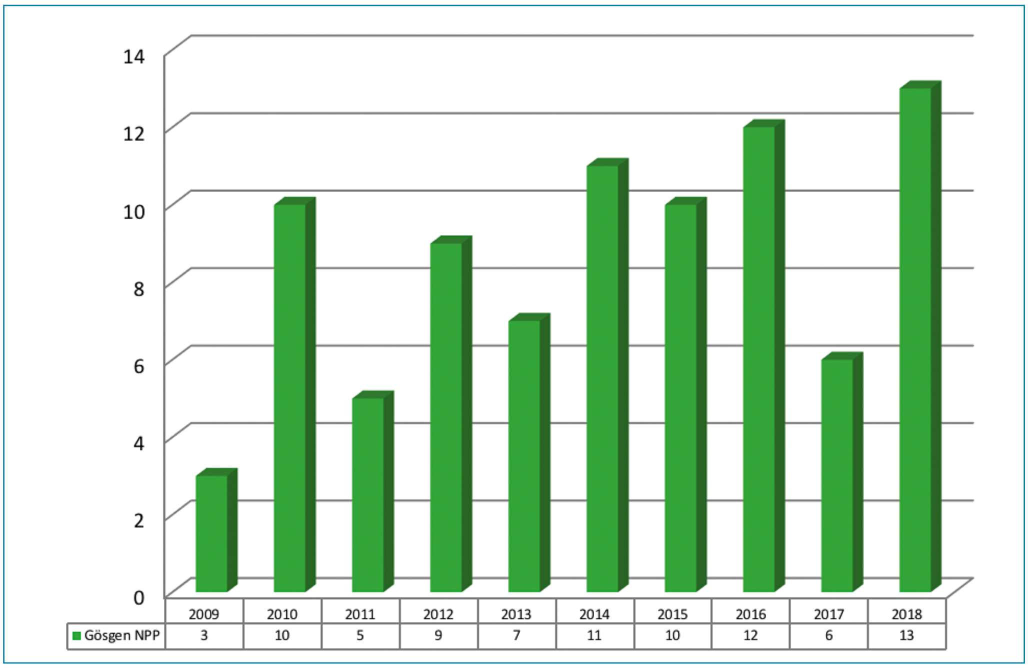


Figure 18:
Annual number of reportable events for Gösgen NPP

Figure 19: *Annual number of reportable events for Beznau NPP*

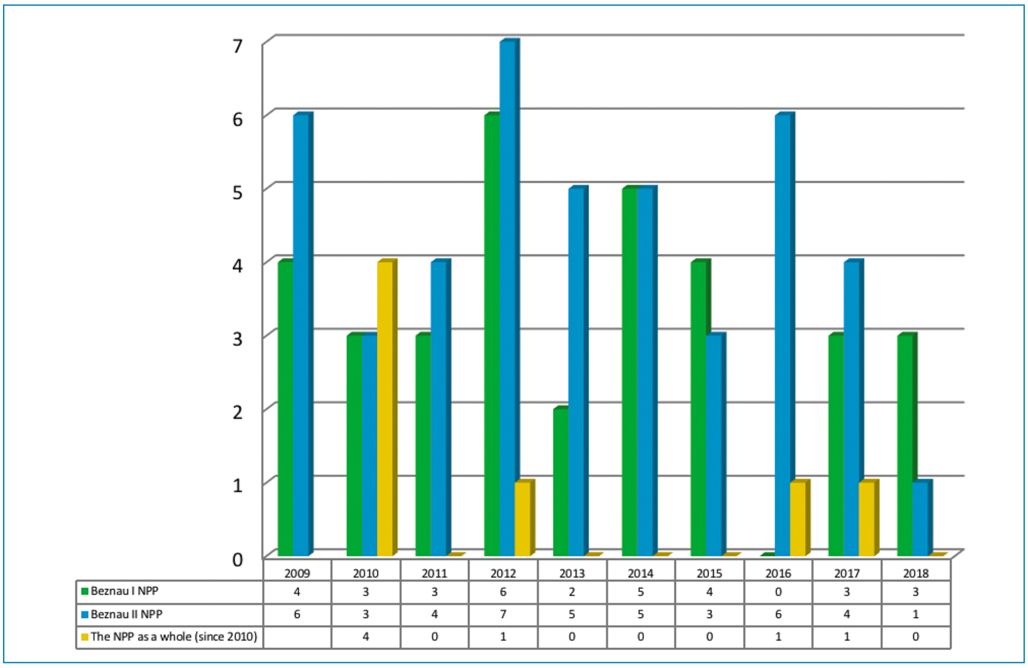
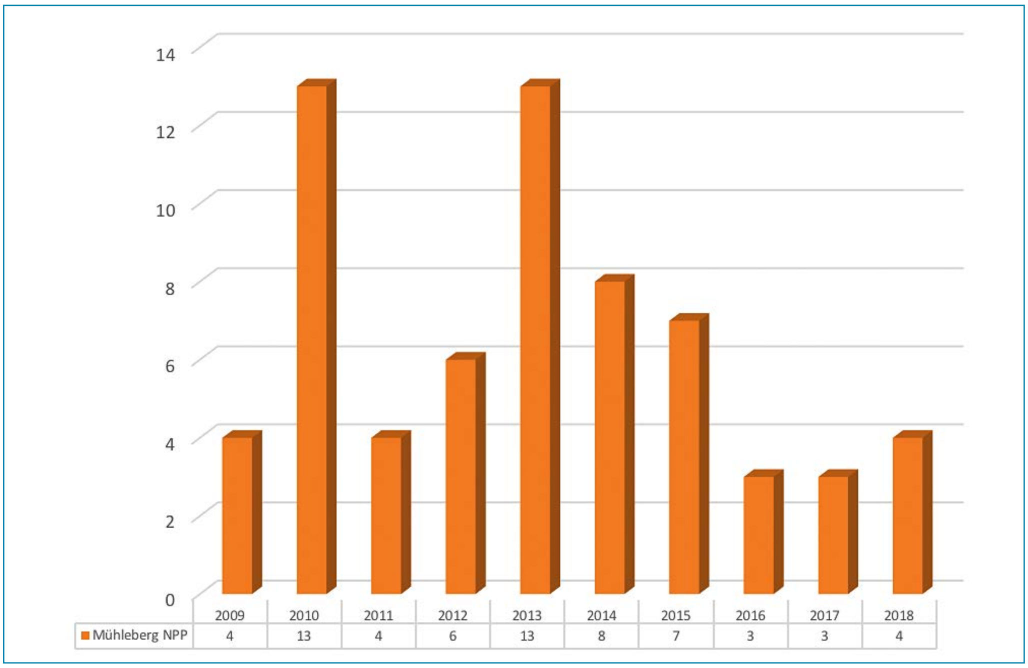


Figure 20: *Annual number of reportable events for Mühleberg NPP*



The reporting system requires operating organisations to report periodically (monthly, annually, after refuelling outages) on operational performance and activities relating to safety. The most important of these are modifications to plant equipment, procedures and organisation and doses to personnel and the public. There is particular emphasis on event reporting and investigation. Lessons learned and event feedback are essential elements of operational experience. In addition, the threshold for event reporting in Switzerland is low, which means that the Inspectorate receives comprehensive reports on even minor safety-related events. The analysis of incidents by both the utility and the Inspectorate is an important tool in efforts to increase nuclear safety (see also Clause 4).

Clause 4: Each Contracting Party shall take the appropriate steps to ensure that procedures are established for responding to anticipated operational occurrences and to accidents.

Each NPP has dedicated procedures for operational anomalies and emergency conditions as required by the NEO.

As top-level organisational documents, the emergency preparedness regulations reflect the operating organisation's policy. They include the steps for alerting the NPP standby safety engineer. They specify the duties of the standby safety engineer, and in particular the requirement to determine whether an emergency actually exists, alert the plant's emergency staff and inform the Inspectorate if an event requires immediate reporting. The regulations also define the on-site criteria for alerts and alarms (see Article 16).

As a means of supporting emergency response measures, emergency operation procedures (EOPs) are designed to bring the plant into a safe operational state, while the Severe Accident Management Guidance (SAMG) is designed to mitigate the consequences of accidents leading to fuel damage.

EOPs specify the measures required to manage incidents and accidents prior to core damage. Modifications to EOPs are reviewed to ensure that they are compatible with the environment in which they will be used. The effectiveness of incorporating human factors engineering principles is judged. EOP validation is based on representative simulations using the plant-specific simulator. Spot checks to ensure that EOPs are adequate are carried out as part of the review of selected cases of the human reliability analysis of the plant-specific PSA or during inspections.

In all plants, SAMG is implemented to cover all relevant operating states. Two NPPs closely followed (Beznau) or adapted (Leibstadt) the SAMG concept of the owners' group, Westinghouse PWR or WOG/BWROG, respectively. Mühleberg NPP (GE BWR) and Gösgen NPP (Siemens KWU PWR) developed plant-specific concepts. The SAMG for each Swiss plant is symptom-oriented. The technical basis for the strategies developed as part of SAMG comprises thermal hydraulic calculations and the full-scope, plant-specific level 2 PSAs. The decision-making support tools that were developed were checked for applicability (validation) by participants in the emergency response organisation. The validation was also carried out using exercise scenarios, in which SAMG plays a major role in managing the accident (see Article 16). SAMG is updated by the licensee to ensure that it complies with the state of the art. ENSI reviews the SAMG by inspections and as part of emergency exercises and the PSR.

All the plants have met the requirement to examine and take account of instrumentation behaviour under severe accident conditions in the course of introducing SAMG. ENSI therefore regards the instrumentation as generally adequate.

All NPPs have Accident Management (AM) procedures for a variety of measures to deal with scenarios beyond the design basis of the plant. The AM procedures (for the measures outlined below) form part of the EOP package, the SAMG or both. As a general rule, the necessary AM equipment (e.g. mobile pumps) is available on site. As a back-up provision, AM equipment is also available from an external storage facility (see Article 16 for more details). Incorporation of the external storage facility in the AM procedures has been finalised.

With a view to preventing fuel damage, the AM measures include measures such as venting the steam generators without external power, venting the RPV via alternative trains, supplying borated water from the Spent Fuel Pool (SFP) to the RPV (by means of fire brigade pumps), supplying coolant via the fire extinguishing system and cross-switching of power supply systems. Inspections (carried out for all NPPs) of the strategies to deal with a prolonged total loss of AC power (Station Blackout, SBO) generally indicate that sufficient AM measures are available to prevent core damage.

As part of Severe Accident Management with the emphasis on mitigating the consequences of fuel damage, the measures include filtered venting of the containment before or after an RPV failure and containment flooding. Alternative measures for reclosing large containment openings are prepared and guided for severe accidents under SBO conditions during shutdown.

With a view to preventing and mitigating accidents taking place in the SFP, the provided measures include re-injecting water into the SFP, thereby compensating for the evaporation and/or vaporisation volume and isolating ventilation openings and ventilation control in the SFP building. Due to post-Fukushima backfitting measures completed so far, all NPPs have connection points allowing AM measures to be applied to SFP cooling without entering the SFP building.
ENSI regularly carries out inspections on the availability of AM means and the process of checking that the procedures reflect the state of the art.
The NEO concerning regulation of the content of the emergency preparedness regulations, the EOPs and SAMG are embodied in guidelines published by the Inspectorate (ENSI-B12, ENSI-G09). Changes to the content of these documents must be reported to the Inspectorate. Plant modifications, operating and training experience, scientific and technological developments and lessons learned from events in NPPs lead to such changes if necessary.

Clause 5: Each Contracting Party shall take the appropriate steps to ensure that necessary engineering and technical support in all safety related fields is available throughout the lifetime of a nuclear installation.

NPPs have developed their own on-site technical support covering the surveillance test programme, reactor engineering and fuel management, operational experience feedback, plant modifications and safety-related computer applications. These functions are the responsibility of the various technical departments in an NPP. In most cases, a department at the licensee's headquarters is responsible for core and cycle design and for fuel procurement. If additional expertise is required, each plant can obtain technical support from the reactor supplier by subcontracting work to them. Technical support from the reactor supplier under accident conditions is guaranteed by special agreements. Nevertheless, the licensee must have sufficient expertise within its own organisation to ensure the quality of any outsourced tasks. In the event of a severe accident, support from external staff is possible. A set of accident management procedures for each NPP is stored in the external storage facility at Reitnau.
With the deregulation of the electricity market and the current increase in economic pressures, retaining corporate knowledge has become an important issue. The Inspectorate is aware of this and the issue is discussed at the regular management meetings between the Inspectorate and NPPs. In addition, a master's course in nuclear engineering has been set up at ETH.

Clause 6: Each Contracting Party shall take the appropriate steps to ensure that incidents significant to safety are reported in a timely manner by the holder of the relevant licence to the regulatory body.

The NEA, the NEO and the Inspectorate's guidelines contain requirements for the notification of events and incidents:

- notification of events to allow early recognition of deviations and their correction;
- notification of incident/accident conditions to alert the Inspectorate's emergency organisation and other authorities;
- notification of events of public interest to allow the Inspectorate to make an independent assessment and inform the public quickly.

The NEA obliges licensees to notify the supervisory authorities within a specified time of special activities or occurrences relating to the handling of nuclear materials and which might interfere with nuclear safety or security. The NEO specifies reporting requirements for nuclear safety, security and the transport of nuclear materials. The Inspectorate is required to regulate the detailed reporting procedures and the method of classifying events and findings in accordance with the NEO. As a result, the Inspectorate's guideline B03 contains criteria defining the reporting obligation threshold for events. The licensee is responsible for giving a preliminary rating to each reportable event or finding based on INES, whereas the Inspectorate is responsible for the final INES rating. The NEO specifies the time limits for initial notification, receipt of the event history report and the report on remedial action based on the INES rating. There is an additional class for events of public interest requiring immediate reporting, even if there is no significance for nuclear safety. A press release by the NPP implies public interest in the event. The Inspectorate uses the licensee's written confirmation of an event as the basis for its initial review of the classification and any immediate action required should an event reveal unexpected barrier degradation. If an event is reported as a General Emergency, Site Area Emergency or Alert, or if there is any public interest, the Inspectorate's special emergency team meets as required by its own internal rules on emergency preparedness. General Emergency, Site Area Emergency and Alert are defined in Appendix 6 of the NEO.

To ensure that nuclear installations apply the Inspectorate's guidelines correctly, event classification is part of both the initial licence exams for shift supervisors and standby safety engineers and subsequent relicensing. During periodic emergency exercises, event classification is an important objective for both NPP and regulatory staff.

As part of its quality management system (see Article 8, Clause 1), the Inspectorate has its own internal procedures for event investigation, which include independent assessment and classification of all events reported nationally. It has set up a working group consisting of experts in engineering, human factors and radiation protection, which assesses events in cooperation with specialists from individual sections. If the final rating is INES 0, the decision on this final INES rating is taken by the Head of the Division responsible for oversight of plant operation. If the rating is INES 1 or higher, the decision is taken by the Director General of the Inspectorate. The results are communicated to the licensee and entered in the systematic safety assessment database. For several years, it has been the Inspectorate's practice to include a summary of reported events and their classification in the Inspectorate's annual regulatory oversight report. This report is publicly available.

Clause 7: Each Contracting Party shall take the appropriate steps to ensure that programmes to collect and analyse operating experience are established, the results obtained and the conclusions drawn are acted upon and that existing mechanisms are used to share important experience with international bodies and with other operating organisations and regulatory bodies.

The process covering non-conformance control and remedial action is important for Swiss NPPs. It is guided by procedures that form part of the management system. Any non-conformance is reported and discussed at the daily morning meeting held by each NPP and follow-up action (e.g. work authorisations) is initiated where necessary.

The safety impact of non-conformances is evaluated. If the event is of interest or significance to safety, the non-conformance must be reported to the Inspectorate. In addition, an internal investigation team in the plant is required to conduct a thorough analysis of the event. If the event is more complex, the NPP will use dedicated root-cause analysis methods. Based on these analyses, the event investigation team will suggest what action is required. These suggestions are reviewed by the plant's internal safety committee before implementation.

Low-level non-conformance events (below the reporting obligation level), near misses and other types of failures or malfunctions are reported to the daily meeting of plant managers and representatives from the main technical divisions. Their significance is then evaluated. Depending on the safety relevance or operational impact of the non-conformance, remedial action is initiated immediately or the problem is transferred to the event investigation team or a technical division for further evaluation.

Having decided what remedies are appropriate, responsibility for implementation is assigned to a division. The final details must be reported to the safety review committee and the resultant operating experience is used to inform future plant improvement programmes.

The CEOs of all NPPs monitor the exchange of operating experience between Swiss NPPs. This CEO group is supported by several working groups dealing with issues such as training, nuclear safety performance, ageing surveillance, management systems, radiological and chemical plant performance, fire services and industrial safety.

Each NPP has a process for dealing with external operating experience, which screens and evaluates information on external events. Depending on their significance and applicability to an individual plant, the information is evaluated in detail and modifications are implemented as necessary. The Inspectorate inspects this process periodically. Furthermore, plants must provide a monthly report to the Inspectorate with information on external events evaluated in detail. Important sources of external information are the World Association of Nuclear Operators (WANO), the Plant Owners' Group, the Incident Reporting System (IRS) of IAEA and OECD/NEA and the Association of Power and Heat Generating Utilities in Germany. Specialist groups of experts from Swiss NPPs meet periodically to exchange operational experience, information from abroad and exchange detailed information on recent events in their own plants.

The Ordinance on the Methodology and Boundary Conditions for the Evaluation of the Criteria for the Provisional Taking-out-of-Service of Nuclear Power Plants not only ensures plant-specific analysis for all internal events rated INES 1 and above in Swiss NPPs, but also surveys reported events rated INES 2 and above in NPPs all over the world.

The Inspectorate has its own process for assessing events in nuclear installations in other countries. If the Inspectorate's assessment indicates potential for safety improvements at Swiss NPPs, the plants are required to analyse the situation in their own installation and take appropriate action. The IRS is the Inspectorate's main source of information. The Inspectorate has been a member of IRS since it was founded in 1980. Members prepare reports on safety issues of relevance to the nuclear community, and attend and organise meetings and workshops on important safety issues. The Inspectorate sends delegates from its own staff to the OECD/NEA/CSNI «Working Group on Operational Experience» (WGOE) and to the «Working Group on Human and Organisational Factors» (WGHOF).

The Inspectorate obtains other important information from IRS reports, NRC information letters and bilateral contacts (e.g. safety commissions) with its neighbours France and Germany.

The following are examples of Swiss events reported to the IRS:

- Significant rise in core damage frequency due to unavailability of both the Beznau NPP Unit 1 emergency diesel generator and the off-site power source;
- Exposure of two workers to doses in excess of the statutory annual limit at Beznau NPP Unit 2;
- Exposure of a worker in excess of the statutory annual dose limits at Leibstadt NPP;
- Failure of primary service water pump shafts at Beznau NPP Units 1 and 2
- Damage to the steel primary containment at Leibstadt NPP
- Indications of dry-out in first cycle fuel assemblies at Leibstadt NPP

The following are examples of information on operational experience from abroad that resulted in major modifications at Swiss NPPs:

- Based on Generic Letter 89–10 issued by the US-NRC, the Inspectorate required all Swiss licensees to reevaluate the functional analysis of motor-operated valves in safety-related systems. Consequently, all Swiss NPPs modified certain gate valves.
- Following the incident at Barsebäck 2 (Sweden) on 28 July 1992 involving clogging of suction-line strainers in the suppression pool, the Inspectorate initiated a programme of short-term measures designed to resolve the problem in all NPPs. The short-term measures included inspections, a detailed review of the types of thermal insulation in use, a clogging analysis of strainers and preparation of accident management measures in BWR plants. This resulted in the replacement of all suction strainers in the emergency core cooling system of BWRs (Mühleberg and Leibstadt) during their outage periods in 1993. The strainer area in the new equipment was much larger. Backfitting was not considered necessary for the PWRs at the time and a reassessment of the issue in the light of recent results from French and NRC research showed that the design of PWR suction strainers is still appropriate. However, one licensee has installed new state-of-the-art cassette-type suction strain-

ers to improve safety and allow greater flexibility in the type of thermal insulation material used in the containment.

- Two hydrogen explosions occurred in European and Japanese BWRs at the end of 2001, resulting in ruptured pipes. This is a known phenomenon and had been the subject of previous assessments; following these two events, the two BWRs in Switzerland were required to reevaluate the earlier assessments. This resulted in immediate improvements to procedures (e.g. filling empty pipes with water). Minor hardware modifications (e.g. improved insulation, installation of thermocouples) were made during the annual outage. The investigations were then completed, but because of differences in the BWR design in Switzerland, it was not considered necessary to undertake hardware modifications or consider a new design basis accident.
- The reactor vessel head corrosion event at the Davis Besse NPP (USA) in 2002 generated considerable attention in the nuclear community. In this event, a significant amount of boric acid corrosion was detected caused by leakage from cracks in the control rod nozzles. Both Swiss operators and the Inspectorate had previous experience of this phenomenon and so were already vigilant. A small head corrosion event caused by leakage had occurred in Switzerland in the early 1970s, and five years before the above US event cracks had been found and reported in the control nozzles of US plants. The Inspectorate had used this previous experience to strengthen the requirements for periodic surveillance by plant operators of nozzle cracks and leakage control. Therefore, the Davis Besse event did not necessitate any additional action.
- The incident at Forsmark 1 NPP (Sweden) on 25 July 2006 also led to major investigations by the Inspectorate. The Inspectorate checked aspects identified as being significant to the sequence of events in detail. All Swiss NPPs carried out a comprehensive check of the technical and organisational measures used to deal with the consequences of a similar type of event. The investigation results were published in a separate report and this is available on the Inspectorate's website. The investigations did not identify any deficiencies in technical and organisational precautions by Swiss NPPs designed to protect plants from the effects of grid disturbances. Nevertheless, the Inspectorate recommended that NPPs intensify simulator training for scenarios involving loss of redundancy in safety or information systems and signals in the control room.
- The Fukushima accident triggered a series of actions taken by the Inspectorate with the aim of understanding the event sequence, its causes and drawing conclusions for the safety of Swiss NPPs. The Swiss National Report for the CNS Second Extraordinary Meeting contains more detail on lessons identified, analyses performed and measures adopted. The Inspectorate has chosen a gradual response approach to the Fukushima accident to allow possible new lessons to be incorporated as soon as they become available from further accident investigations, which are still ongoing in Japan. In spite of insights gained from the national response approach and European approach (EU stress test), which confirmed that Swiss NPPs have high safety standards, areas of further improvement were identified. Essential topics to be addressed by the licensees include protection against earthquakes and flooding, the design of spent fuel pools, availability of the ultimate heat sink and availability of accident management equipment from off-site locations. Details are given in Articles 16 and 18.

The Inspectorate's Annual Report includes information on how information from external operating experience has been used. Special attention is given to analyses and plant modifications performed in response to the Fukushima accident.

Clause 8: Each Contracting Party shall take the appropriate steps to ensure that the generation of radioactive waste resulting from the operation of a nuclear installation is kept to the minimum practicable for the process concerned, both in activity and in volume, and that any necessary treatment and storage of spent fuel and waste directly related to the operation and on the same site as that of the nuclear installation take into consideration conditioning and disposal.

The NEA includes the principle that the generator of radioactive waste is responsible for its safe management until disposal. Before an NPP is licensed, it must demonstrate that the waste generated by the facility can be safely and permanently managed and disposed of. The Radiological Protection Act and the Radiological Protection Ordinance stipulate that the volume of radioactive waste produced must be kept to the minimum possible. Under the NEA, radioactive waste originating in Switzerland must be disposed of in Switzerland.

To ensure compliance with legal requirements during the licensing phase, plans for nuclear installations are subject to a critical review by nuclear safety authorities. The Inspectorate's supervisory activities ensure compliance during construction and operation of such installations.

Each NPP stores the spent fuel discharged from the reactor on site for several years. The NEA prohibits the export of spent nuclear fuel for the purpose of reprocessing. In the past, NPP operators have exported a total of some 1,139 tonnes of spent fuel to La Hague (F) and Sellafield (UK). All this spent fuel has finally been reprocessed. All waste allocated on the basis of reprocessing contracts had been returned to Switzerland by the end of 2016 and is currently stored at the central interim storage facility (ZZL) awaiting final disposal.

All separated Pu products from reprocessing Swiss fuel elements have also been repatriated in the form of MOX fuel elements, all of which have already been reused in the PWRs at the Beznau and Gösgen sites. Even some of the associated U products have already been reused in Swiss reactors in the form of RepU oxide fuel elements.

Since July 2006, any spent fuel from the Mühleberg and Leibstadt NPPs is transported to the Central Interim Storage Facility and stored in dry dual-purpose casks (DPC). Beznau NPP operates its own dry storage facility on site, whereas Gösgen NPP started on-site operation of a separate wet storage facility for spent fuel in May 2008. However, even KKG will have to transfer spent fuel elements into DPCs in the late 20s due to a licensing condition for the wet storage facility.

While foreign DPC designs were used for storage in previous years, the specific properties of Swiss spent fuel assemblies led to several design and licensing projects for dedicated DPC designs, especially to address issues such as high burn-up, MOX elements and reprocessed U elements. In setting up these projects, Switzerland initiated and is now leading international discussions on ageing management for dry spent fuel storage systems. All Swiss utilities are required to establish comprehensive ageing management programmes to consider ageing of the storage facility components, the DPCs and their contents.

Any operational waste from the NPPs is collected and segregated. Waste with such low activity levels that it can be exempted from regulatory control is cleared for re-use or conventional disposal under the supervision of the Inspectorate. The conditions required for clearance are included in Annex 2 of the Radiological Protection Ordinance. The associated procedures are detailed in the regulatory guide ENSI-B04 which also applies to any other (institutional) radwaste in Switzerland.

Radioactive waste in the form of resins, sludges or activated components is conditioned as soon as practicable on site at the NPPs. However, incinerable waste is conditioned externally at the Central Interim Storage Facility (ZZL), which successfully operates the world's first plasma incinerator for radwaste. The previously used «conventional» incineration facility at the Paul Scherrer Institute is currently being decommissioned. The ZZL installations also provide services for decontamination, segregation, handling of bulky items and, quite recently, processing radwaste containing asbestos.

According to the NEO, any procedure for conditioning radioactive waste must be approved by the Inspectorate. Approval is only granted if waste products comply with accepted storage criteria, meet the requirements of NAGRA, the disposal planning organisation, and can be transported in compliance with the regulations for transport of hazardous goods. Detailed requirements for qualification of such waste types are documented in the regulatory guide ENSI-B05. The utilities have continuously redocumented and in some cases also reconditioned «historic» waste packages which had originally been conditioned for dumping at sea, but remained in Switzerland after this disposal technique was halted. All waste packages are included in a nationwide Nagra registration and documentation system and controlled by an independent register at ENSI. This also applies to the PSI Research Institute responsible for the central waste collection facility for institutional waste.

Specific requirements for interim storage facilities and their operation are detailed in the regulatory guide ENSI-G04, which is currently being revised. The updated version will be published by the end of 2019.

Up-to-date ENSI regulatory guides and the respective NEA and NEO provisions comprehensively cover all pre-disposal aspects of the Swiss national waste management system. This also includes the requirements of the corresponding WENRA reports, the safety reference levels (SRLs) for storage of waste and spent fuel, decommissioning and disposal. The SRLs for waste processing as described in the WENRA processing report are only partly covered. A regulatory guide (ENSI G-23: Design requirements for nuclear installations other than power reactors), which will cover the missing requirements, is currently being prepared.

Developments and Conclusion

Switzerland complies with the obligations of Article 19.

Outlook

ENSI will continue to support efforts to harmonise safety requirements at European and international level within the IAEA and the Western European Nuclear Regulators Association (WENRA). ENSI has always aimed to provide regulatory guidelines that are both compatible with IAEA Safety Standards and harmonised with the WENRA safety requirements. Moreover, ENSI is committed to exceed international standards.

In the next reporting period, ENSI will need to address the following challenges:

Long-term Operation: Three of Switzerland's NPPs have been operating for more than 40 years. As a result, regulatory activities for these plants will need to focus more on the specific issues arising from LTO. Swiss law does not specify any restriction on the period of operation; nuclear power plants can be operated as long as they are safe. For this reason, the assessment of safety is accorded high priority. There is a requirement for systematic annual safety assessments and a comprehensive Periodic Safety Review (PSR) every 10 years.

Decommissioning of Mühleberg NPP: In 2013, the owner of Mühleberg NPP, BKW Energie Ltd., decided to shut down the plant at the end of 2019. ENSI has decreed provisions to increase the safety of the plant during the remaining period of operation (see Article 18). On 18 December 2015, BKW submitted a formal application to DETEC requesting the decommissioning order specified in Article 28 of the Nuclear Energy Act. The licensing authority issued the corresponding decommissioning order on 20 June 2018. Shutdown is scheduled for 20 December 2019.

Deep Geological Repository: The process to select a site for the disposal of radioactive waste in deep geological formations in Switzerland is continuing. In 2018, the Swiss government approved three remaining sites, each of which is suitable for a high-level waste repository as well as for a low- and intermediate-level waste repository. Nagra, Switzerland's National Cooperative for the Disposal of Radioactive Waste, will carry out further investigations and safety analyses at the three remaining sites in the forthcoming years. In 2022, building on this additional information and a safety-based comparison of the sites, Nagra expects to be able to announce the sites for which it will prepare and submit a general licence application

Maintaining Competence: In the long term, the phase-out of nuclear power and the changing energy landscape in Switzerland, paired with the fact that the perception and reputation of engineering professions are changing, might lead to a lack of qualified staff for operators, sub-contractors and nuclear safety regulators. Adequate measures need to be taken to ensure early replacement of retiring staff to guarantee that sufficient time is available for knowhow to be transferred to new employees.

Emergency Preparedness and Response: Lessons from nuclear accidents have demonstrated the consequences of risk misperception. Careful consideration is required when taking various radiological and non-radiological factors into account when making decisions to ensure that the actions taken do more good than harm.

Appendix 1: List of Abbreviations

AC	Alternate Current
ADAM	Accident Diagnostics, Analysis and Management system
ALARA	As Low As Reasonably Achievable
AM	Accident Management
AMP	Ageing Management Programme
ANPA	Data system for plant parameters (Anlageparameter)
ASME	American Society of Mechanical Engineers
AUTANOVE	Autarkic Emergency Power Supply (Autarke Notstromversorgung, Project at the Beznau NPP)
BBC	Brown, Boveri&Cie
BDBA	Beyond-Design-Basis Accidents
BKW	Bernische Kraftwerke
BWR	Boiling Water Reactor
BWROG	Boiling Water Reactor Owners Group
CDF	Core Damage Frequency
CEO	Chief Executive Officer
CET	Core Exit Temperature
CHF	Swiss Franks
CNS	Convention on Nuclear Safety
CSNI	Committee on the Safety of Nuclear Installations (OECD-NEA)
DBA	Design-Basis Accidents
DBE	Design Basis Earthquake
DBF	Design Basis Flood
DC	Direct Current
DEC	Design Extension Conditions
DETEC (UVEK)	Department of Environment, Transport, Energy and Communication (Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation)
DIWANAS	Diversitäre Wärmesenke und Nachwärmeabfuhr-System (Project at the Mühleberg NPP)
DPC	Dual-purpose casks
DSSA	Deterministic Safety Status Analysis
ECCS	Emergency Core Cooling System
ECURIE	European Community Urgent Radiological Information Exchange
ENSI	Swiss Federal Nuclear Safety Inspectorate ENSI (Eidgenössisches Nuklearsicherheitsinspektorat)
ENSREG	European Nuclear Safety Regulatory Group
EOP	Emergency Operating Procedures
ERO	Emergency Response Organisation
ETH	Swiss Federal Institute of Technology
EU	European Union
EURATOM	European Atomic Energy Community

FCVS	Filtered Containment Venting System
FMB NBCN	Federal Nuclear, Biological, Chemical and Natural Crisis Management Board
FN (AN)	File Note (Aktennotiz)
FOCP	Federal Office of Civil Protection
FOEN	Federal Office for the Environment
FOPH	Federal Office of Public Health
GDC	General Design Criteria
GE	General Electric
HEPA	High Efficiency Particle Arrestor
HERCA	Heads of European Radiological protection Competent Authorities Association
HLW	High-Level Waste
HOF	Human and Organisational Factors
HPP	Hydro(electric) Power Plant
HSK	Hauptabteilung für die Sicherheit der Kernanlagen (precursor of ENSI)
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IDA-NOMEX	Interdepartmental Working Group to Review Emergency Protection Measures in case of Extreme Events in Switzerland (Interdepartementale Arbeitsgruppe zur Überprüfung der Notfallschutzmassnahmen bei Extremereignissen in der Schweiz)
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
INES	International Nuclear and Radiological Event Scale
INEX	International Emergency Exercise
IRRS	Integrated Regulatory Review Service
IRRT	Integrated Regulatory Review Team (precursor of IRRS)
IRS	International Reporting System for Operating Experience
ISO	International Standards Organisation
ISOE	Information System on Occupational Exposure
JRODOS	Java-based Real-time Online Decision Support system
KKB	Nuclear Power Plant Beznau (Kernkraftwerk Beznau)
KKG	Nuclear Power Plant Gösgen (Kernkraftwerk Gösgen)
KKL	Nuclear Power Plant Leibstadt (Kernkraftwerk Leibstadt)
KKM	Nuclear Power Plant Mühleberg (Kernkraftwerk Mühleberg)
KPMG	Klynveld, Peat, Marwick und Goerdeler (Swiss auditor)
KWU	Kraftwerk Union AG
L/ILW	Low-Level and Intermediate-Level Waste
LASAT	Lagrangian Simulation of Aerosol-Transport
LCO	Limiting Conditions for Operation
LOCA	Loss Of Cooling Accident

LTO	Long-Term Operation
LWR	Light Water Reactor
MADUK	Measurement network in the vicinity of NPPs (Messnetz zur automatischen Dosisleistungsüberwachung in der Umgebung der Kernkraftwerke)
MCR	Main Control Room
Nagra	National Cooperative for the Disposal of Radioactive Waste (Nationale Genossenschaft für die Lagerung radioaktiver Abfälle)
NBC	Nuclear, Biological and Chemical
NBCN	Nuclear, Biological, Chemical and Natural
NEA	Nuclear Energy Agency of the OECD
NEO	Nuclear Energy Ordinance
NEOC	National Emergency Operations Centre (Nationale Alarmzentrale NAZ)
NEWS	Nuclear Events Web-based System
NGO	Non-Governmental Organisation
NPP	Nuclear Power Plant
NRC	U.S. Nuclear Regulatory Commission
NSC	Nuclear Safety Commission
OBE	Operating Basis Earthquake
OECD	Organization for Economic Co-operation and Development
OHSAS	Occupational Health and Safety Assessment Series
OLNC	OnLine Noble Chemistry primary water operation mode
OSART	Operational Safety Review Teams (IAEA)
PC	Primary Circuit
PEGASOS	Probabilistic Earthquake Hazard Analysis for the Locations of the Nuclear Power Plants in Switzerland (Probabilistische Erdbebengefährdungsanalyse für die KKW-Standorte in der Schweiz)
PGA	Peak Ground Acceleration
PRP	PEGASOS Refinement Project
PSA	Probabilistic Safety Analysis
PSI	Paul Scherrer Institute (research institute)
PSR	Periodic Safety Review
PWR	Pressurised Water Reactor
QM	Quality Management
RCIC	Reactor Core Isolation Cooling
RHR	Residual Heat Removal
RPO	Radiological Protection Ordinance
RPV	Reactor Pressure Vessel
SAMG	Severe Accident Management Guidance
SAR	Safety Analysis Report
SBO	Station Blackout
SER	Safety Evaluation Report
SFOE	Swiss Federal Office of Energy

SFP	Spent Fuel Pool
SIA	Swiss Association of Engineers and Architects (Schweizerischer Ingenieur- und Architektenverein)
SQS	Swiss certification company (Schweizerische Vereinigung für Qualitäts- und Management-Systeme)
SRL	Safety Reference Levels (WENRA)
SSC	Structures, Systems, and Components
SSE	Safe Shutdown Earthquake
SSHAC	Senior Seismic Hazard Analysis Committee
SUSAN	Special emergency system of KKM (Spezielles, unabhängiges System zur Abfuhr der Nachzerfallswärme)
Sv	Sievert
Total-SBO	Total Station Blackout
U.S. NRC	U.S. Nuclear Regulatory Commission
VDNS	Vienna Declaration on Nuclear Safety
W	Westinghouse
WANO	World Association of Nuclear Operators
WENRA	Western European Nuclear Regulators' Association
WGHOF	NEA Working Group on Human and Organisational Factors
WGIP	NEA Working Group on Inspection Practices
WGOE	NEA Working Group on Operating Experience
WOG	Westinghouse Owners Group
ZWILAG	Zwischenlager Würenlingen AG
ZZL	Zentrales Zwischenlager

Appendix 2: List of the Inspectorate's guidelines currently in force

Status: January 2019

Languages: All guidelines are originally published in German. Some guidelines have been translated into French and English.

Note:
- All guidelines are available on the ENSI website (www.ensi.ch).
- Guidelines of the series A cover the assessment of facilities, guidelines of the series B cover the surveillance of operations, and guidelines of the series G are guidelines with general requirements, which cover both, the assessment of facilities and surveillance of operations. Guidelines of the series R were issued before the Nuclear Energy Act and the Nuclear Energy Ordinance entered into force in February 2005.
- The security guidelines are not listed.

Guideline	Title of guideline	Date of current issue
ENSI-G01	Safety classification for existing nuclear power plants	2011/01
ENSI-G02, Part 1	Design principles for operating nuclear power plants: Concepts for safety and design requirements	2016/09
ENSI-G03	Specific design principles for deep geological repositories and requirements for the safety case	2009/04
ENSI-G04	Design and operation of storage facilities for radioactive waste and spent fuel assemblies	2015/06
ENSI-G05	Transport and storage casks for interim storage	2008/04
ENSI-G07	The organisation of nuclear installations	2013/07
ENSI-G08	Systematic safety evaluations of the operation of nuclear installations	2015/06
ENSI-G09	Operational documentation	2014/06
ENSI-G11	Vessels and piping classified as important to safety: Engineering, manufacture and installation	2013/06
ENSI-G13	Radiation protection measuring devices in nuclear installations: Concepts, requirements and testing	2015/10
ENSI-G14	Calculation of radiation exposure in the vicinity due to emission of radioactive substances from nuclear installations	2009/12
ENSI-G15	Radiation protection objectives for nuclear installations	2010/11
ENSI-G17	Decommissioning of nuclear installations	2014/04
ENSI-G20	Reactor core, fuel assemblies and control assemblies: Design and operation	2015/02
ENSI-A01	Requirements for deterministic accident analysis for nuclear installations: Scope, methodology and boundary conditions of the technical accident analysis	2018/09
ENSI-A03	Periodic Safety Review of nuclear power plants	2014/10

ENSI-A04	Application documents for modifications to nuclear installations requiring a permit	2009/09
ENSI-A05	Probabilistic Safety Analysis (PSA): Quality and scope	2018/01
ENSI-A06	Probabilistic Safety Analysis (PSA): Applications	2015/11
ENSI-A08	Analysis of source terms: Extent, methodology and boundary conditions	2010/02
ENSI-B01	Ageing management	2011/08
ENSI-B02	Periodical reporting for nuclear installations	2015/06
ENSI-B03	Reports for nuclear installations	2016/11
ENSI-B04	Clearance measurement of materials and areas from controlled zones	2018/11
ENSI-B05	Requirements for the conditioning of radioactive waste	2007/02
ENSI-B06	Vessels and piping classified as important to safety: Maintenance	2013/06
ENSI-B07	Vessels and piping classified as important to safety: Qualification of non-destructive testing	2008/09
ENSI-B09	Collecting and reporting of doses of persons exposed to radiation	2018/07
ENSI-B10	Basic training, recurrent training and continuing education of personnel in nuclear installations	2010/10
ENSI-B11	Emergency exercises	2013/01
ENSI-B12	Emergency preparedness in nuclear installations	2015/10
ENSI-B13	Training and continuing education of the radiation protection personnel	2010/11
ENSI-B14	Maintenance of electrical and instrumentation and control equipment classified as important to safety	2010/12
HSK-R-07	Guideline for the radiological monitored area of the nuclear installations and the Paul Scherrer Institute	1995/06
HSK-R-08	Structural safety for nuclear power plants, Swiss Federal supervising procedures for construction work	1976/05
HSK-R-16	Seismic plant instrumentation	1980/02
HSK-R-30	Supervisory procedures for construction and operation of nuclear installations	1992/07
HSK-R-31	Supervisory procedures for construction and backfitting of nuclear power plants, 1E classified electrical equipment	2003/10
HSK-R-40	Filtered containment venting of light-water reactors, design requirements	1993/03
HSK-R-46	Requirements for the application of computer-based instrumentation and control important to safety in nuclear power plants	2005/04
HSK-R-50	Requirements important to safety for fire protection in nuclear installations	2003/03
HSK-R-101	Design criteria for safety systems of nuclear power plants with light-water reactors	1987/05
HSK-R-102	Design criteria for the protection of safety equipment in nuclear power stations against the consequences of airplane crash	1986/12
HSK-R-103	On-site measures against the consequences of severe accidents	1989/11

Imprint:
Implementation of the Obligations of the
Convention on Nuclear Safety

Switzerland's Eight National Report
in Accordance with Article 5 of the Convention

Publisher:
Swiss Federal Nuclear Safety Inspectorate ENSI
Industriestrasse 19
CH-5200 Brugg
Phone: +41 56 460 84 00
info@ensi.ch

www.ensi.ch
Cover picture: low pressure turbines
at Leibstadt nuclear power plant.

ENSI-AN-10683

ENSI-AN-10683

ENSI, CH-5200 Brugg, Industriestrasse 19, Telefon +41 (0)56 460 84 00, www.ensi.ch