Schweizerische Eidgenossenschaft
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Swiss Federal Nuclear Safety Inspectorate ENSI

EU STRESS TEST
SWISS NATIONAL REPORT
ENSI REVIEW OF THE OPERATORS' REPORTS

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Eidgenössisches Nuklearsicherheitsinspektorat ENSI
Inspection fédérale de la sécurité nucléaire IFSN
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Swiss Federal Nuclear Safety Inspectorate ENSI

EU Stress Test: Swiss National Report

ENSI review of the operators' reports

Executive summary

Context

The EU stress test is part of the review process which Switzerland initiated immediately after the reactor accident in Japan.

The earthquake on 11 March 2011 and the resultant tsunami led to severe accidents with core melt in three nuclear power plant units at the Fukushima Dai-ichi site. On 12 April 2011, these events were classified by the Japanese authorities as INES 7 ("major accident").

As a direct consequence of the major accident in Japan, ENSI issued three formal orders (on 18 March 2011, 1 April 2011 and 5 May 2011) in which the operators of the Swiss nuclear power plants were required to implement immediate measures and to conduct additional re-assessments. The immediate measures comprised the establishment of an external emergency storage facility for the Swiss nuclear power plants, including the necessary plant-specific connections, and back-fittings to provide external injection into the spent fuel pools. The additional re-assessments, which were to be carried out immediately, focused on the design of the Swiss nuclear power plants against earthquakes, external flooding and a combination thereof. Investigations on the coolant supply for the safety systems and the spent fuel pool cooling considering the first insights gained from the accident in Japan were also requested.

In addition to the aforementioned orders, and on the basis of the internationally accessible information, ENSI carried out an analysis of the events at Fukushima and published the results in four reports. These reports provide detailed descriptions of the causes, consequences and radiological impacts of the accident at Fukushima; they analyse the contributory human and organisational factors, and specify lessons that can be derived from this information together with 37 specific checkpoints for further investigation.

In a fourth formal order on 1 June 2011, the Swiss nuclear safety authority ENSI instructed the Swiss operators to take part in the EU stress test. The EU Commission adopted a specification regarding the content and time-frame for the EU stress test on 25 May 2011. For the purposes of the EU stress test, there was to be particular examination of the robustness of the nuclear power plants in case of impacts beyond the design basis due to earthquakes, external flooding and extreme weather conditions, loss of power supply and heat sink, and severe accident management. As the first step, it was necessary to present the hazard assumptions and design bases for the nuclear power plants (design basis), and to assess their adequacy. In the second step, the objective was to identify and evaluate the protective measures implemented and their safety margins (safety margins) as compared to the design, including any weak points that might be present. In conclusion, improvement measures were to be derived from this information as appropriate.

The operators of the Swiss nuclear power plants submitted their reports promptly by 31 October 2011 and ENSI has reviewed them.

Results

The submissions by the operators of the Swiss nuclear power plants and the results of ENSI's review confirm that the Swiss nuclear power plants display a very high level of protection against the impacts of earthquakes, flooding and other natural hazards, as well as loss of electrical power and ultimate heat sink. All the accidents analysed can be controlled, taking account of the current hazard assumptions. In addition, the operators have implemented extensive preventive and mitigative provisions. The statutory requirements on safety provisions needed to fulfil the fundamental safety functions (control of reactivity, cooling of the fuel assemblies and confinement of radioactive substances) are therefore met.

Up to three safety trains are available in the Swiss nuclear power plants in order to achieve and maintain the safe shutdown state for those events analysed in connection with the EU stress test. These safety trains consist of the conventional safety systems, the special emergency systems and the accident management measures required at legal level.

The safety margins determined are mainly attributable to the robust design of the special emergency systems that are in place at all Swiss nuclear power plants. The systems have special protection against external events, and they also have an independent power supply and a separate supply of cooling water.

In overall terms, eight new "open points" were identified which ENSI will follow up to further improve the safety of the Swiss nuclear power plants. These open points together with the checkpoints identified in the analysis of the events at Fukushima, are being processed according to their importance and urgency in an action plan. The action plan should be detailed on a yearly basis and illustrate the ENSI forthcoming oversight activities related to Fukushima. ENSI has set the ambitious goal of investigating the identified issues and implement the derived measures by 2015.

Reactor

Earthquakes

One important basis for the determination of the current hazard assumptions in Switzerland was a seismic study performed for all the power plant sites with the same methodology for the first time in the late 1970s. The Swiss nuclear power plants display adequate protection against the 10,000-year earthquake based on these assumptions. In addition, the operators reported safety margins beyond the design basis. ENSI however identified the following open points that require further examination: automatic scram via the seismic instrumentation, seismic robustness of the isolation for the containment and the primary circuit, and seismic stability of containment venting.

Taking account of the latest knowledge, the existing seismic hazard assumptions can no longer be assessed as adequate. Even before the EU stress test, ENSI therefore requested new seismic proof to be submitted by 31 March 2012.

Flooding

The current hazard assumptions were redetermined in the general licence applications for new nuclear power plants (2008) or the new safety demonstration for flooding as required by ENSI (2011). The Swiss nuclear power plants display adequate protection against the 10,000-year flood based on these assumptions. In addition, the operators reported safety margins beyond the design basis. ENSI however identified the following open point that requires further examination: complete blockage of hydraulic engineering installations because of debris.

Extreme weather conditions

For the purpose of the design of the plants, the hazard assumptions were defined on the basis of rules and standards valid at the time, in particular those of the Swiss Association of Architects and Engineers. In individual cases (regarding extreme temperatures in particular) it can be derived from operational experience that more attention must be devoted to the assessment of the potential effects of climate change. ENSI identified the following open point that requires further examination: review of the existing hazard assumptions and the associated proof in order to determine whether these elements are up to date.

It should be noted that the loads due to extreme winds, tornados, snowfall and rainfall are covered by other loads (e.g. aircraft crash or explosion), which form the current basis for the design of nuclear buildings that are important to safety.

Loss of power supply

The staggered loss of the offsite power supply (LOOP), of the emergency power supply (SBO, Station Blackout) and of the special emergency supply (Total SBO, Total Station Blackout) were examined.

The Swiss nuclear power plants display adequate protection against the loss of power, including the SBO scenario, in accordance with the design basis because, in addition to the emergency power supply, an independent special emergency power supply is available. These supplies, which ensure operation of the systems required for safety purposes, can be operated autonomously for 72 hours (with the exclusive use of local equipment).

In order to control the total SBO scenario (as a scenario beyond the design basis), battery-powered DC (direct current) power supplies and mobile accident management (AM) 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. For the purpose of bringing an incident under control at the boiling water reactors, steam-driven high-pressure injection systems supplied exclusively from batteries are used to bridge over the period until AM measures are implemented for the low pressure injection. In the case of the pressurised water reactors, the AM measure of secondary heat removal via the steam generators ("feed and bleed") is of crucial importance.

ENSI identified the following open point: development of a comprehensive strategy for the targeted deployment of the mobile accident management diesel generators to ensure operation of selected DC or AC (alternate current) consumers in the long term in case of a total SBO (or an SBO, respectively).

Loss of ultimate heat sink

Three nuclear power plants have a full-scale alternative supply of cooling water from groundwater wells at their disposal in order to bring a failure of the primary ultimate heat sink under control. In the case of the Mühleberg nuclear power plants, however, a blockage of both cooling water intakes (which is very unlikely) means resorting to an additional supply option that was back-fitted during the 2011 plant outage and is ensured by means of mobile pumps. For the purposes of long-term operation, a diverse heat sink is also to be back-fitted here at ENSI's request.

A failure of the primary ultimate heat sink and of the alternative heat sink does not represent an aggravation compared to the total SBO scenario.

Severe accident management

Every Swiss nuclear power plant has its own emergency response organisation that replaces the normal operating organisation in case of an emergency, and which can resort to specially protected emergency rooms and its own means of communication. The structure of the emergency response organisation is stipulated in the emergency preparedness procedures, which constitutes a key document that is approved by ENSI. The preparedness and suitability of the emergency response organisation is reviewed at regular intervals during emergency exercises.

Each nuclear power plant has extensive procedures which contain targeted preventive measures to prevent core damage. In addition, decision-making aids for accident management (Severe Accident Management Guidance, SAMG) have been developed on the basis of international standards and plant-specific analyses of severe accident phenomena. This guidance comprises mitigative measures in order to prevent severe core damage, to retain a destroyed core in the reactor pressure vessel and, in particular, to maintain the integrity of the containment as the last retention barrier after core melt. These procedures and guidance cover both power and non-power operation, and their suitability is reviewed at regular intervals during emergency exercises based on different accident scenarios.

In order to implement the accident management measures contained in the procedures and decision-making aids, numerous items of mobile emergency equipment are kept in protected storage on the sites, and they can be aligned to to permanently installed connection points in the plants. The Swiss nuclear power plants also have permanently installed systems for containment flooding and venting, and for reducing hydrogen in the containment. Moreover, as a consequence of the events at Fukushima, a central external emergency storage facility has been set up. The emergency equipment and materials stored there can be made available by helicopter in order to bring severe accidents under control, in addition to the emergency equipment that is already available on the sites.

ENSI identified the following open points: existing deployment strategies for the containment venting systems in case of severe accidents, and restoration of containment integrity during shutdown conditions in case of a total SBO.

Spent fuel pools

The spent fuel pools (SFP) at the Swiss nuclear power plants are adequately protected against the events that were examined, namely earthquake, flooding and extreme weather conditions. The integrity of the SFPs is therefore ensured as an essential prerequisite in order to maintain cooling of the fuel assemblies stored in them. Cooling of the SFPs is guaranteed for a period of at least 98 hours (during which the fuel is covered) due to the large water inventory.

According to their design basis, the two newer nuclear power plants in particular have robust SFP cooling systems. In case of severe earthquakes and floods at the two older nuclear power plants, long-term SFP cooling can only be ensured by means of accident management measures, for which sufficient time is available. Prior to the EU stress test, ENSI requested the back-fitting of a new and specially protected SFP cooling system in connection with the review of SFP cooling for the two older nuclear power plants.

Targeted accident management measures for SFP cooling are stipulated in procedures at all Swiss nuclear power plants. Based on knowledge gained from Fukushima, ENSI nevertheless requested additional measures in order to improve emergency injection to the SFPs, the removal of heat and the monitoring of the SFPs.

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0 Introduction and procedure

0.1 Nuclear supervision in Switzerland

ENSI, the Swiss Federal Nuclear Safety Inspectorate, is the Federal government's supervisory body for the nuclear energy sector. ENSI is an independent public-law entity which supervises Switzerland's nuclear facilities. These nuclear facilities include the nuclear power plants, the interim storage facilities for radioactive waste and the nuclear research facilities of the Paul Scherrer Institute in Villigen, the Swiss Federal Institute of Technology in Lausanne (Ecole Polytechnique Fédérale de Lausanne) and the University of Basel. The scope of ENSI's supervision extends from the planning, construction, operation and shutdown of the facilities to the disposal of radioactive waste. The authority's remit also includes radiation protection for staff and the general public, as well as protection against sabotage and terrorism. In addition, ENSI supervises the transport of radioactive substances from and to the nuclear facilities, and the studies regarding geological disposal of radioactive waste. Licensing procedures for new nuclear power plants were in place in Switzerland before the events at Fukushima; ENSI was involved in these procedures, and it compiled safety assessment reports for this purpose.

0.2 Considerations by ENSI

On 11 March 2011, the Tohoku-Chihou-Taiheiyou-Oki earthquake and the ensuing tsunami led to severe accidents with core meltdown in three nuclear power plant units at the Fukushima Dai-ichi (Fukushima I) site in Japan. On 12 April 2011, these events were classified by the Japanese authorities as INES 7 ("major accident").

As a direct consequence, ENSI issued three orders to the Swiss nuclear power plants on 18 March 2011 /A-2/, on 1 April 2011 /A-3/ and on 5 May 2011 /A-4/, in which immediate measures and additional re-assessments were required. The immediate measures include setting up an external storage facility for emergency equipment for the nuclear power plants, including the necessary plant-specific connections and back-fitting of feed lines for the external supply of the spent fuel pools. The re-assessments to be conducted immediately (among others on the basis of the provisional shutdown Ordinance /A-9/) focused on the design of the Swiss nuclear power plants in respect of earthquakes, external flooding and the combination of both events, as well as on the coolant supply for the safety and auxiliary systems and the spent fuel pool cooling. In parallel with these investigations, inspections related to key issues were carried out, namely inspections of the existing spent fuel pool cooling systems, of the protection against external flooding and of the filtered containment venting systems.

In a fourth order /A-5/ on 1 June 2011, the Swiss licensees were asked to take part in the EU stress test. The content and timeframe for the EU stress test were stipulated by the EU Commission in a Specification /A-1/ on 25 May. This specification was drawn up by WENRA (Western European Nuclear Regulators Associations) and adopted by ENSREG (European Nuclear Safety Regulators Group), which comprises members of the nuclear supervision authorities of the EU member states.

The following Table 0-1 shows the investigations and back-fitting measures set in motion in the Swiss nuclear power plants, and the timeline for their implementation.

On the basis of the reviews conducted to date, the operators and ENSI have derived a number of improvement measures that are detailed in the following sections of this report.

Table 0-1: Investigations and back-fitting measures for the Swiss NPPs

Date	Type	Subject
18.03.2011	Order	**First order** by ENSI ordering a design re-assessment related to the provisional shutdown criteria with regards to earthquakes and flooding, a re-assessments of cooling water supply and spent fuel pools, and the implementation of immediate measures regarding emergency management
31.03.2011	Report	Operators' submission of data on the design of the cooling water supply and of the spent fuel pools
01.04.2011	Order	**Second order** by ENSI to define the conditions for the design re-assessment related to the provisional shutdown criteria
05.05.2011	Order	**Third order** by ENSI with the review results on the reports submitted by the operators on 31.03.2011 and additional conditions derived therefrom in connection with the improvement measures to be submitted on 31.08.2011, and with the requirement for additional proof for the spent fuel pools
01.06.2011	Implementation	An shared external storage facility for emergency equipment was set up by the operators
01.06.2011	Order	**Fourth order** by ENSI asking the operators to perform the assessments of the EU stress test
30.06.2011	Proof	Operators' submission of revised proof of safety in case of flooding
15.08.2011	Report	Operators' submission of progress reports on the EU stress test
31.08.2011	Statement	Statement by ENSI regarding the review results on the proof of safety in case of flooding submitted on 30.06.2011
31.08.2011	Report	Operators' submission of improvement measures in the areas of cooling water supply and spent fuel pools
15.09.2011	Statement	Statement by ENSI regarding the EU stress test progress reports submitted on 15.08.2011
31.10.2011	Report	Operators' submission of final reports for the EU stress test (Operators' Reports)
15.11.2011	Statement	Statement by ENSI with the review results regarding the improvement measures submitted on 31.08.2011
21.11.2011-02.12.2011	Statement	Statement by the IAEA regarding the (IRRS) review mission to ENSI
30.11.2011	Proof	Operators' submission of documents related to seismic resistance
31.12.2011	Statement	Statement by ENSI with the review results on the EU stress test final reports (Operators' Reports) submitted on 31.10.2011
31.03.2012	Proof	Operators' submission of revised proof of safety in case of earthquakes and combination of earthquake and earthquake-induced dam failure
31.03.2012	Report	Submission of operators' reports on protection against hydrogen deflagrations and explosions in the area of the spent fuel pool
30.06.2012	Statement	Statement by ENSI with the review results on the proof of seismic safety submitted on 31.03.2012
30.06.2012	Statement	Statement by ENSI with the review results on the reports submitted on 31.03.2012 concerning protection against hydrogen deflagrations and explosions in the area of the spent fuel pools
31.12.2012	Implementation	Back-fitting of connections for mobile external emergency equipment

Above and beyond the quoted orders and on the basis of internationally accessible information, ENSI has carried out an analysis of the events at Fukushima and has published the results in four reports. These reports provide detailed descriptions of the causes and consequences of the sequences of events at Fukushima Dai-ichi and Dai-ni /A-14/, analyses of the contributory human and organisational factors /A-15/, and statements on the Lessons Learned and specific checkpoints /A-16/ that can be derived from these findings. These checkpoints will be followed up in the coming years on the basis of key thematic issues in the frame of ENSI oversight activities. The fourth, most recent report /A-17/ deals with the radiological consequences of the Fukushima accident.

0.3 Scope of ENSI review

ENSI's order dated 1 June 2011 regarding its participation in the EU stress test /A-5/ is based on Article 36, paragraph 3 of the Nuclear Energy Ordinance (NEO) /A-7/, according to which the operators must keep track of operating experience in comparable plants, and must assess its significance for their own plants. The scope of the investigations to be carried out in connection with the stress test is essentially stipulated by the ENSREG specifications /A-1/. The table of contents for the final reports to be submitted by the operators was further detailed on the basis of the review insights gained as a result of the orders already issued by ENSI /A-11/.

In connection with the EU stress test the following aspects must be examined: the robustness of nuclear power plants in case of impacts beyond the design basis due to earthquakes, external flooding and extreme weather conditions, as well as loss of the power supply and of the heat sink. For this purpose, the first step is to set out the hazard assumptions and design bases for the nuclear power plants and to evaluate their adequacy. As a second step, the protective measures initiated and the safety margins in relation to the design, together with any cliff-edge effects[1], must be identified and evaluated. Finally, any relevant improvement measures must be derived from this information.

In their letters /B-1/, /G-1/, /L-1/ and /M-1/, the operators of the Swiss nuclear power plants submitted on time their progress reports on the EU stress test by 15 August 2011. These reports contain information about the work progress, the methodology applied for the final EU stress test report, the studies utilised and the first interim results. ENSI commented on these reports /A-12/ and concluded that all the operators have defined the "safe shutdown state" and that the information is compliant with the Swiss regulations. The methods used to reassess the plants were presented by the operators in an easily comprehensible form. In respect of earthquakes and flooding, the operators were able to refer to the latest studies, such as the plant-specific probabilistic safety analyses, or the proof of protection against flooding submitted in June 2011. From ENSI's viewpoint, the procedures outlined by the operators in their progress reports differed in their level of detail, but were basically in accordance with ENSI's expectations.

Finally, in letters /B-2/, /G-2/, /L-2/ and /M-2/, the operators of the Swiss nuclear power plants submitted on time the final reports on the EU stress test to ENSI by 31 October 2011. ENSI has reviewed these reports in accordance with the legal bases quoted below.

[1] A "cliff-edge effect" denotes an abrupt aggravation of the progression of an accident. An aggravation of this sort may occur, for example, if the capacity of the batteries is exhausted after failure of the entire alternating current supply (Total Station Blackout, Total SBO).

0.4 Legal basis

The statutory and regulatory framework for the peaceful use of nuclear energy is stipulated by the Swiss constitution (first level), Federal legislation (second level), the ordinances (third level) and the ENSI guidelines (fourth level). Legislation regarding the use of nuclear energy and radiation protection is enacted solely at national level. The Federal Parliament and the Federal Council have the sole right to enact laws in this area. The material provisions regarding authorisation and regulation, monitoring and inspection are based on the Nuclear Energy Act (NEA) /A-6/, the Federal Law on Radiological Protection (RPA) /A-22/ and the ENSI Act (ENSIG) /A-30/.

For the EU stress test the fundamental provisions of the Nuclear Energy Act /A-6/ regarding the principles of nuclear safety and the operators' responsibilities for the safety of their nuclear power plants apply, as well as the fundamental requirements in the Nuclear Energy Ordinance /A-7/ (NEO) and in the Ordinance of the Federal Department of the Environment, Transport, Energy and Communications (DETEC) on Hazard Assumptions and the Evaluation of Protection Measures against Accidents in Nuclear Installations /A-8/ (DETEC-O).

Articles 7, 8 and 10 of the NEO contain internationally recognised principles to guarantee the safety of nuclear facilities. The strategy specified in Article 7 to ensure the nuclear safety of nuclear facilities at four levels (the "defence in depth" concept) is stated in more practical detail in Articles 8 and 10. According to Article 8, protective measures for nuclear facilities must be implemented against accidents which originate both inside and outside the facility. In addition, those accidents which must be brought under control without an inadmissible release of radioactive substances are explicitly stated. Article 10 defines principles for the design of the safety functions of nuclear power plants. These include, in particular, the single failure criterion, the principles of redundancy and diversity, the functional and physical separation, the automation principle and the conservativism in design. As regards compliance with these design requirements, however, the applicable principle according to Article 82, NEO, is that existing nuclear power plants should be back-fitted only to the extent that is necessary on the basis of experience and the state-of-the-art in back-fitting technology and, beyond that, insofar as this results into a further reduction of risk and is appropriate.

The DETEC-O stipulates hazard assumptions for accidents which originate inside and outside the plant, as well as the radiological and technical criteria for proof of adequate protection against accidents. Accordingly, hazards due to natural events, in particular earthquakes, flooding and extreme weather conditions, must be determined with the help of probabilistic hazard analysis. For proof of adequate protection against natural events, a account must be taken of hazards with a frequency greater than or equal to 10^{-4} per year.

ENSI is responsible for drawing up guidelines which are support documents that formalise the implementation of legal requirements and facilitate uniformity of implementation practices. While compliance with the laws and ordinances by the operators is mandatory, ENSI 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.

In connection with the harmonisation of European regulations, ENSI has reviewed the body of Swiss regulations on the basis of the Safety Reference Levels of WENRA (the Western European Nuclear Regulators' Association). At present, about twenty percent of the Safety Reference Levels have yet to be adopted in ENSI guidelines. In parallel the Swiss nuclear power plants have checked implementation of the WENRA Safety Reference Levels in their installations. ENSI reviewed their assessment and confirmed the operators’ conclusion that for all practical purposes all the Reference Levels are already implemented in the plants.

For the IAEA IRRS mission that ENSI hosted from 21 November to 2 December 2011, a review of the Swiss regulations compared to the IAEA Safety Requirements NS-R-1 (design) and NS-R-2 (operation) was performed by ENSI. The comparison resulted in a high degree of compliance (88% and 84% respectively) and confirmed that the Swiss regulations are up-to-date and fully in line with established international standards.

0.5 Methodology

On the basis of the requirements stipulated by the ENSREG specifications, this report distinguishes between the following hazard levels:

- H1 Hazard that the plant was originally designed to withstand;
- H2 Hazard for which the plant was requalified (may be identical to H1);
- H3 New hazard assumptions.

The new hazard assumptions are based on studies that were already requested by ENSI on the basis of new knowledge prior to the events in Japan, or which were carried out in connection with the licensing procedures for new nuclear power plants in Switzerland or with the orders issued by ENSI. Detailed information on the hazard levels for earthquakes and flooding is provided in sections 2 and 3 of this report.

0.6 Classification of referenced documents

The documents referenced by the operators are classified as follows:

- D1 Validated in the licensing process, or ENSI has at least conducted a preliminary review;
- D2 Not D1, but quality-assured by the operator;
- D3 Neither D1 nor D2.

Reference documents from the IAEA or equivalent organisations need not be classified. Detailed information on the referenced documents is provided in sections 2 to 6 of this report.

0.7 Definition of Safe Shutdown State

According to the Swiss regulatory requirements, a Safe Shutdown State is achieved if the technical criteria pursuant to Articles 9 to 11 of the DETEC Ordinance /A-8/ on Hazard Assumptions and the Evaluation of Protection Measures against Accidents in Nuclear Installations are met. For accidents in categories 1 to 3 (frequency: 10^{-1}/y to 10^{-6}/y), these include compliance with the fundamental safety functions of control of reactivity, cooling of radioactive material, and confinement of radioactive material. It therefore follows from the Swiss regulations that the two plant states - "hot shutdown" and "cold shutdown" - are both to be understood as safe shutdown states.

The plant-specific technical shutdown criteria during normal operation and operational events are stated in the technical specifications for nuclear power plants as per Annex 3 of the NEO /A-7/. The technical specifications also stipulate the conditions under which the plant must be brought into the "hot shutdown" or "cold shutdown" states.

According to the ENSREG-requirements /A-1/, the proof that the safe shutdown state is ensured for several days must be based on the assumption of a loss of off-site power.

1 General data about sites and nuclear power plants

In the following section, ENSI provides an overview of the locations and main characteristics of the nuclear power plant units in Switzerland. This section also describes back-fitting measures carried out in the past that take on particular importance for the purposes of the EU stress tests, together with key safety features. For detailed plant descriptions, please refer to the detailed presentations in the operators' final reports.

1.1 Brief description of the site characteristics

There are a total of five nuclear power plant units at four different sites in Switzerland (see Figure 1-1). These are: the Beznau nuclear power plant (KKB) with two units, and the Gösgen (KKG), Leibstadt (KKL) and Mühleberg (KKM) nuclear power plants with one unit each. These plants contribute about 40% of the country's total electricity production. All the Swiss nuclear power plants are located next to rivers and in seismically relatively inactive zones. The subsequent sections of this report cover special site-specific features. The holders of operating licences for the nuclear power plants are shown in Table 1-1.

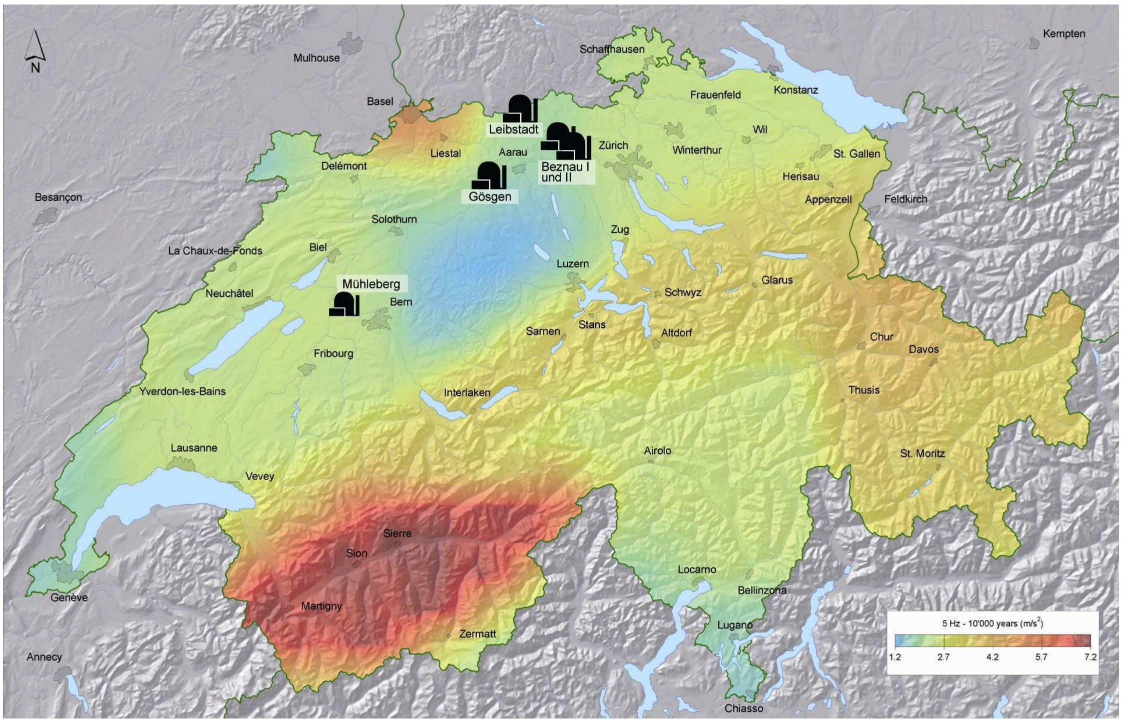

Figure 1-1: Map of seismic hazard for Switzerland (Source: Swiss seismology Centre ETH Zürich) with locations of Swiss Nuclear power plants

1.2 Main characteristics of the units

Three of the Swiss nuclear reactors are pressurised water reactors (PWR); two of these are of American design and one is of German design. The other two Swiss nuclear reactors are American boiling water reactors (BWR) of different generations. The units of the Beznau nuclear power plant have been in operation for over 40 years, and the unit at the Mühleberg nuclear power plant has operated for almost 40 years. The key technical data for the nuclear power plants are shown in Table 1-1 below.

Table 1-1: Key data for the Swiss nuclear power plants

	KKB 1	**KKB 2**	**KKG**	**KKL**	**KKM**
Thermal power [MW]	1130	1130	3002	3600	1097
Gross electrical output [MW]	380	380	1035	1220	390
Net electrical output [MW]	365	365	985	1165	373
Reactor type	PWR	PWR	PWR	BWR	BWR
Reactor supplier	W	W	KWU	GE	GE
Turbine supplier	BBC	BBC	KWU	BBC	BBC
Generator data [MVA]	2 x 228	2 x 228	1140	1318	2 x 214
Main heat sink	River water	River water	Cooling tower	Cooling tower	River water
Commercial operation started in	1969	1971	1979	1984	1972
Spent fuel pools (SFP)	2 SFPs in separate building	2 SFPs in separate building	1 SFP in P-containment, 1 SF loading pond in S-containment	1 SFP in P-containment, 1 SFP in separate building	1 SFP in S-containment
Interim waste storage facility	Internal interim storage facility (air-cooled)	Internal interim storage facility (air-cooled)	External wet storage facility	External interim storage facility	Internal interim storage facility
Holder of operating licence	Axpo AG	Axpo AG	Kernkraftwerk Gösgen-Däniken AG	Kernkraftwerk Leibstadt AG	BKW FMB Energie AG
Number of reactor cooling loops	2	2	3	-	-
Containment type	Full pressure containment	Full pressure containment	Full pressure containment	Mark III containment with venting system	Mark I containment with venting system

The safety of Switzerland's nuclear power plants is examined comprehensively during the Periodic Safety Reviews (PSR) which are required by law every 10 years at the latest. This review process has led to numerous refurbishment and back-fitting measures in the past. Major back-fitting measures that are particularly important in connection with the EU stress test are listed below.

- Since the 1990s, all the nuclear power plants have additional, independent special emergency systems in a separate, bunkered building. These systems serve in particular to provide protection against natural and man-made external events; they were back-fitted in the older nuclear power plants (KKB and KKM) whereas they constituted from the beginning a design element for the newer nuclear power plants (KKG and KKL).
- Since the 1990s, all the nuclear power plants have a filtered containment venting system to mitigate the consequences of a severe accident. This system consists of a passive train that is secured by a rupture disk in normal operation, and an active train secured by motor- and hand-operated valves. To enable the controlled discharge of radioactive substances, the valves in the active train may be opened either from the control room or manually from a radiologically protected area.
- Since the 1980s, systems to prevent hydrogen explosions have been gradually back-fitted in all nuclear power plants. Besides H_2 monitoring equipment, the following equipment has also been installed, depending on the nuclear power plant: passive autocatalytic recombiners, H_2 mixing systems, H_2 ignition systems in the primary containment, and N_2 systems to inert the primary containment.
- Since the 1990s, alternative feed lines to the reactor pressure vessel and the primary containment have been gradually back-fitted in all the nuclear power plants for the purposes of emergency management (Accident Management, AM); these feed lines aim at preventing core damage, or mitigating the effects of a core damage. Depending on the nuclear power plant, either permanently installed systems (e.g. hilltop reservoirs or fire extinguishing networks) and/or mobile equipment (fire extinguishing pumps or fire brigade vehicles) are available to supply coolant.
- To complement the existing emergency procedures, written decision-making aids to mitigate the effects of severe accidents (Severe Accident Management Guidance, SAMG) have been developed over the last ten years on the basis of the Level 2 Probabilistic Safety Analyses in all the nuclear power plants, both for power and non-power operation.

In addition to these back-fitting measures, numerous further upgrade measures have been implemented in Swiss nuclear power plants in the past; their overall aim was to continue improving the provisions at the individual levels of the "defence in depth" concept. This improvement process is being pushed forward consistently with the immediate measures implemented after the events in Fukushima and the back-fitting measures derived from the investigations.

1.3 Description of the systems for execution of main safety functions

To allow a clear presentation of the safety systems present in the Swiss nuclear power plants they have been subdivided into three "Safety trains" by which the plants can be brought into a safe shutdown state in case of accidents. The safety trains can be used in all plant operational states (full power operation as well as low power and shutdown states). The characteristics of the three safety trains are described below:

Safety train 1: This consists of the conventional safety systems which are used to control accidents due to internal events (such as loss of coolant accidents (LOCAs), internal flooding) and, depending on the original design concept of the nuclear power plant, external events related to natural causes (such as earthquakes and external flooding). The conventional safety systems of the older nuclear power plants (KKB and KKM) are not entirely designed to withstand earthquakes, whereas the safety systems in the newer nuclear power plants (KKG and KKL) are protected against earthquakes by design. Moreover, and especially in relation to the design principles of functional independence, physical separation and level of automation, there are differences between the safety systems of older and newer nuclear power plants. In contrast to the newer nuclear power plants, the older plants were not built consistently complying with those principles, though they satisfy the single failure criterion by means of redundant system trains. In all nuclear power plants, control and monitoring of the conventional safety systems is handled via the main control room. Examples of conventional safety systems include the emergency core cooling systems with which the reactor core can be cooled and the decay heat can be removed.

Safety train 2: The special emergency systems ("Notstandsysteme") constitute another safety train which is primarily intended to control accidents due to external events, but which also provides further protection in addition to the conventional safety systems in the case of internal events. Special design features of the special emergency systems include their functional independence and physical separation from the conventional safety systems, and an autarkic operation of at least 10 hours without manual intervention. In all the nuclear power plants, control and monitoring of the special emergency systems is handled via an emergency control room ("Notsteuerstelle"), which is also specially protected and is both physically and functionally separated from the main control room. Examples of special emergency systems include the special emergency core cooling systems, although (depending on the nuclear power plant) these do not cover all the functions of the conventional emergency core cooling systems. For instance, the special emergency core cooling systems on the boiling water reactors do not have a high-pressure injection, but they do have venting and a low-pressure injections as redundant functions.

Safety train 3: The preventive accident management measures implemented in all nuclear power plants constitute the third safety train. This train consists exclusively of manual measures that are to be implemented locally by operating staff; they are stipulated in specific emergency procedures, are ordered by the emergency staff and are carried out with the deployment of either permanent built-in or mobile equipment.

Table 1-2 shows which of the aforementioned safety trains should be used to ensure the fundamental safety functions. More detailed information about each of the plant-specific safety trains is available in the operators' final reports.

Table 1-2: Fundamental safety functions and safety trains

Fundamental safety functions	**Safety functions**	**Plants**											
		KKB			**KKG**			**KKL**			**KKM**		
		1	2	3	1	2	3	1	2	3	1	2	3
Control of reactivity	Shutdown of reactor and ensured sub-criticality	X	X	X	X	X	X	X	X	X	X	X	X
Cooling of fuel assemblies	Removal of decay heat from the reactor and reduction of pressure	X	X	X	X	X	X	X	X	X	X	X	X
	Removal of decay heat from the SFP and wet storage facility	X	-	X	X	X	X	X	-	X	X	-	X
	Removal of decay heat from the primary containment	X	X	X	X	-	X	X	X	X	X	X	X
Containment of radioactive substances	Isolation of primary containment	X	-	X	X	-	X	X	-	-	X	-	-
	Protection of primary containment integrity by:												
	Venting of the primary containment	-	-	X	-	-	X	-	-	X	-	-	X
	Prevention of deflagration and explosion of hydrogen	-	-	X	-	-	X	-	-	X	-	-	X

Legend:

1: Conventional safety systems

2: Special emergency systems

3. Accident management measures

1.4 Significant differences between units

The two units at the Beznau nuclear power plant are largely identical. There are only some slight differences relating to a small number of auxiliary functions, but these are not significant for the purposes of the EU stress test.

1.5 Use of PSA as part of the safety assessment

Amongst other purposes, the Probabilistic Safety Analysis (PSA) is used to assess the risk that a severe accident may occur in a nuclear power plant. A severe accident is defined as an event, due to which the reactor core can no longer be cooled, with the consequence that it starts to melt.

The risk of core damage and the risk of radioactive releases are determined in two steps which are designated as "Level 1 PSA" and "Level 2 PSA". The Level 1 PSA comprises a determination of those accident sequences that cause severe damage to the reactor core (up to a core meltdown). One of the outcomes of the Level 1 PSA is the determination of the core damage frequency. The Level 2 PSA, which builds on the results from the Level 1 PSA, comprises an analysis of the progression of core damage until radioactive substances are released into the environment. In this case, a period of at least 48 hours after the occurrence of the initiating event is taken into account for the containment function. The release frequency as well as the characteristics and amount of the released radioactive material are determined as a result of the Level 2 PSA.

PSAs in Switzerland are subject to a continuous improvement and review process (Living PSA).

Operators' main results

All the operators' final reports cover the specific PSAs for their respective plants.

The operators show that the initiating events covered by their PSAs include internal events such as fires, loss of coolant or failures of heat removal, as well as external events, such as earthquakes, accidental aircraft crashes or floods. For all the nuclear power plants, the Level 1 PSA includes a probabilistic assessment of power and non-power operation. The Level 2 PSA includes a probabilistic assessment of power operation for all the nuclear power plants, and for KKB, KKG and KKM (in part) it also includes a probabilistic assessment of non-power operation.

In particular, the operators report the overall results of the PSA on the basis of two key risk indicators, namely core damage frequency and LERF (Large Early Release Frequency), and/or in some cases, they provide a qualitative presentation of these results. In order to determine the LERF, KKB takes account of the seismic back-fits to improve the containment isolation that were implemented in 2011 and will be implemented in 2012.

The operators' main results regarding the PSA are based largely on D1 documents. Some of the information provided by KKM (especially regarding earthquakes) is based on new calculations which KKM does not explicitly classify.

ENSI review

ENSI is essentially in agreement with the classification of the referenced documents. It should be noted that the PSAs for KKG and KKM are currently undergoing another detailed review by ENSI in connection with the evaluation of the Periodic Safety Review. The initial results of this review have been communicated to the operators, and the operators' reports take ENSI review comments into account, at least partially. From ENSI's viewpoint, the PSA results considering more recent calculations and submitted by KKG and KKM in connection with the EU stress test shall be designated as D2.

In ENSI's view, the operators' PSAs are generally comprehensive and detailed. All the relevant internal and external initiating events are taken into account. The extension of the Level 2 PSA to include an assessment of non-power operation, initiated on the basis of new legal requirements, has been implemented for KKB and KKG. In the case of KKM, this analysis is available for internal events and will be completed in 2012. A corresponding analysis for KKL will be available in 2013.

The probabilistic safety objectives recommended by the IAEA for existing plants are attained, according to the information and presentations provided by the operators (for KKB, this applies even when the aforementioned seismic back fits are not considered). This assessment already takes account of the stricter seismic hazard assumptions based on the results of the PEGASOS project (Probabilistic Seismic Hazard Analysis for Swiss Nuclear Power Plant Sites, see also section 2). The seismic PSAs will undergo further refinement in the coming years (especially after a new seismic hazard analysis becomes available following the completion of the PEGASOS Refinement Project).

As part of its integrated reactor oversight, ENSI pursues the goal of systematically integrating the findings from the deterministic and probabilistic safety assessments into its decision-making processes. For this purpose, the probabilistic evaluation is incorporated into the assessment of requested plant modifications (including also changes to the Technical Specifications), the evaluation of operational experience, and the determination of the component importance in relation to safety. This approach resulted in specific improvements to the plants and, in ENSI's view, it has proven its merits.

2 Earthquakes

Specified conditions regarding the hazard assumptions

ENSI has specified three different seismic hazard levels for the seismic hazard assumptions to be considered in the stress test:

- H1 Hazard which the plant was originally designed to withstand;
- H2 Hazard for which the plant was requalified (may be identical with H1);
- H3 Hazard which is to be taken as the basis for the new deterministic proof regarding the 10,000-year earthquake (to be submitted by 31 March 2012) in accordance with the latest seismic hazard studies.

The seismic hazards against which the Swiss nuclear power plants were originally designed (hazard level H1) are based on individual underlying assumptions and requirements which essentially corresponded to the state-of-the-art during the various periods when the nuclear power plants were planned and built. Since the plants were commissioned, ENSI (or HSK, as it then was) triggered several re-assessments of the seismic hazard. In the course of this ongoing development, ENSI asked the nuclear power plant operators at the end of the 1990s to re-determine the seismic hazard in accordance with the latest methodological fundamentals, and in particular to provide a comprehensive quantification of the uncertainty of the calculation results.

In order to implement ENSI's requirement, the nuclear power plant operators commissioned the PEGASOS project (Probabilistic Seismic Hazard Analysis for Swiss Nuclear Power Plant Sites) which was carried out in the period from 2001 to 2004. In PEGASOS, the seismic hazard was re-determined on the basis of a probabilistic method (SSHAC Level 4) developed in the US. To take comprehensive account of the level of knowledge in international specialist circles, independent specialist organisations and experts from within Switzerland and abroad were called in. The main subject areas examined in the project were the characterisation of seismic hypocentres, wave propagation and the local effects at the sites of the nuclear power plants in Switzerland. Switzerland has held a pioneering role with the PEGASOS project. It is until now the only study of this type in Europe. The new seismic hazard resulting from the project was incorporated into the plant-specific Probabilistic Safety Analyses (PSA). Targeted seismic upgrades were implemented at the plants on the basis of the results from the PSA. The thereby newly calculated PSA studies showed that the IAEA limit for the core damage frequency is maintained.

The conclusions resulting from the PEGASOS project appear to have a far wider range of uncertainty in comparison with the previous earthquake hazard analysis. In order to reduce the wide range of uncertainty identified in the PEGASOS results, the nuclear power plant operators launched the follow-up PEGASOS Refinement Project (PRP) in 2008. The PRP takes into account the new knowledge that has become available in the field of earthquake research since PEGASOS was completed as well as detailed studies of the site characteristics (e.g. by means of exploratory geological drilling). The PRP will probably continue until the end of 2012 and is reviewed continuously by ENSI with the help of a team of experts.

As a consequence of the Fukushima accident, ENSI has already asked the operators to provide new deterministic proof of safety for the 10,000-year earthquake, on the basis of the available interim results from the PRP (hazard level H3). This proof must be submitted by 31 March 2012.

As no confirmed results from the PRP are available as yet, ENSI has stipulated for the purposes of the EU stress test that the determination of the seismic safety margins should refer to hazard levels H1 and/or H2. The results from PEGASOS and PRP are to be qualitatively incorporated into the assessment of the adequacy of the design basis.

Three different safety trains are considered in the presentation and evaluation of the protection of safety equipment against earthquakes. The safety trains are explained in section 1.3 of the current document.

Classification of referenced documents

According to the reports provided by the operators, the vast majority of the documents referenced for the evaluation of seismic safety are classified as D1. This means that they have been approved or at least preliminarily reviewed by ENSI. There are exceptions in the case of internal plant studies, certain studies on the PEGASOS/PRP projects and the investigations ordered by ENSI (but not yet completed) after the events related to the accident at Fukushima. These documents are classified as D2, i.e. they were quality-assured by the operators.

2.1 Design basis

2.1.1 Earthquakes against which the plants are designed

Operators' main results

Table 2-1 indicates the maximum acceleration values (peak ground acceleration, PGA) on which the seismic design of the Swiss nuclear power plants is based, for the safe shutdown earthquake (SSE) and − in some cases − for the operating basis earthquake (OBE). These acceleration values are specified for selected reference elevations (bedrock surface, foundation of reactor buildings (RB), ground surface), and are derived from the acceleration spectra assigned in each case. The peak accelerations were defined in accordance with the applicable state-of-the-art, which continued to be developed substantially during the planning period for the four nuclear power plants. This ongoing development is reflected in hazard levels H1 and H2.

Table 2-1: Peak ground acceleration values (in g[2])

	Hazard level H1				Hazard level H2			
	SSE		OBE		SSE		OBE	
	horiz.	vertical	horiz.	vertical	horiz.	vertical	horiz.	vertical
KKB								
Bedrock surface	*0.12*	*0.08*			*0.15*	*0.10*	*0.075*	*0.05*
RB foundation	0.12	*0.08*			0.15	0.10	*0.075*	*0.05*
Ground surface					0.21	0.14		
KKG								
Bedrock surface	0.15	*0.075*	*0.07*	*0.035*	0.20			
RB foundation	0.15							
Ground surface	*0.255*				0.28			
KKL								
Bedrock surface	0.15	0.10	0.075	0.050	0.15	0.10	0.075	0.05
RB foundation					*0.21*	*0.14*	*0.105*	*0.07*
Ground surface	0.28				0.28		*0.14*	
KKM								
Bedrock surface	*0.12*	*0.08*			*0.15*	*0.10*	*0.06*	*0.04*
RB foundation	0.12	0.08			0.15	0.10	*0.06*	*0.04*
Ground surface								

The original peak accelerations (hazard level H1) were still defined on a deterministic basis for the older plants at Beznau and Mühleberg; however, they were already defined on a probabilistic basis for the newer plants at Gösgen and Leibstadt.

The applicable hazard level (H2) in the EU stress test is characterised by a peak acceleration for the SSE, determined on a probabilistic basis, with an excess frequency of 10^{-4} per year. One important basis for the determination of hazard level H2 was the study entitled "Types of Seismic Risk in Switzerland" /A-18/, in which the seismic hazard for all the power plant sites was determined with the same methodology for the first time.

In their discussion of the adequacy of the design basis (hazard level H2), the operators point out that no definitive results are available from the PRP as yet. In most cases, in fact, the operators assume that the PRP will result in higher design requirements as compared with hazard level H2, but they stress that the plants have high safety margins in relation to the design basis (see section 2.2).

[2] All PGA values as indicated in the operators' reports, supplemented with valid values from other reference reports (italics)

ENSI review

In ENSI's view, the design bases of the Swiss nuclear power plants against earthquakes are adequately and correctly presented by the operators. The hazard level H2 is consistent with the state-of-the-art knowledge of the late seventies. On the basis of knowledge gained from new seismic studies, ENSI also assumes that the design requirements will increase after the completion of the PRP and that accordingly, it is no longer possible to consider the hazard level H2 as adequate for the design.

The latest Probabilistic Safety Analyses (PSA) by the Swiss nuclear power plants already take account of stricter seismic hazard assumptions. The results indicated that the probabilistic safety objectives recommended by the IAEA for existing plants are attained. In case of new construction projects and back-fitting measures, higher seismic hazard assumptions have already been taken into account by the operators of the Swiss nuclear power plants.

When the results from the PEGASOS and PRP projects are taken into account, the hazard level H3 regarding design-basis earthquakes for the Swiss nuclear power plants should conform to the latest international state-of-the-art.

2.1.2 Provisions to protect the plants against the design basis earthquake

Operators' main results

At the Swiss nuclear power plants, the scope of safety equipment protected against the safe shutdown earthquake (SSE) and the operating basis earthquake (OBE) varies according to the plant age. It is generally true that the fundamental safety functions of:

- Control of reactivity,
- Cooling of radioactive material (fuel assemblies), and
- Confinement of radioactive material

must be fulfilled in case of an earthquake. The resulting specific requirements for Structures, Systems and Components (SSC) are defined by means of structure and earthquake classes. The SSC that are to be designed and classified against earthquakes must not be endangered by the seismic failure of other items of equipment with lower classifications, or with no classification.

At the newer nuclear power plants (Leibstadt and Gösgen), hazard level H2 was already covered by the design of the safety equipment in safety trains 1 and 2. At the older nuclear power plants (Beznau and Mühleberg), however, the stipulation of hazard level H2 as the new design basis created a requirement for a seismic requalification of the original safety equipment so that in conjunction with the newly installed special emergency systems an earthquake-resistant safety train 2 was guaranteed.

The protection of core cooling and of the cooling of the spent fuel pools (SFP) against earthquakes for the Swiss nuclear power plants is described in the following. The definition of safety trains has been given in section 1.3.

<u>Scope of protection at KKB:</u>

Core cooling: Safety train 1 is not requalified against hazard level H2,
safety train 2 is designed against hazard level H2.

SFP cooling: Safety train 1 is not requalified against hazard level H2, <u>no</u> safety train 2, safety train 3 is credited (long time delays before cooling is needed)

Scope of protection at KKG

Core cooling: Safety trains 1 and 2 are designed against hazard level H2

SFP cooling: Safety trains 1 and 2 are designed against hazard level H2.

Scope of protection at KKL

Core cooling: Safety trains 1 and 2 are designed against hazard level H2

SFP cooling: Safety train 1 is designed against hazard level H2, no safety train 2

Scope of protection at KKM

Core cooling: Safety train 1 is not requalified against hazard level H2, safety train 2 is designed against hazard level H2.

SFP cooling: Safety train 1 is not requalified against hazard level H2, no safety train 2, safety train 3 is credited (long time delays before cooling is needed)

At the time in question, the spent fuel pools were examined in respect of the retention of their integrity in case of earthquakes. Especially in the older nuclear power plants (KKB and KKM), long time delays are available to restore the cooling by means of accident management measures (safety train 3). At all the nuclear power plants, however, the core cooling is guaranteed by means of the automatically triggered safety equipment in safety trains 1 and/or 2.

The necessary administrative protection measures are stipulated in plant-specific operating and accident procedures and in emergency instructions. For accidents that cannot managed within the scope of the design, additional decision-making aids are available (Severe Accident Management Guidelines, SAMG) which are intended to limit the consequences of core damage. The organisational procedures in the event that an emergency occurs are regularly practised during the emergency exercises, in liaison with the supervisory authority, i.e. ENSI.

The Swiss nuclear power plants have seismic plant instrumentation at their disposal which can be used to register seismic ground motions and compare them with the limit values for the design-basis earthquakes. If the limit values defined for the OBE and/or SSE are exceeded, an alarm is triggered in the main control room (MCR). The measures to be implemented by the operational team are stipulated in operating procedures. At present, the Swiss nuclear power plants are jointly extending the measurement network operated by the Swiss Seismological Service in north-western Switzerland and in the Swiss Mittelland, in order to register very weak earthquakes in the regions of the nuclear sites which cannot be measured with the plants' own instrumentation. Valuable information regarding seismically active fault zones can be obtained from this network.

In case of a severe earthquake, damage in the surrounding area may also jeopardise the safety of the nuclear power plants. Accordingly, it is generally assumed for the purposes of the proof of seismic safety that the external power supply has failed. Moreover, the emergency exercises carried out together with the participating emergency organisations (emergency staff, fire brigade, police) include simulations of situations such as impeded accessibility of the power plant site and failure of means of communication.

Now that the external storage facility at Reitnau has been set up at ENSI's request, the operators of the Swiss nuclear power plants can also have targeted access to additional auxiliary equipment to combat the consequences of severe earthquakes, should the emergency equipment stored on the power plant site be unavailable.

The access route to the Beznau nuclear power plant is most at risk due to the plant's location on an island in the river Aare. If those access roads needed to transport additional staff are blocked, reinforcements as well as the necessary equipment can also be flown in by helicopter as part of the arrangements for supplies from the external storage facility at Reitnau.

ENSI review

During the re-assessment of the seismic hazard assumptions at the end of the 1970s (hazard level H2), the design of classified Structures, Systems and Components (SSC) at the Swiss nuclear power plants was reviewed and in particular, the robustness of the safety equipment against earthquakes was increased at the older plants. As part of the Periodic Safety Reviews (PSR) conducted at 10-year intervals, continued compliance of the seismic design with the current requirements is also reviewed. The focus here is on structural changes of the plant, and on new knowledge regarding the seismic hazard, the regulations, the calculation methods, the materials and the structural design. In this context, additional targeted back-fitting measures have been carried out on structures and equipment, on the basis of knowledge gained from the PSA. Whether accident procedures, emergency instructions and decision-making aids for severe accidents (Severe Accident Management Guidelines) are up-to-date is also checked by ENSI as part of the PSRs.

ENSI confirms that according to knowledge available at present, adequate precautions are in place to manage the SSE (hazard level H2) at the Swiss nuclear power plants, hence performance of the fundamental safety functions is ensured. Nevertheless, ENSI initiated an in-depth review of the seismic safety of the Swiss nuclear power plants on the basis of the latest seismic hazard assumptions (hazard level H3) (ENSI order dated 01.04.2011, /A-3/) immediately after the events at Fukushima. The nuclear power plant operators must submit the analyses on this aspect to ENSI by 31.03.2012. In the light of the knowledge gained from Fukushima, the investigations undertaken to date have shown that the SFP cooling at the older nuclear power plants (KKB and KKM) should be improved in order to bring about a further reduction of the risk. As requested by ENSI in its order of 5 May 2011 /A-4/, KKB and KKM will back-fit new SFP cooling systems by 2015 at the latest; the design of these systems will be based on the latest seismic hazard assumptions.

In ENSI's view, the arrangement whereby the automatic scrams were triggered ahead via the seismic instrumentation proved its merits in the severe earthquakes which occurred in Japan. Triggering of this sort has not yet been implemented in the Swiss nuclear power plants. ENSI will follow up on the question as to whether in the Swiss nuclear power plants automatic scrams should be triggered by the seismic instrumentation (**open point 2-1**).

In summary, ENSI finds that the Swiss nuclear power plants have a high level of protection against earthquakes. At all the Swiss nuclear power plants, the available special emergency systems play an important role in this regard. These systems were required in the past by the supervisory authority in order to guarantee protection against the consequences of earthquakes, aircraft crashes, external flooding, explosions, major fires and impacts caused by third parties. With these systems the safety functions for reactor shutdown, core cooling and removal of decay heat are performed automatically and autonomously for at least 10 hours if needed; in the longer term, switching operations by the operating staff are required.

2.1.3 Plants' compliance with their current licensing basis

Operators' main results

All the Swiss NPPs have certified quality management systems as per standard ISO 9001:2000. Procedures and processes are established for all operational activities and in particular for those of relevance to nuclear safety, with unambiguous assignment of responsibilities and authorities in the organisation. For this purpose, the tasks relevant to safety and security are recorded so that they can be systematically planned, executed, monitored and documented, audited both internally and externally, and adapted as appropriate. The quality management systems cover the aspects of safety, security, occupational protection, accident prevention and health protection as well as environmental protection.

An important tool for guaranteeing the on-demand availability of safety-relevant SSCs is embodied by the requirements in the technical specifications (TS) of the NPPs and their monitoring. The TS stipulate which SSC must be ready to operate, in which operational phases, how long reactor operation can still be continued in the event of an SSC failure, and the intervals at which the on-demand availability of the SSC must be proven.

Moreover, comprehensive programmes for maintenance, recurring tests and inspections, system and component function tests and the monitoring of ageing are in place to monitor and ensure the proper functioning of SSCs.

Changes to plants are systematically implemented on the basis of QM processes and for this purpose, comprehensive safety reviews and/or evaluations must be undertaken for all safety-relevant changes in order to determine the impact of the change on plant safety, taking account of compliance with the official requirements.

As part of the Periodic Safety Reviews (PSR) that are carried out every ten years, the condition of the NPPs and their operational management are reviewed to ensure compliance with legal requirements, the provisions of the licences and the official stipulations contained in ENSI permits. Finally, compliance of the plant condition with the approval bases is examined in the course of ongoing supervision, and during inspections by − and technical discussions − with the supervisory authority.

Tours of inspection of the plants by experienced seismic engineers (seismic walkdowns) are carried out in order to review seismic safety at all the nuclear power plants. These usually take place in conjunction with the PSR or as the basis for assessing the failure probabilities (fragilities) as part of the PSA. Special seismic walkdowns and additional reviews of the seismic safety of the plants were carried out after the events at Fukushima. As a further protective measure, all the nuclear power plants undergo a "seismic housekeeping" programme on the basis of internal plant instructions, to ensure the consistent storage and fixture of mobile objects in compliance with seismic considerations.

When external equipment and devices are required to cope with the effects of earthquakes, the focus is on the regional professional fire brigades and medical/ambulance services. These are not reviewed by the operators, but it is assumed that they are ready to deploy.

Additional external emergency protection resources to which all the Swiss nuclear power plants may resort if needed are stored in a central external storage facility which has been in place at Reitnau since June 2011. Operational equipment – such as emergency power units, mobile pumps, power cables, water hoses, diesel fuel, borating agents, various tools, radiation protection equipment and other accident management equipment – is stored here. This storage facility was set up as an immediate measure after Fukushima. An operational concept including assignment of responsibility for ensuring the availability of the storage facility is being developed at present.

ENSI review

In connection with the operation of nuclear power plants, the Nuclear Energy Act (NEA) stipulates a requirement to implement quality assurance measures for all activities carried out in the facility (Article 22, para. 2, letter j, NEA). ENSI's requirements for management systems are stated in the guideline ENSI-G07. Accordingly, the Swiss nuclear power plants have certified management systems and associated processes, procedures and programmes to ensure the availability of the structures/buildings, systems and components (SSC) that are important in terms of safety. Operators' activities in this regard are supervised by ENSI. The Technical Specifications are subject to mandatory permits, and compliance is subject to special monitoring by ENSI. In case of changes to plants, the impact of the change on the plant and on the risk must be analysed in depth. This should ensure that any changes that are to be implemented will not result in any undesirable and unintentional impact on the safety arrangements or any impairment of the safety functions. Finally, compliance of the plant design with the bases for approval (licensing) and the state-of-the-art is also reviewed at intervals when the PSR is conducted. This review investigates whether new knowledge regarding safety gained from operating experience, safety analyses and from research and development in the nuclear field should be implemented by the operators of the nuclear power plants.

As one of the immediate measures after Fukushima, ENSI ordered that the operators must have access to an earthquake- and flood-resistant external storage facility which contains additional operational resources, such as emergency power units, mobile pumps, borating agents and fuel. These operational resources have been available since 1 June 2011. ENSI is supervising the development of the relevant operating concept, and the measures to guarantee availability of these resources when required. These activities also include the maintenance and deployment plans for the equipment in the Reitnau external emergency storage facility.

The results of the seismic walkdowns and the implementation of seismic housekeeping are reviewed by ENSI as part of the Periodic Safety Reviews (PSR) and the Probabilistic Safety Analyses (PSA). For this purpose, ENSI also carries out its own tours of inspection at the plants, together with external seismic experts.

To summarise, ENSI confirms that comprehensive and reviewed precautions have been implemented in all Swiss nuclear power plants to ensure the availability of those SSCs that are important for safety purposes in case of an earthquake. No divergences from the licensing (approval) bases were identified during the review.

2.2 Evaluation of safety margins

The operators have determined the seismic safety margins for the safety trains (defined in section 1.3) on the basis of IAEA Safety Guide NS-G-2.13, "Evaluation of Seismic Safety for Existing Nuclear Installations", 2009 release, /A-10/. Their seismic robustness in respect of the associated safety equipment (SSC) was to be determined in each case, as expressed by the so-called HCLPF value (high confidence of low probability of failure). The HCLPF value describes the peak ground acceleration (PGA) at the reference elevation for which the probability of failure of the safety equipment analysed is less than 5%, with a confidence level of

95%. For accelerations below the HCLPF value, it may be assumed that the probability of seismic failure is less than 1%.

The robustness of a safety train is determined by the safety equipment with the lowest HCLPF value. The robustness of the overall system is derived from the safety train with the highest HCLPF value.

The safety margin (S) is defined by the ratio of the plant's HCLPF value (PGA_{HCLPF}) to the peak ground (horizontal) acceleration value (PGA) for hazard level H2:

$$S_{HCLPF} = PGA_{HCLPF} / PGA_{SSE\ (H2)}$$

Table 2-2 below indicates the ground (horizontal) acceleration value $PGA_{SSE\ (H2)}$ for the respective plant and the associated reference elevation.

Table 2-2: Ground (horizontal) acceleration values $PGA_{SSE\ (H2)}$ for hazard level H2

		KKB	KKG	KKL	KKM
$PGA_{SSE(H2)}$	[g]	0.21	0.28	0.28	0.15
Reference elevation		ground surface	ground surface	ground surface	RB foundation

The safety equipment considered in the individual safety trains had to be specifically named, and its HCLPF values had to be reported. The HCLPF values from the current probabilistic seismic analyses could be used, even if these values were no longer based on the spectral form of hazard level H2 but (at differing levels of progress) on knowledge gained from the PEGASOS and/or PRP projects.

In the probabilistic seismic analyses, the HCLPF values represent a result from the so-called fragility analysis in which the probability of seismic failure of the safety equipment is determined as a function of the ground acceleration at the reference elevation. The fragility values are determined on the basis of the failure mechanisms that are assessed as applicable. Consideration must also be given here to a potential risk to the safety equipment examined on account of adjacent but less robust plant components.

For lack of time, the HCLPF values stated by the operators in the final reports were not reviewed by ENSI in connection with the EU stress test. ENSI will review the HCLPF values on a sampling basis, as part of its review on the proof of safety in case of the 10,000-year earthquake which must be submitted on 31 March 2012.

2.2.1 Range of earthquake leading to severe fuel damage

Core cooling

Operators' main results

Table 2-3 summarises the HCLPF values (PGA_{HCLPF}) and safety margins (S_{HCLPF}) for the individual safety trains as reported by the operators in the final reports. With each of these safety trains, the Swiss nuclear power plants can be brought into a safe shutdown state or maintained in such a condition following an earthquake, both in power and non-power operation, so that the fundamental safety functions of "Control of reactivity" and "Cooling of fuel assemblies" can be fulfilled.

Table 2-3: Safety margins for core cooling

			KKB	KKG	KKL	KKM
		Units [ ]				
Acceleration, hazard level H2	PGA_{SSE} (H2)	[g]	0.21	0.28	0.28	0.15
Reference elevation			ground surface	ground surface	ground surface	RB foundation
Buildings, 1st safety train (e.g. switchgear building)	PGA_{HCLPF}	[g]	0.27	0.93	0.65	0.28
	S_{HCLPF}	[-]	1.3	3.3	2.3	1.8
Reactor building	PGA_{HCLPF}	[g]	0.59	1.37	1.47	0.77
	S_{HCLPF}	[-]	2.8	4.9	5.2	5.1
Special emergency building	PGA_{HCLPF}	[g]	1.51	1.16	0.65	1.38
	S_{HCLPF}	[-]	7.2	4.1	2.3	9.2
Reactor scram *1	PGA_{HCLPF}	[g]	0.72	ca. 0.8	1.1	0.53
	S_{HCLPF}	[-]	3.4	ca. 2.8	3.9	3.5
1st safety train	PGA_{HCLPF}	[g]	-	0.29	0.50	0.17
	S_{HCLPF}	[-]	-	1.0	1.8	1.1
2nd safety train	PGA_{HCLPF}	[g]	0.46 *6	0.43 *5	0.57 *4	0.31 *3
	S_{HCLPF}	[-]	2.2	1.5	2.0	2.1
3rd safety train	PGA_{HCLPF}	[g]	0.42 *2	ca. 0.9 *7	-	-
	S_{HCLPF}	[-]	2.0	ca. 3.2	-	-

*1 Control rod drive mechanism only

*2 Availability of operating staff in MCR limiting

*3 Dam limiting

*4 Elect. control cabinets limiting

*5 Special emergency diesel plant limiting

*6 AC power supply limiting

*7 Fire brigade building limiting

\- No information

In addition, for safety trains 2 and 3, those safety equipment are listed (see notes *2 to *7) which are limiting as regards the seismic robustness of the respective safety train (e.g. for safety train 2 at KKL, the electrical control cabinets in the special emergency building). As further supplementary information, Table 2-3 contains the HCLPF values and safety margins for selected buildings for which it is crucially important in case of an earthquake that they keep their function, either for all the safety trains (reactor building) or for safety train 1 (e.g. switchgear building) and/or safety train 2 (special emergency building).

The seismic robustness of the reactor scram is also stated explicitly, since this is a safety function for all the safety trains. The decisive factor for this function is the seismic robustness of the control rod drive mechanisms (see note *1).

Insofar as is explicitly reported, the safety trains of all the Swiss nuclear power plants have safety margins against seismic hazard level H2. At all the Swiss nuclear power plants, safety train 2 (i.e. the special emergency systems) has the greatest robustness for coping with an earthquake in accordance with the design basis. The safety margins (S_{HCLPF}) vary here from 1.5 to 2.2. A higher safety margin is reported only at KKG for the third safety train (accident management measures) with a value of S_{HCLPF} = 3.2.

ENSI review

In ENSI's view, it can generally be concluded from the safety margins stated by the operators that the earthquake resistance of the power plant buildings and the control rod drive mechanisms in the Swiss nuclear power plants are not limiting as regards ensuring the fundamental safety functions of "Control of reactivity" and "Cooling of fuel assemblies". At KKG, KKL and KKM, safety train 2 is (as expected) seismically more robust than safety train 1. In ENSI's experience, this statement also applies to KKB. At all the Swiss nuclear power plants, safety train 2 has a comparatively high safety margin as opposed to safety train 1. Except at KKM, components of the special emergency systems are limiting as regards the seismic robustness of safety train 2. For KKM, the earthquake resistance of the Mühleberg dam wall determines the safety margin because, in case of a seismically induced failure of the dam wall, the cooling water supply of the special emergency system would be endangered due to blockage of the intake structure.

In ENSI's view, and on the basis of the safety margins reported by KKB and KKG, the third safety train represents another robust possibility (although no longer strictly design basis) for bringing the plants into a safe condition after an earthquake or for keeping them in such condition. However, ENSI regards the HCLPF value reported by KKG as only of limited reliability, because in addition to the necessary technical equipment (which is stowed in the fire brigade building and elsewhere), operating staff must also be available promptly and in sufficient numbers under aggravated conditions. For the third safety train, KKB reports lower earthquake resistance than for the second safety train, because the earthquake resistance of the main control room (MCR) was assessed as limiting in respect of the availability of operating staff. KKL and KKM can resort to the third safety train too: since the operators did not provide any relevant information, the robustness of the third safety train cannot be evaluated for those two plants.

In ENSI's assessment, the safety margins reported by the operators show that several robust safety trains are available in the Swiss nuclear power plants in order to bring the plants into a safe shutdown state even after an earthquake which exceeds hazard level H2. The reported safety margins confirm the conservative seismic design of the Swiss nuclear power plants. It should again be mentioned, as a restriction, that the HCLPF values reported for the safety equipment were not reviewed by ENSI in relation to the EU stress test. The nuclear power plant operators will submit new seismic analyses to ENSI to provide the deterministic proof of safety by 31.03.2012. In this context, ENSI will also review the determined HCLPF values.

Spent fuel pool (SFP) cooling

Operators' main results

In order to ensure the safe storage and cooling of the fuel assemblies in the spent fuel pool, maintenance of the integrity of the fuel pools in case of a severe earthquake is an essential condition. Except for KKM, the operators report high safety margins for the integrity of the spent fuel pools (see Table 2-4), which are located in the reactor building or in separate fuel assembly storage buildings, depending on the plant. The integrity of the spent fuel pool at KKM is limited by the seismic resistance of the pool slot plugs. For the spent fuel pool itself, KKM indicates a PGA_{HCLPF} value of 0.64 g, and hence a high safety margin S_{HCLPF} of 4.3.

Table 2-4: Safety margins for SFP cooling

			KKB	KKG	KKL	KKM
		Units [ ]				
Acceleration, hazard level H2	$PGA_{SSE\ (H\ 2)}$	[g]	0.21	0.28	0.28	0.15
Reference elevation			ground surface	ground surface	ground surface	RB foundation
1st safety train	PGA_{HCLPF}	[g]	-	0.29	0.50	0.17
	S_{HCLPF}	[-]		1.0	1.78	1.1
2nd safety train	PGA_{HCLPF}	[g]	[ ]	0.43	[ ]	[ ]
	S_{HCLPF}	[-]		1.54		
3rd safety train, spent fuel pool integrity	PGA_{HCLPF}	[g]	2.0	0.9	1.09	0.24[*1]
	S_{HCLPF}	[-]	9.6	3.2	3.9	1.6

[*1] pool slot plugs are limiting   - No information   [ ] No SFP cooling system

In the newer Swiss nuclear power plants, SFP cooling is ensured by the safety systems of the first safety train (KKL) or the first and second safety trains (KKG). According to Table 2-4, these systems reach safety margins of 1.5 to 1.8, although in both plants, robustness against earthquakes is limited by electrical equipment or also (at KKG) the control stations in the main control room.

In the older Swiss nuclear power plants, SFP cooling in normal operation is ensured by the cooling systems of the first safety train, whose components are not, or are only partially requalified against an SSE (hazard level H2). Nevertheless, KKM reports a safety margin greater than 1 for the SFP cooling, and the emergency diesel generator is the seismically weakest item of equipment in the safety train. KKB provides no information on the earthquake resistance of safety train 1. After an SSE, only the third safety train is available for SFP cooling at KKB.

For the third safety train, the operators credit the high seismic robustness of the SFP, as (to a limited extent) this maintains the large water reserve in the SFP, and the cooling of the fuel assemblies is guaranteed by evaporation and the make-up of coolant. An injection of cooling water to the SFP is not required at any Swiss nuclear power station within the first 72 hours.

KKG has an additional wet storage facility with passively designed cooling. For the earthquake resistance of this storage facility, KKG states an HCLPF value of >0.9 g, corresponding to a safety margin of > 3.2.

ENSI review:

ENSI is generally in agreement with the operators' evaluation that keeping the integrity of the SFP in order to ensure safe storage and cooling of the fuel assemblies in case of a severe earthquake is a matter of decisive importance. Except for KKM, the seismic robustness of the SFP in Swiss nuclear power plants can be rated as high, on the basis of the information from the operators. For this reason, KKM intends to improve the earthquake resistance of the pool slot plugs as they are the limiting component. Except for KKB, greater safety margins are generally reported for those buildings where the SFPs are located than for the SFPs themselves. In the course of other investigations, KKB has produced deterministic proof of stability for the SFP building on the basis of hazard level H3. In ENSI's view, this means that a risk to the integrity of the SFP can be ruled out.

Given the importance of maintaining SFP integrity, ENSI required, in its order of 5 May 2011 /A-4/, that all Swiss nuclear power plants must systematically reassess the spent fuel pools as well as their connections by 31.03.2012.

The newer nuclear power plants, KKG and KKL, have spent fuel pool cooling systems which in ENSI's view (as expected) display a high safety margin in relation to an earthquake of hazard level H2. Since the older nuclear power plants (KKM and KKB) do not have such robust systems, reliable additional supply options are required as accident management measures. In the order of 18 March 2011 /A-2/, all the Swiss nuclear power plants were required, by 31.12.2012, to back-fit two additional external feed options to supply further coolant to the spent fuel pools. The equipment must be qualified or designed against earthquakes of hazard level H3, and refilling of the pools must be possible without entering the pool areas. In their final reports, the operators provided no specific information about the earthquake resistance of the existing additional supply facilities based on accident management measures (third safety train). Taking account of the robustness of the accident management measures for core cooling and the long time delays available for injecting water into the SFPs (>72 hours), ENSI considers that the seismic robustness of safety train 3 is limited by the integrity of the SFPs.

2.2.2 Range of earthquake leading to loss of containment integrity

Operators' main results

The safety margins reported by the operators to guarantee the integrity of the containment in case of a severe earthquake are shown in Table 2-5. According to the operators' statements, containment penetrations and automatically triggered isolation valves are the limiting factors to earthquake resistance. KKG is the only plant which also credits manual measures to close isolation valves, for which provision is made within the preventive accident management. The safety margin to guarantee containment integrity is significantly improved by this measure (see note *1).

The information on the earthquake resistance of containment venting was, in part, supplied by the operators at a later stage in response to a request from ENSI, and it indicates major differences in the safety margins.

Table 2-5: Safety margins for containment integrity

			KKB	KKG	KKL	KKM
		Units [ ]				
Acceleration, hazard level H2	$PGA_{SSE\ (H\ 2)}$	[g]	0.21	0.28	0.28	0.15
Reference elevation			ground surface	ground surface	ground surface	RB foundation
Containment integrity	PGA_{HCLPF}	[g]	0.54	0.48 (0.72)*1	0.65	0.40
	S_{HCLPF}	[-]	2.6	1.7 (2.6) *1	2.33	2.7
Containment venting	PGA_{HCLPF}	[g]	0.61*	0.23	0.41	0.40
	S_{HCLPF}	[-]	2.9	0.8	1.5	2.7

*1 Manual closure of isolation valves

ENSI review

In ENSI's view, the assessment of containment integrity generally includes an assessment as to whether the fundamental safety function of "Confinement of radioactive material" is fulfilled in case of the occurrence of a severe earthquake. For this purpose, it is necessary to ensure both the isolation of the containment in order to retain radioactive substances in case of a primary circuit (PC) leak (which cannot necessarily be excluded), and the isolation of the PC in order to prevent a discharge of coolant outside the containment (containment bypass).

ENSI considers plausible the operators' statements that the containment shell itself should be rated as extremely robust. The safety margins reported by the operators for the containment integrity are greater than the safety margins for the most seismically robust safety train for core cooling (see Table 2-3), so that even in case of an earthquake-induced failure of the core cooling, the containment is still preserved as a retention barrier.

In ENSI's view, however, the reported safety margins for containment integrity can only be regarded as plausible insofar as the containment isolation depends only on the mechanical robustness of the isolation valves, i.e. if the containment isolation features consistent fail-safe behaviour. For example, the containment isolation at KKG is also dependent on the D.C. power supply, for which KKG reports a lower safety margin than is shown in Table 2-5, without considering the manual closure of the motor-driven isolation valves. In the case of the other operators, except KKM, ENSI notes the absence of an evaluation of the extent to which the containment isolation is independent of the power supply.

According to the operators’ main results, the PC pipes have very high seismic robustness (approx. 0.8 – 1.0 g), but the operators do not undertake an evaluation of the seismic robustness of the isolation of the primary circuit (containment bypass).

In respect of the seismic proof that has yet to be provided, ENSI considers that there is a need for another more detailed examination of the seismic robustness of the isolation of the containment and the primary circuit (**open point 2-2**).

The containment venting system at KKG, as part of the containment, displays low seismic robustness but this is determined by the waste gas cleaning tank that is positioned outside of the containment. A failure of this tank would therefore have no effects on the integrity of the containment itself. The safety margins for the containment integrity at the Swiss nuclear plants are assessed by ENSI as high.

In ENSI's opinion, the system for containment venting must in general be at least as seismically robust as the containment integrity, in order to guarantee ongoing effective protection of the containment in case of accidents due to severe earthquakes with failure of the core cooling (an exception may be allowed if the safety margins of the venting system are already quite high). This requirement is not met at KKG and KKL. Moreover, KKG (unlike KKL) does not report a safety margin for the containment venting, although the system was originally designed against hazard level H2. From ENSI's viewpoint, therefore, measures to improve the earthquake resistance of the containment venting systems in case of beyond-design basis accidents should be reviewed at KKG and KKL (**open point 2-3**).

For the older nuclear power plants (KKB and KKM) safety margins are reported which are greater than or equal to the safety margins for the containment integrity. ENSI regards the earthquake resistance of the containment venting systems of these plants to retain radioactive substances in case of a severe earthquake as adequate.

2.2.3 Earthquake exceeding DBE and consequent flooding exceeding DBF

Operators’ main results

The operators of KKB and KKG show that flood waves caused by earthquake-induced dam or weir breaches are covered by the design of the plants against flooding. At KKL, the height difference between the power plant site and the flood level is so great that there is no hazard even in case of any dam breaches that might occur.

At KKM, however, it is impossible to exclude flooding of the power plant site, with a hazard posed to the safety equipment of all the safety trains by dam wall breaches caused by a severe earthquake. A seismic safety margin of 2.1 against seismic hazard H2 (see Table 2-3) is reported for the Wohlensee dam wall. Both the earthquake resistance of the Wohlensee dam wall and of the dam walls at Schiffenen and Rossens are currently being re-examined by KKM, taking account of hazard level H3, in connection with the deterministic proof of safety required by ENSI by 31.03.2012.

ENSI review

In ENSI's view, flooding induced by a severe earthquake does not lead to a hazard to the safety of the KKB, KKL and KKG nuclear power plants, thanks to the high level of protection for the special emergency systems (safety train 2).

According to present knowledge the Wohlensee dam wall is limiting with regard to the seismic robustness of safety train 2 at KKM. A conclusive evaluation of the seismic robustness will only be possible upon receipt of the new deterministic seismic proof that is yet to be submitted, in which the earthquake resistance of the Wohlensee as well as the Schiffenen and Rossens dam walls will be re-examined.

2.2.4 Measures which can be envisaged to increase robustness of the plants against earthquakes

Operators' main results

The Gösgen nuclear power plant is the only one to conclude that, on the basis of the reported safety margins, the supporting structures for cables and the control stations in the main control room should be seismically upgraded. Moreover, there is an examination of the potential extent of improvements to the seismic robustness of the emergency diesel generator units, and to the fixtures for auxiliary equipment.

ENSI review

Additional targeted back-fitting measures for structures and equipment in order to improve their earthquake resistance have already been implemented at the Swiss nuclear power plants on the basis of knowledge gained from the PSAs. This continuous process is being advanced still further at KKG by the planned improvement measures. At KKB, the emergency power supply is being renewed and made more seismically robust as part of the ongoing AUTANOVE project (see also section 5).

ENSI currently sees no need for further improvement measures over and above the back-fitting of seismically robust SFP cooling systems in the older nuclear power plants (KKB, KKM) that has already been requested, and the additional injection capabilities for the SFP as part of accident management. The open points identified in sections 2.1.2 and 2.2.2, as well as the proof of safety in case of earthquake which must be provided following the ENSI orders post Fukushima, could lead to further measures.

3 Flooding

In accordance with ENSI's specified requirements, the licensees were basically required to take account of three hazard levels:

- H1 Flooding hazard which the plant was originally designed to withstand;
- H2 Flooding hazard for which the plant was requalified (may be identical with H1);
- H3 New results for the flooding hazard derived from studies carried out in connection with the general licence applications for new nuclear power plants or the new deterministic proof of safety for the 10,000-year flood.

For this purpose, the plants base their statements on documents already submitted to ENSI in connection with the orders dated 18 March 2011 /A-2/ and 1 April 2011 /A-3/, which have been reviewed by ENSI.

With regard to harmonising the representation of safety reserves, ENSI pointed out in the interim report /A-12/ that all plants should indicate the safety reserves in case of flooding with reference (at least) to flooding hazard H3 and on the basis of specified given flood levels.

In addition, ENSI stipulated a requirement to conduct sensitivity studies in order examine the effects of blockages by debris flows (partial or total closure of flow cross-sections due to floating debris) and of a subsequent sudden collapse of the blockage as potential cliff-edge effects. Debris blockages of this type must basically be assumed upstream and downstream of the site wherever the flow cross-section is artificially restricted (e.g. by bridges or weirs)[3] and where a debris blockage may impact the flooding situation at the site.

3.1 Design basis

3.1.1 Flooding against which the plants are designed

Operators' main results

At KKB, KKL and KKM, the design of protection against flooding was originally determined on the basis of dam and/or weir breach scenarios, whereas the protection design at KKG was based on a 1,000-year flood (flooding hazard H1). The flooding hazard at KKM was reanalysed in 1991 pursuant to the application for an unlimited-term operating licence and/or the increase in power. This analysis produced a lower maximum flood level for the dam-breach scenario, which was also – originally – limiting. This H2 flooding hazard is now the basis for the KKM design.

In the cases of KKB and KKM, the results of more recent hazard investigations (H3) are based on site-specific studies carried out for the general licence applications dating from 2008 for new nuclear power plants. KKG refers to a flood that is specified by ENSI as hazard assumption H3. KKL's approach is based on analyses undertaken in 2011 in connection with the deterministic proof of safety in case of the 10,000-year flood.

[3] An acceptable criterion according to which it can safely be expected that no debris flow blockage will occur is given in the Technical Report on the Flood Hazard Map, Aare Villigen – Klingnau of the Department of Construction, Transport and Environment of the Canton of Aargau (December 2010) http://www.ag.ch/raumentwicklung/de/pub/themen/gefahrenkarte/originaldokumente.php/rails/dropdown/template/11_gefahrenkarte_hochwasser/show/213.

According to the studies relating to the new H3 flooding hazard, it is no longer the weir breach scenarios but (as a new feature) the naturally-induced flood with a frequency of 10,000 years that would lead to the highest flood levels for KKB and KKL. In both cases, however, the flood levels are covered by the original design. At KKG, higher flood levels must now be expected than those on which the design was originally based. At KKM, the newly determined flooding hazard confirms the old design basis in respect of flood levels, but not in respect of bedload and sediment transport which could endanger the special emergency cooling water system intake. KKG and KKM have therefore implemented back-fitting measures and have prepared temporary flood protection measures (see sections 3.1.2 and 3.2.2). On the basis of new knowledge, a blockage of the intake structures and therefore a loss of the cooling water supply cannot be excluded for KKM in case of a breach of the Wohlensee dam wall.

The operators assign classification D1 to all the documents taken as the basis in this regard.

ENSI review

ENSI confirms that the classification of the documents by the operators is correct. The information on the design basis against flooding (H1, H2) and on the newly determined flooding hazard (H3) is reliable. The new flooding hazard H3 has been derived either considering a 10,000-year flood or, in case of KKM, an extreme flood scenario which actually gives rise to a bigger discharge than the 10,000-year flood. The discharge values for the 10,000-year flood were calculated through extrapolation of river level data considering historical flood records where appropriate. The flood levels were computed using a 2D-model for the flooding scenarios including a detailed orographic representation. For KKB and KKL, the original design basis (in conformance with hazards H1, H2) remains appropriate. However, this does not apply to KKG and KKM because, in the case of KKG, flooding of the power plant site cannot be excluded and, in the case of KKM, it is impossible to rule out a blockage of the special emergency intake structure due to the previously underestimated transport of bedload and sediment. The following sections deal with the resulting consequences. KKM's statements regarding a breach of the Wohlensee dam wall are assessed in section 3.2.1.

3.1.2 Provisions to protect the plants against the DBF

Operators' main results

In the original design the protection of the Swiss nuclear power plants against the consequences of flooding consists either in an elevation that ensures, for the power plant site, an adequate safety distance above the height of the design-basis flood, or in flood protection by means of permanently sealed buildings. At the Beznau and Mühleberg nuclear power plants, the protection of important safety equipment is ensured by flood-proof buildings that are sealed beyond the design-basis flooding level, as well as by positioning such equipment above the flood level used to determine the design of buildings that are not flood-proof. At the KKG and KKL plants, the protection of safety-relevant equipment consists in locating the power plant site above the flood level used to determine the design (the "dry site" concept).

Except for KKM, the safety-relevant flood-proof equipment includes components of the conventional safety systems (safety train 1) and the components of the special emergency systems (safety train 2). Additional protective precautions against the consequences of flooding comprise mobile operational resources (pumps, emergency power units, flood barriers, etc.) together with administrative measures such as prepared accident management or shift instructions and timely flood alarms.

The fundamental design-basis features of the plants in respect of flooding are summarised below. The definition of the safety trains is given in section 1.3 of this report.

Scope of protection for KKB:

Core cooling: Safety trains 1, 2 and 3 are protected in case of flooding and weir breaches

Spent fuel pool cooling: Safety train 1 is not protected, no safety train 2, safety train 3 is credited (long time delays before cooling is needed)

Scope of protection for KKG:

Core cooling: Safety trains 1, 2 and 3 are protected in case of flooding and weir breaches

Spent fuel pool cooling: Safety trains 1, 2 and 3 are protected in case of flooding and weir breaches

Scope of protection for KKL:

Core cooling: Safety trains 1, 2 and 3 are protected in case of flooding and weir breaches

Spent fuel pool cooling: Safety train 1 is protected in case of flooding and weir breaches, no safety train 2, safety train 3 is credited (long time delays before cooling is needed)

Scope of protection for KKM:

Core cooling: Safety trains 2 and 3 are protected in case of flooding and dam breaches

Spent fuel pool cooling: Safety train 1 is not protected, no safety train 2, safety train 3 is credited (long time delays before cooling is needed)

The protection of cooling water sources and the source of cooling water to the safety trains is summarised below.

KKB: Safety trains 1 and 2 have flood-proof groundwater wells that are independent of the river water supply

KKG: Safety train 1 has two intake structures one of which is flood-proof, safety train 2 has flood-proof groundwater wells that are independent of the river water supply

KKL: Safety trains 1 and 2 have flood-proof groundwater wells that are independent of the river water supply

KKM: Safety train 1 has a river water supply that is not flood-proof, and safety train 2 has a flood-proof river water supply

The following protective measures are in place for the emergency power supply systems of the Swiss nuclear power plants:

All nuclear power plants: The emergency power supply systems for safety trains 1 and 2 are flood-proof (cooling of emergency power units by means of groundwater wells or air)

KKM: The emergency power supply system for safety train 1 has only one emergency power unit (does not satisfy the single failure criterion)

One important protective measure that is implemented in all Swiss nuclear power plants except KKM is the diversified cooling water supply from groundwater wells, which ensures the supply of cooling water even in case of the assumed failure of cooling water intake structures as a consequence of an extreme flood. Groundwater wells of this sort are components of the specially protected, autarkic special emergency systems (safety train 2) that are present in all Swiss nuclear power plants, and which also ensure the special emergency power supply in case of a failure of the external power supply and the emergency diesel generator. KKM also has a special emergency system in which (unlike KKB, KKG and KKL) the special emergency cooling water is taken not from groundwater wells but also from the river Aare. The latest analyses have shown that, in certain cases, blockage of the special emergency intake structure in the Aare cannot be ruled out. During the outage in 2011, measures were therefore implemented at KKM to increase the reliability of the coolant supply via the special emergency intake structure.

The operators have shown that in case of flooding and assuming failure of the regular cooling water supply and the external power supply, and under the assumption of additional failures independent from the initiating event, redundant safety system trains are still available to remove the decay heat from the reactor cores and guarantee core coolability. In the analyses, no credit was given for assistance from external emergency protective equipment or resources. On the other hand the plants can resort to the special emergency systems that are protected against external impacts, with their own supplies of coolant and power, thereby ensuring compliance with the fundamental safety functions. In the case of KKM, however, mobile pumps must be deployed to ensure the coolant supply in certain rare cases, such as blockage of the special emergency intake structure. This measure is prepared, and its effectiveness is proven by tests. If the cooling water supply for the special emergency system should fail, despite all the measures implemented, the decay heat from the reactor can still be removed by a "feed-and-bleed" operating mode, whereby the coolant can then be supplied for short periods by the condensate water storage tanks or the Torus and, for longer periods, by a reservoir in a higher location or by the river.

The coolability of the spent fuel pools is proven at KKL on the basis of the site's safety against flooding, and at KKG on the basis of coolability by safety trains 1 and 2. At KKB, it must be assumed that safety train 1, which is required for the spent fuel pool cooling but is not flood-proof, could fail in case of flooding. Safety train 2 is not intended for cooling the spent fuel pool. Cooling of the spent fuel pools is ensured for at least 98 hours (time to reach top of active fuel) due to the large reserve of water. Within this timeframe coolant must be supplied by means of accident management measures (safety train 3). At KKM, the flood protection for the auxiliary cooling water system – and hence the cooling of the spent fuel pool – has been improved by temporary flood protection measures. However, in case of the assumed failure of the emergency power supply system (which does not meet the single failure criterion), the spent fuel pool cooling will fail. In this case, passive heat transport mechanisms and the large stock of coolant in the storage pool ensure that no further supply of coolant is required before 13 days (time to reach top of active fuel) have elapsed from the beginning of the accident.

Instructions for accidents, emergency procedures or shift instructions are available in all Swiss nuclear power plants in case of flooding. Timely automatic flood alarms are ensured for the KKB, KKG and KKM sites that are at risk of flooding. Early alarms make it possible to summon the nuclear power plants' emergency staff in good time and, if necessary, to shut down the plants at an early stage before the flood reaches the site. On-demand availability of systems and equipment is monitored by recurring inspections and compliance with the Technical Specifications. The availability of the mobile emergency protective equipment stored in the central Reitnau facility is also monitored.

In case of flooding, it was generally assumed that the power supply from the external grid would have failed. Consideration was also given to aggravated situations regarding the accessibility of the nuclear power plants for the purposes of relieving staff or making external assistance or resources available. It can generally be stated that an accident can be dealt with, without the assistance of external auxiliary resources for at least 72 hours in all Swiss nuclear power plants. Rapid accessibility to the sites is therefore not required. Accessibility could however be significantly restricted at KKB, whose site is located on an island in the river Aare. The island has two access routes over which vehicles could pass even in the event of a 10,000-year flood. If it is assumed that one bridge is destroyed in an extreme flood and the weir bridge can no longer be crossed, external auxiliary resources such as diesel fuel can be obtained from the external storage facility at Reitnau or additional staff can be brought in by helicopter.

ENSI review

The review of the protection of Swiss nuclear power plants against flooding was initiated by ENSI immediately after the events at Fukushima as part of a targeted safety review (ENSI orders dated 18 March 2011 /A-2/ and 1 April 2011 /A-3/). The operators submitted the relevant analyses to ENSI by 30 June 2011. The review then carried out by ENSI showed that the nuclear safety of the Swiss nuclear power plants is guaranteed in case of flooding. Improvement measures requested by ENSI in connection with the review are detailed in section 3.2.2 of this report. The official review that has already been conducted shows that the operators' main results on flood protection in section 3.1.2 are based on checked documents in category D1. The latest results regarding the flooding hazard (hazard level H3) were taken into account when providing proof of safety against flooding.

ENSI confirms that removal of the decay heat from the reactor cores is guaranteed both at KKB and KKG, even if failure of the river water cooling and the external power supply is assumed, with the further assumption of a failure of the emergency power supply. Core cooling can be guaranteed by the specially protected special emergency system, as well as cooling of the spent fuel pool in the KKG reactor building. As regards the coolability of the spent fuel pool at KKB, it has become evident that in case of a flood-induced failure of the service water system, long-term cooling of the pool can only be ensured on the basis of interventions by operators (safety train 3). In its third order /A-4/, ENSI therefore required that KKB proposes measures to upgrade the systems for spent fuel pool cooling (including the necessary auxiliary and support systems) in order to protect them against flooding, as well as measures to extend the in-plant accident management measures for heat removal, water injection and monitoring of the spent fuel pool after a failure of the pool cooling systems (also see section 3.2.2). KKG has not made any explicit comments on the safety against flooding of the external wet storage facility for spent fuel assemblies in connection with the EU stress test. However, the relevant review was carried out in connection with ENSI's first order dated 18 March 2011 /A-2/. ENSI confirms that the KKG wet storage facility possess very high protection against external impacts, and that the decay heat from the fuel assemblies stored in the wet storage facility can be removed with the four-train passive pool cooling system in case of flooding.

At KKL, safety against flooding is proven because the elevation of the power plant is significantly higher than the maximum expected flood level. However, impairment of the service water system cannot be entirely excluded as a result of flooding events. Nevertheless, the failure of this system does not have any safety-relevant effects because, if it fails, the protected emergency cooling water system with its emergency cooling towers and supply from groundwater wells (safety train 1) acts as a heat sink.

Removal of decay heat from the reactor core at KKM is guaranteed in case of inundation due to a 10,000-year flood, taking account of the improvements implemented in the meantime to the flood protection for the cooling water intakes (safety trains 1 and 2). These back-fitting measures, however, merely represent transition solutions because ENSI has requested a diverse coolant supply (see section 3.2.2). Thanks to the improvement implemented meanwhile to the flood protection for the cooling water intakes (safety train 1), the spent fuel pool cooling is now also protected against flooding. However, the latter system would fail in case of the assumed single failure in the emergency power supply system, in which case the large stock of coolant in the spent fuel pool allows an adequate delay time until further coolant is supplied. For this reason, ENSI has requested an improvement to the spent fuel pool cooling system (see section 3.2.2).

To summarise, ENSI finds that the Swiss nuclear power plants have a high level of protection against the consequences of flooding both in power operation and during shutdown. Compliance with the fundamental safety functions of "Control of reactivity", "Cooling of fuel assemblies" and "Confinement of radioactive material" is achieved in case of flooding. The flood analyses confirmed the safety-related benefits of the special emergency systems that are additionally available in all Swiss nuclear power plants. In case of need, the safety functions for reactor shutdown, core cooling and decay heat removal are automatically and autonomously maintained for at least 10 hours; switching actions by the operating staff are required for longer periods.

3.1.3 Plants' compliance with their current licensing basis

Operators' main results

All Swiss nuclear power plants have certified quality management systems as per standard ISO 9001:2000. Procedures and processes with unambiguous allocation of responsibilities and authorities in the organisation have been established for all operational activities, and especially for those relevant to nuclear safety. For this purpose, the safety- and security-relevant tasks are recorded so that they can be systematically planned, carried out, monitored, documented and subjected to both internal and external audits, and can be adapted as necessary. The quality management systems cover the aspects of safety, security, occupational safety, accident protection, health protection and environmental protection.

An important tool for guaranteeing the on-demand availability of safety-relevant SSCs is embodied by the requirements in the technical specifications (TS) of the NPPs and their monitoring. The TS stipulate which SSC must be ready to operate, in which operational phases, how long reactor operation can still be continued in the event of an SSC failure, and the intervals at which the on-demand availability of the SSC must be proven.

In addition, comprehensive programmes for maintenance, recurring tests, system and component function tests as well as tests to monitor ageing are in place to monitor and ensure the functional capability of the SSCs.

Plant changes are implemented systematically on the basis of QM processes; for all safety-relevant changes, comprehensive safety reviews and/or assessments must be carried out to determine the impact of the change on plant safety, taking account of conformance with the official requirements.

As part of the Periodic Safety Reviews (PSR) that are conducted every 10 years, the condition of the nuclear power plants and their operational management are examined to determine compliance with legal requirements, with the provisions of the licences and with the official stipulations contained in ENSI permits. Finally, compliance of the plant condition with the licensing base is also examined as part of ongoing supervision, and during inspections by – and technical discussions − with the supervisory authority.

External emergency protection resources, to which all Swiss nuclear power plants may have recourse if required, are accommodated in a central external storage facility. Operational equipment – such as emergency power units, mobile pumps, power cables, coolant hoses, fuel, borating agents, tools, radiation protection equipment and other accident management equipment – is stored here. This storage facility was set up as one of the post-Fukushima measures, and a corresponding operational concept including assignment of responsibility for maintaining operational readiness is currently being developed.

Immediately after the events at Fukushima, targeted reviews in the areas of coolant and power supply, spent fuel pool cooling, safety against earthquake and flooding, and control of the H_2 problem were carried out or initiated in all Swiss nuclear power plants (see section 0.2). In respect of flooding, specific deterministic proof of safety in case of the 10,000-year flood was requested, and was submitted to the supervisory authority by the end of June 2011. Additional reviews were conducted in connection with the feedback of operating experience through WANO, the World Association of Nuclear Operators.

ENSI review

In connection with the operation of nuclear power plants, the Nuclear Energy Act (NEA) stipulates a requirement to implement quality assurance measures for all activities carried out in the facility (Article 22, para. 2, letter j, NEA). ENSI's requirements for management systems are stated in the guideline ENSI-G07. Accordingly, the Swiss nuclear power plants have certified management systems and appropriate processes, procedures and programmes to ensure the availability of the structures, systems and components (SSC) that are important in terms of safety. Operators' activities in this regard are supervised by ENSI. The Technical Specifications are subject to mandatory permits, and compliance is subject to special monitoring by ENSI. In case of changes to plants, the impact of the change on the plant and on the risk must be analysed in depth. This should ensure that any changes to be implemented will not result in any undesirable and unintentional impact on the safety arrangements or any impairment of the safety functions. Finally, compliance of the plant design with the basis for licensing and the state-of-the-art is also reviewed at intervals when the PSR is conducted. This review investigates whether new knowledge regarding safety gained from operating experience, safety analyses and from research and development in the nuclear field should be implemented by the operators of the nuclear power plants.

As one of the immediate measures after Fukushima, ENSI ordered that the operators must have access to an earthquake- and flood-resistant external storage facility that contains additional operational resources, such as emergency power units, mobile pumps, borating agents and fuel. These operational resources have been available since 1 June 2011. ENSI is supervising the development of the relevant operating concept, and the measures to guarantee availability of these resources when required.

To summarise, ENSI confirms that comprehensive and reviewed provisions have been implemented in all Swiss nuclear power plants to ensure the availability of those SSCs that are relevant to safety, should they be required. No divergences from the licensing basis were identified during the review.

3.2 Evaluation of the safety margins

3.2.1 Estimation of safety margin against flooding

Operators' main results

KKB and KKL indicate the flood levels to be expected in case of a 10,000-year flood (H3). According to them, a flood height of up to 327.37 meters above sea level is reached at the KKB site. At KKL, the flood height of 313.75 meters above sea level remains several meters below the plant site, which is located at 332.0 meters above sea level. KKG does not state a flood level for a 10,000-year flood in its report for the EU stress test. The background documentation quoted in this report however indicates that a flood such as the one taken as the basis for hazard level H3 would inundate the plant site up to a flood height of about 382.50 meters above sea level. From KKG's viewpoint, the flow rate attributable to a 10,000-year flood is so low that no flooding of the plant site is to be expected. KKM states that in a flood scenario (H3), which covers the 10,000-year flood at this site, a flood height of 466.25 meters above sea level is attained. All operators classify the documents on which their determination of the flood levels is based as D1.

Likewise, all the operators consider the consequences of a discharge that substantially exceeds the 10,000-year flood (by 20 % or more). No cliff-edge effect is identified for any plant in this regard. In this case, KKB and KKG base their considerations on documents that they classify as D1. KKM's statements are based on sensitivity studies which are not described in more detail. KKL provides an estimate without referring to additional studies.

The consequences of the failure of individual or multiple hydraulic installations are also considered by all operators. In this context, neither KKB, KKG nor KKL identify any cliff-edge effect. According to KKM's statement, a simultaneous breach of several dam walls may trigger a cliff-edge effect as this situation could possibly lead to higher flood levels than those on which the design (H2) is based. The operators classify all documents relating to the failure of hydraulic installations as D1.

The operators' main results reproduced above in summarised form are presented in more detail below for each specific plant.

According to the original design (H1), the buildings at KKB that contain the equipment of safety train 1 required for a safe shutdown of the plant are designed to be flood-resistant up to a height of 1.65 m above the site ground level, with the exceptions of the auxiliary building and the turbine building. The important components for safe shutdown contained in these two buildings are located above the design-basis flood height, with the exception of the service water pumps that are positioned in lower rooms of the turbine building. In case of a failure of these pumps however, safety train 1 for core cooling via secondary side is still available. The special emergency building built subsequently with equipment for safety train 2 is flood-proof up to a height of 6 m above the power plant site. The 10,000-year flood (H3) results in maximum flooding of the power plant site of 0.37 m. This results in adequate safety factors in relation to the original design and the special emergency design. A failure involving weir breaches was taken into account conservatively by the original design, leading to the definition of the design-basis flooding height of 1.65 m. New studies show that the Beznau site would only be flooded up to a level of about 0.11 m in case of a failure of the limiting weir. Even in the case of a very infrequent flood with 20% more discharge than in a 10,000-year flood, the design-basis flood height of +1.65 m is not attained. Finally, KKB also considers the consequences of a total debris blockage of the dam in Beznau with the help of a new sensitivity study, according to which the relevant scenario does not produce a cliff-edge effect.

As regards safety margins in case of flooding, KKG states that safety train 1 has a safety factor of 1.1 in relation to the discharge of 1,550 m^3/s associated with hazard H3. This means that decay heat removal can be ensured with this safety train up to a discharge level into the Old Aare of 1,700 m^3/s. Safety train 2 provides greater safety reserves. On the basis of the flood protection for the special emergency building, a safety factor of at least 1.35 is attained here, equivalent to a discharge level of 2,100 m^3/s with a flood level of approx. 1.5 m above the power plant site. Cliff-edge effects could be produced at a discharge level of approx. 3,400 m^3/s or more, with an associated flood level of approx. 2.3 m, as water could then penetrate the special emergency building. These statements are based on D1 documents. Finally, KKG states that a debris blockage of bridges could potentially influence the volume of water flowing to the plant site due to backwater effects, but does not comment on the impact on the plant.

The KKL site is flood-proof even under extreme assumptions regarding the flooding hazard. This statement also applies to the hazard from flood waves due to the failure of hydraulic installations. In addition, KKL examines the consequences of a blockage of rainwater drains and the duct system for the power plant site on the basis of a document designated as D1. No cliff-edge effect is identified for these scenarios. In overall terms, KKL states that no weak points are present that would necessitate improvement measures.

The buildings at KKM that contain safety-relevant systems, as well as the interim storage facility, are protected against the consequences of flooding up to a level of 472.0 meters above sea level. The 10,000-year flood will attain a maximum flood height of 466.25 meters above sea level. This means that the function of the safety systems for safety train 2 is basically guaranteed up to a level of 472.0 meters above sea level. In case of a breach of the Wohlensee dam wall, however, a total failure of the cooling water supply with river water cannot be excluded regardless of the newly implemented improvement measures (see section 3.2.2). In this case, the removal of the decay heat from the reactor must be implemented by means of a "feed-and-bleed" operating mode until the special emergency cooling water supply can be returned to operation. In this operating mode, coolant is initially fed from the condensate water storage tank or the Torus via the steam-driven high-pressure feed system into the reactor, the steam produced is fed via the venting valves into the Torus, and the decay heat is removed from the Torus into the outer Torus by means of venting. At a reactor pressure <4.5 bar, cooling water can then be fed into the reactor pressure vessel from the hilltop reservoir.

The KKM's spent fuel pool is in a flood-proof location in the reactor building (+29.4 m). The additional dry storage facility for fuel assemblies that is in place is designed to ensure criticality safety, and it remains sub-critical even in case of inundation. Finally, KKM states that cliff-edge effects with a total failure of the cooling water supply would only occur if the discharge values for the scenario taken as the basis for the flooding proof are exceeded by approx. 20 to 30%. In this case too, the removal of decay heat could be ensured with the "feed-and-bleed" operating mode. This also applies to the case of a debris blockage or a blockage of the Aare by rubble or boulders followed by a blockage of all cooling water intake structures.

ENSI review

From ENSI's viewpoint, the classification of the documents used to determine the high water levels in case of flooding as D1 is correct, and the flood levels reported by the operators are basically reliable. One exception is the statement by KKG regarding the flow rate to be assigned to the 10,000-year flood. Essential points of the hazard analysis on which this statement is based were already rejected by ENSI in another review. For this reason, ENSI stipulated in connection with the EU stress test that as the new hazard (H3) KKG should base its considerations on the hazard that was determined for the general licence application dating from 2008 for a new nuclear power station on the directly adjacent Niederamt site.

The classification of the KKB and KKG documents that form the basis for the statements about sensitivity in relation to discharges is correct in ENSI's view. KKM's sensitivity studies are classified by ENSI as D2. The operators' main results are plausible. For KKL in particular, the operator's rough estimate, based on the fact that the location is several meters higher than the river and the level of the opposite bank is comparatively low, is sufficient to allow a cliff-edge effect to be excluded.

The majority of the documents used to evaluate the influence of a failure of hydraulic installations should, in ENSI's view, be classified as D1. There are exceptions in the cases of the new assessments by KKB and KKL, which should be classified as D2 in respect of the failure of hydraulic installations. However, the statements that no cliff-edge effects are generally to be expected at KKB, KKG and KKL are reliable. KKM's statement that the simultaneous breach of several dam walls could possibly exceed the design-basis flood height (H2) is plausible according to preliminary assessments. Within the targeted safety review of the protection of Swiss nuclear power plants against flooding initiated by ENSI immediately after the events at Fukushima, the structural integrity of dam walls in case of H3-flooding has already been demonstrated by KKM. KKM is requested to demonstrate the structural integrity of the Wohlensee, Rossens and Schiffenen dam walls in case of H3-earthquake by the end of March 2012 (see section 2.2.3).

ENSI classifies KKB's statements on debris blockage as D2. The choice of the retaining weir at Beznau is appropriate for the study of the impact of debris blockages because an artificial constriction of the river cross-section is present here, and a complete debris blockage at this point has potentially major effects on the flooding situation at KKB. The new sensitivity study provided by KKB was not reviewed due to time contraints. Therefore ENSI is unable to state whether or not a debris blockage at the aforementioned location produces a cliff-edge effect for KKB. As regards KKG, ENSI considers that the operator's statements do not provide a basis to determine whether a cliff-edge effect occurs in case of debris blockage scenarios. Consequently, such an effect cannot be excluded. The document referenced in connection with a blockage of the rainwater drains and the duct system at KKL should be classified as D2 in respect of this subject. In ENSI's view, the statements by KKL on this matter are plausible. The risk from debris blockage of the river and a related cliff-edge effect can be excluded because the location is several meters higher than the river and the level of the opposite bank is comparatively low. KKM's assessment that a debris blockage of the river produces a cliff-edge effect for the plant is not based on specific debris blockage scenarios for bridges or culverts which constrict the cross-section of the river. ENSI is therefore unable to state whether or not such debris blockage scenarios could produce a cliff-edge effect for KKM. Based on the operator's statement, ENSI assumes that debris blockages can exacerbate the plants' hazard situation. The information provided by KKG and KKM on this aspect is not adequate, or is not based on site-specific studies. ENSI will follow up on the effects of a total debris blockage of the relevant hydraulic installations (**open point 3-1**).

In summary, the evidential documents on flooding that were examined by ENSI have shown that the 10,000-year flood can be dealt with and, in addition, that safety margins are available for higher discharges. Cliff-edge effects that could occur in case of flooding of the special emergency systems (safety train 2) are only possible in the case of extremely high discharge volumes. The analyses also gave consideration to the failure of dam walls and weirs of run-of-river power plants, and the resultant flood levels. A failure of this sort was already taken into account for the design of the plants, so it does not lead to inadmissible flooding levels. However, in the case of KKM – as already mentioned in section 3.1.2 – a total failure of the cooling water supply due to blockage cannot be excluded in case of a breach of the Wohlensee dam wall. In order to ensure the cooling water supply even in this unlikely case, KKM plans to erect a diverse cooling water system that is separate from the river water cooling as a long-term solution, in addition to the improvement measures already implemented (see section 3.2.2).

ENSI points out that the accident analyses carried out in connection with the flooding hazard also contain additional failure assumptions. In accordance with the requirements specified by the IAEA and the Swiss requirements for the analysis of design-basis accidents (guideline ENSI-A01), it was assumed that in addition to the initiating event, an independent individual single failure occurs. For this purpose, the single failure is (or was) assumed to be in a location where it imposes the maximum restriction on the availability of the safety systems required to deal with the accident. In the accident analyses carried out by KKB and KKM, for example, it was assumed that, in case of flooding, the emergency diesel generator (the "flood diesel" at KKB or emergency diesel generator 090 at KKM) and the safety systems which they supply would fail, and in the KKG flood analysis it was assumed that the steam generators required for heat removal would fail. Proof is therefore furnished that compliance with the fundamental safety functions is ensured in the Swiss nuclear power plants even if additional failures are assumed.

3.2.2 Measures which can be envisaged to increase robustness of the plants against flooding

Operators' main results

KKB determines that measures to increase the robustness of the plants against flooding due to a 10,000-year flood are not necessary, thanks to very large safety reserves, especially in respect of the flood height and degree of redundancy of the safety trains.

Prior to the events at Fukushima, KKG had already implemented a number of measures to improve flood protection on the basis of new knowledge about the flooding hazard for the site, such as:

- Introduction of an automatic advance flooding alarm to guarantee timely prior warning
- Additional sealing of building shells, air inlets and doors, etc., of buildings with equipment used for the safe shutdown of the plant
- Specification of the organisational and administrative measures to be implemented in case of a "flood" accident in the emergency procedures
- Preparation for the erection of dam bulkheads
- Installation of flood valves to seal ventilation intakes

As an additional measure, KKG plans to build a flood protection wall to prevent water ingress through a breach in an embankment, in combination with the preparation of a shut-off bulkhead for access via the power plant road, which would simplify the accident management measures.

The KKL flood analyses have shown that the plant is protected against flooding events with high safety margins. No changes to the plant or adaptations of its design are therefore required, as far as is known at present. Likewise, no follow-up measures can be derived from the assessments in connection with the stress test.

At KKM, the following improvements have already been implemented in connection with orders by ENSI:

- Provision of mountable flood walls for protection against flooding of the auxiliary cooling water pumps in the pump building, and enhancement of the relevant operating instructions
- Provision of mobile pumps to inject water into the SUSAN intake structure
- Implementation of an additional injection option (intake shaft) into the SUSAN intake structure
- Back-fitting of three special vertical pipes on top of the SUSAN intake structure to ensure the cooling water supply for SUSAN

These measures were implemented in the period from June to September 2011. In order to guarantee the availability of the cooling water supply even in case of a total failure of the river water cooling from the Aare, KKM plans to implement a diversified heat sink in the medium term. It is also envisaged to back-fit an additional spent fuel pool cooling system and to extend the in-plant accident management measures as regards the additional injection capabilities and the monitoring for the spent fuel pool.

ENSI review

KKB's flood analyses have shown that the cooling of the reactors in both units continues to be guaranteed in case of the 10,000-year flood, and that there is no need for additional measures. In its assessment of the reliability of the spent fuel pool cooling in connection with the third order /A-4/, ENSI nevertheless asked that the pool cooling must be improved. KKB then proposed to implement the following improvement measures:

- Installation of an additional independent spent fuel pool cooling system with coolant supply from the protected special emergency well
- Extension of the in-plant accident management measures for injection into the spent fuel pools via the existing alternative FEC pool cooling system, and via the new protected FNC pool cooling system
- Installation of redundantly designed temperature and filling level measurements in each spent fuel pool as accident monitoring overview displays
- Installation of equipment for pressure relief of the spent fuel pool storage building in the event that all spent fuel pool cooling systems should fail

ENSI has basically approved the relevant concept proposals, which were submitted at the end of August 2011.

As regards KKG, ENSI confirms that no additional measures to improve flood safety result from the analysis of the hazard caused by a 10,000-year flood. The flood is dealt with by systems that have special emergency protection. For the purpose of continuous improvement of protection against accidents, KKG has nevertheless decided to erect a flood protection wall with a retaining bulkhead to shut off the access road as part of the planned new plant perimeter. Thanks to this project, flooding of the power plant site should also be prevented in case of a flood that exceeds the requirements imposed by the 10,000-year flood.

No additional measures are required at KKL for the purposes of the plant's safety against flooding.

KKM has already implemented a number of measures to improve flood protection in connection with the extended outage in 2011; these measures have been reviewed and approved by ENSI via permits. In addition to these measures, ENSI required to back-fit a diversified heat sink as well as measures to upgrade the spent fuel pool cooling.

The open point 3-1 identified in section 3.2.1 which calls for additional specific analyses related to debris blockage of hydraulic installations may lead, if appropriate, to additional improvements which will increase the robustness of the Swiss nuclear power plants in case of flooding.

4 Extreme weather conditions

As regards applied loads resulting from extreme weather conditions, Switzerland's nuclear power plants were designed in the 1960s and 1970s according to the assumptions that were valid at that time. For example, weather conditions played a part in the design of the buildings, the ventilation systems, the cooling water intakes and the heat exchangers for the emergency and residual heat removal systems. The design against phenomena due to extreme weather conditions also determines the robustness of the plant, although other loads (such as an aircraft crashing onto the reactor building or exposures from an explosion) are usually larger. In addition, all operators examine the potential effects of extreme weather conditions on the risk of core damage as part of the PSA (Probabilistic Safety Analysis).

This section assesses the protection of Switzerland's nuclear power plants against meteorological hazards caused by strong winds, tornadoes, extreme temperatures and snowfall, as well as hydrological hazards resulting from heavy rainfall on the plant site. The effects of flooding caused by heavy rain, snow melt and dam breaks are assessed in Section 3 of this report.

The occurrence of extreme meteorological and hydraulic events shows that more attention must be paid to the assessment of the potential effects of climate change.

4.1 Design basis

During the design phase for the plants, various extreme weather conditions were taken into account as additional loads on the buildings. The loads resulting from extreme weather conditions were determined at the same time as the applications for construction licences were submitted (1960s and 1970s), using the then valid methods based on the standards of the Swiss Association of Architects and Engineers (SIA). Depending on the location and (for example) the altitude, the SIA standards take account of the various assumed snow or wind loads as additional loads, in combination with the resultant operational loads. In particular, the determination of the hazard assumptions is stipulated in the current regulations by the DETEC Ordinance /A-8/ on Hazard Assumptions and the Evaluation of Protection against Accidents in Nuclear Plants. According to this ordinance, the operators must prove that the loads which could occur on the basis of a 10,000-year recurrence period can be dealt with.

4.1.1 Reassessment of weather conditions used as design basis

Operators' main results

The operators' final reports assess the following weather conditions in terms of the hazard they pose: extreme winds and/or tornadoes, heavy rainfall on the plant site and extreme summer and/or winter temperatures. The operators also consider extreme snowfalls which act as additional static loads on buildings. In addition, the operators mention further individual hazards. When several extreme weather conditions overlap, various scenarios are possible. For example, extreme summer temperatures increase the risks of forest fires or heavy thunderstorms which can lead to strong local winds, with heavy rainfall on the plant.

The operators' final reports on the determination of the relevant hazard assumptions make special reference to the plant-specific PSA (D1 in this respect), to the Safety Analysis Reports for the new nuclear power plants (D1) on existing sites for which applications were submitted (and have now been suspended), and to the data made available by MeteoSwiss (the Federal Office of Meteorology and Climatology).

Extreme winds and/or tornadoes

Measured data on the velocities of wind gusts at the site or in its immediate vicinity are available for all plants. On the basis of these data, a wind hazard curve (yearly frequency with which maximum wind speeds are exceeded) was determined with the help of an "extreme value" statistical evaluation. All the final reports (except the KKB report) explicitly state the expected maximum wind speed for an excess frequency of 10^{-4} per year (10,000-year event). These values are 169 km/h for KKG, 192 km/h for KKL and 107 km/h for KKM.

For the site-specific tornado occurrence frequencies, KKM and KKG refer in their final reports to the relevant analyses for the replacement nuclear power plant at Mühleberg (EKKM) and the planned Niederamt nuclear power plant (KKN) on the KKG site. Considering a conservative assumption on the tornado class (class F2), the resultant dynamic pressures at KKG are slightly higher than for extreme wind gusts, but are still covered by other load cases such as earthquake or aircraft crash. Likewise, flying debris ("wind missiles") is covered by the case of an aircraft crash. At KKM, the 10,000-year tornado is covered by the SIA standard design, hence poses no problem. KKB and KKL did not mention any tornado occurrence frequencies in their final reports.

The design against wind as per the SIA standard varies for the individual buildings depending on their construction type and height. For example, the reactor building at KKM was designed for 159 km/h (corresponding to a surface load of 1.2 kN/m^2). Depending on the building, the assumed wind load at KKL varies between 0.85 kN/m^2 and 1.0 kN/m^2, but all buildings with important safety systems are adequately designed against high wind velocities, especially those buildings that are designed to withstand aircraft crashes. At wind speeds of 200 km/h or more, KKL anticipates isolated instances of damage due to wind missiles, although the safety-relevant concrete structures are not endangered in this way. KKG comments that extreme winds are covered by other design loads such as explosions, aircraft crash or earthquake. KKB does not indicate the plant's design basis against extreme winds. In this context, KKB considers its operating period of 40 years and points out that no damage due to extreme winds has occurred during this period. At KKB, all the safety-relevant equipment – except for the main steam (FD) relief station – is accommodated in concrete shell buildings. The main steam relief station is located between the turbine building and the safety building in a steel structure with metal plate cladding, so it is well protected.

Extreme summer and/or winter temperatures

Extreme summer and/or winter temperatures for the 10,000-year event were only covered by KKM. Nevertheless, KKM concludes that a new proof is to be provided regarding extreme temperatures.

Each operator presents the information on the design temperatures with very different levels of detail. At KKB, for example, outdoor temperatures of between -15℃ and +32℃ are taken as the sole criterion for the original design. In addition, extreme temperatures of -25℃ to +40℃ for 6 hours were stipulated for the ventilation of the back-fitted special emergency building. KKM writes that the temperatures measured in summer 2003 were above the design-base temperature for the SUSAN ventilation system (32.1℃), but this did not lead to excessive heating of the equipment. At Leibstadt, the design-basis temperature varies between -25℃ to -15℃ (minimum) and 30℃ to 65℃ (maximum), depending on the system and component. KKG comments that the cooling chain for the intermediate cooling water is based on a maximum cooling water temperature of 23.5℃, although 50℃ was usually assumed for the mechanical design.

Operating experience shows that function tests carried out at high summer and low winter temperatures were always successful, with one exception. At KKB, the failure of a "flood diesel" led to the back-fitting of a water cooler in the air circuit of these diesels. Other instances where design-base temperatures were exceeded had no impact on the function of the safety systems. Operating experience also shows – as KKM comments – that the relevant design-base temperatures have already been exceeded and – as KKL notes in addition – that outdoor temperatures are of little significance with regards to safety.

Heavy rainfall on the plant site

In respect of the hazard due to extreme rainfall on the plant site, KKG refers to existing analyses for the planned KKN nuclear power plant, and KKL refers to a study that was commissioned (D2). The information provided by KKL shows the potential duration of such heavy rainfall varies between 0.5 h and 6 h, whereby the maximum possible volume of rain also varies. For a 1-hour precipitation event, this value is about 120 mm/h. For KKG, the value is 34 mm in 10 minutes, but there is no reference to the duration of the heavy rainfall. KKB states the 500-year exceedance frequency for the hourly volume of rainfall as 12 mm/h on the power plant site. KKM provides no information on the expected volumes of heavy rainfall on the plant.

The plants' design-basis values against heavy rainfall on their sites are not stated by the operators, but KKL indicates the dimensioning of the site drainage, which corresponds to a 20-year heavy rainfall for the power plant unit.

According to the information stated by KKG and KKL, the drainage systems are adequately dimensioned, so heavy rainfall on the plant site is dealt with.

Snow loads

Regarding extreme snow loads, the KKG and KKM plants refer to the analyses for the planned KKN and EKKM nuclear power plants. The reported snow heights for both sites are slightly less than 150 cm for the 10,000-year event. The corresponding distributed loads due to the 10,000-year event vary between 1.3 kN/m^2 (fresh snowfall) and 5.2 kN/m^2 (wet snow).

Except for KKB, the operators demonstrate that the plants were designed on the basis of the SIA standard with snow loads of up to 1.2 kN/m^2.

The assumed design loads for buildings (building class BC I) for KKG and KKL are higher due to other load cases such as explosions, aircraft crashes or earthquakes. Operating experience at KKM shows that even in extremely cold winters, no snow remains on the reactor building because of the poor insulation, so no hazard to the reactor building ensues. Nevertheless, KKM concludes that new proof is to be provided regarding extreme snow loads.

ENSI review

In ENSI's view, the following hazards specified by ENSREG are relevant in Switzerland: extreme winds, tornadoes, heavy rainfall on the plant site, extreme summer and winter temperatures, and extreme snow loads. Lightning is not explicitly mentioned by ENSREG /A-13/. In Switzerland, the design of plants in this respect complies with the "Swiss standard lightning bolt" on the basis of a stipulation by HSK (now ENSI) which, in ENSI's opinion, covers the requirement. Overlapping of various extreme weather conditions cannot be excluded. ENSI considers that the operators have presented the main combinations, but not the resulting loads and impacts on the safety-relevant buildings (see open point in Section 4.2.2).

In order to determine the hazard assumptions for the 10,000-year event, the operators to some extent calculated the frequencies with which maximum values are exceeded, in particular for extreme winds, heavy rainfall, snow loads and extreme temperatures. The extreme-value statistical methods used for this purpose generally correspond to the state-of-the-art. In the operators' final reports, the plants do not present the exceedance frequency for the values on which the design was originally based.

For all plants except KKL, reference can be made to the corresponding safety analysis reports for the planned new nuclear power plants in order to determine the extreme weather hazard assumptions, provided that ENSI has assessed the relevant hazards in the general licence application (D1 for assessed hazards, otherwise D2).

Extreme winds and/or tornadoes

As stated in the operators' final reports, the exceedance frequencies of maximum wind velocities are based on studies which ENSI classifies as D1. There is an exception for the maximum wind velocities stated by KKL for the 10,000-year event, which originate from a new study which has not yet been reviewed by ENSI and is classified by ENSI as D2. The differences between the site-specific 10,000-year values are due to site-specific characteristics (e.g. location protected against wind) but are also caused in part by the different procedures adopted in order to determine the hazard. Due to the missing information and in order to harmonise the determination of hazards, ENSI considers that there is a further requirement for clarification (see open point in Section 4.2.2).

The frequencies for the occurrence of tornadoes, as cited in the final reports by KKG and KKM, were determined in accordance with the requirements stipulated in the guideline ENSI-A05. In this context, KKG and KKM comment on the impact of the 10,000-year tornado. As in the case of extreme winds, ENSI considers that there is a requirement for further clarification regarding the 10,000-year hazard (see open point in Section 4.2.2).

In ENSI's view, it can generally be stated that the buildings in building class I for all the plants are designed against greater loads than those to be expected in case of extreme winds or tornadoes. This is especially true of the reactor and special emergency buildings that are protected against the impacts of aircraft crashes and earthquakes. In particular, the function of the second safety train is ensured in these cases.

All the operators take account of the wind and tornado hazards in the plant-specific PSAs. Additional heavier and rarer extreme winds and tornados are considered in plant-specific PSA as well. The results from the studies indicate that winds and tornadoes do not result in dominant contributions to the risk.

Extreme summer and/or winter temperatures

KKM is the only operator to provide information on the 10,000-year temperature event. ENSI classifies the comments on this subject as D2. Reliable information on the 10,000-year temperature event is therefore largely missing, as well as presentations of the planned measures that can be implemented before an extreme temperature is attained. A comprehensive analysis of the effects of 10,000-year extreme temperatures on the plants is missing from the operators' final reports (see open point in Section 4.2.2).

All the operators state the relevant design bases for extreme temperatures. In individual cases, the design-basis temperatures have been exceeded for brief periods without significant effects on safe operation. Regardless of this, ENSI considers that climate change makes it necessary to analyse the design of safety-relevant equipment against extreme temperatures (see open point in Section 4.2.2).

Heavy rainfall on the plant site

For the 10,000-year heavy rainfall event on the plant site, KKG and KKL refer to current studies. The information in these cases is classified as D2 . For the KKB and KKM plants, however, no information is given for the 10,000-year event. Because hazard assumptions have not been submitted or have not yet been reviewed in detail, ENSI considers that there is a requirement for further clarification regarding the determination of 10,000-year heavy rainfall on the plant site (see open point in Section 4.2.2).

In ENSI's view, it can generally be stated that the buildings in building class I at all the plants are designed against greater loads than those to be expected in case of extreme heavy rainfall. This is especially true of the reactor and special emergency buildings that are protected against the impacts of aircraft crashes and earthquakes. In particular, the function of the second safety train is ensured in these cases. However, the original design bases are not presented by the operators. In addition, it can be deduced from the plant-specific PSA that the risk from local heavy rainfall on the plant site is low.

Snow loads

The reported 10,000-year values for extreme snowfalls at the site of KKG and KKM are based on D2 information. There is no information on the 10,000-year event for the KKB and KKL plants. Because hazard assumptions have not been submitted or have not yet been reviewed in detail, ENSI considers that there is a requirement for further clarification regarding the determination of 10,000-year snow loads (see open point in Section 4.2.2).

In ENSI's view, it can generally be stated that the buildings in building class I for all the plants are designed against greater loads than those to be expected in case of extreme snow loads or that, due to high surface temperatures, no snow will remain on the roof of the reactor buildings. This is especially true for the reactor and special emergency buildings that are protected against the impacts of aircraft crashes and earthquakes. In particular, the function of the second safety train is ensured in these cases.

In the case of KKM, the ability to implement countermeasures to reduce the snow load can be taken into account, because there is a long time delay until extreme snow levels are attained. Furthermore, ENSI regards KKM's argument – that the generation of heat in the reactor building will cause the snow to melt – as plausible. However, it is ENSI's view that the operators' main results must be documented more comprehensively (see open point in Section 4.2.2).

4.2 Evaluation of safety margins

4.2.1 Estimation of safety margin against extreme weather conditions

Operators' main results

In the operators' final reports, only a small part of the safety margins are directly indicated as factors for extreme weather conditions. In cases where this is difficult or inappropriate, either the hazard is discussed, or the operating experience of the individual plants is referred to.

For extreme winds, KKG and KKM report a safety margin based on the design bases. The safety factors for peak speeds of a gust of wind vary between 1.25 for the KKM reactor building to about 100 for KKG. For extreme snow loads, this factor is 25 at KKG.

ENSI review

As regards the operators' assessments of the safety margins for extreme weather conditions, only KKM and KKG provide assessments for extreme winds, and only KKG provides an assessment for extreme snow loads. In ENSI's view, it is not appropriate to make a direct comparison of the reported safety margins as their determination is based on different procedures. The existence of a margin guarantees that the plant has a certain degree of robustness against extreme weather conditions. The operators do not report a margin for the other extreme weather conditions. ENSI is not carrying out any further evaluation of the safety margins because there are still some open points regarding the determination of the individual hazards.

4.2.2 Measures which can be envisaged to increase robustness of the plants against extreme weather conditions

Operators' main results

From its studies of extreme weather conditions, KKM concludes that new proof must be furnished regarding extreme snow loads and extreme temperatures.

ENSI review

ENSI regards the measures deduced by KKM as appropriate. Based on the operators' statements, ENSI concludes that the buildings important for safety are adequately protected against extreme weather conditions. However, there is no complete and comprehensible proof of the precise determination of the hazards and their impact on the plants. ENSI therefore identifies the following open point: as part of its supervision, ENSI will follow up on the proofs of protection against extreme weather conditions, including combinations thereof (**open point 4-1**).

5 Loss of electrical power and loss of ultimate heat sink

Some overlaps occur between the scenarios dealt with in section 5, hence electrical engineering aspects are treated separately in section 5.1, while process-level aspects are covered in sections 5.2 and 5.3. Accordingly, section 5.1 does not deal with the safety trains that ensure core cooling and removal of decay heat.

The same boundary conditions apply to all the scenarios covered in section 5. It is assumed that the transport routes for heavy equipment and materials (road, rail, waterways) are blocked for 72 hours, and that lighter materials can be transported to the site by air after the first 24 hours. Earlier availability of the new external equipment storage facility at Reitnau can be discussed within the first 24 hours, as applicable.

5.1 Loss of electrical power

In the final reports the Swiss nuclear power plant operators were required to consider the following three scenarios involving sequential loss of all electrical power supplies, under the aforementioned boundary conditions:

- Scenario 1: loss of external power supply (LOOP, Loss of Offsite Power) for several days.
- Scenario 2: loss of external power supply and of emergency electrical power supply (SBO, Station Blackout).
- Scenario 3: loss of external power supply including loss of emergency power and special emergency power supply (Total SBO).

Sub-sections 5.1.1 to 5.1.3 assess the effects of these failure scenarios, and sub-sections 5.1.4 and 5.1.5 present the conclusions and measures.

In all three scenarios, it is assumed that direct current (DC) continues to be supplied. The sections 5.1.2 and 5.1.3 contain information on the period for which it is supplied.

The operators' main results on losses of power supply are largely based on D1 documents, and in particular on the safety analysis reports and the existing emergency procedures. In addition, certain aspects were clarified and recorded in the operators' final reports (D2), and are evaluated by ENSI as part of the present review. ENSI obtained additional information on individual statements in the operators' reports that ENSI regarded as incomplete.

The protective measures implemented in the Swiss nuclear power plants to ensure the power supply, which comply with the "Defence-in-depth" principle and have several levels of protection, are designated in this section as "safety layers" of the electrical energy supply. The following safety layers are in place:

1st Safety Layer:	External main grid the generator feeds into
2nd Safety Layer:	Auxiliary power supply in island mode in case of failure of the main grid
3rd Safety Layer:	External reserve grid (third-party grid) in case of failure of the external main grid and of the auxiliary power supply
4th 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 the supply of conventional safety systems
5th Safety Layer:	Special emergency electrical power supply from special emergency diesel generators for the supply of the special emergency systems

6th Safety Layer: Local accident management (AM) equipment such as for instance mobile emergency power units and possible connections to nearby hydroelectric power plants

7th Safety Layer: Accident management equipment stored at the central Reitnau storage facility and other off-site locations (mobile emergency power units)

As the design basis, classification 1E is generally applicable to all the electrical systems in the conventional emergency electrical power supply within the NPP and the special emergency electrical supply, and to the electrical components of the safety systems. This means that proof of qualification must be available for all the components involved in safety functions, that the components can withstand the earthquake loads in case of a safe shutdown earthquake (SSE) at the location where they are installed, that the installation locations of such components are above the design-basis flood levels, and that the design-basis ranges of the components for ambient conditions are proven in case of normal operation as well as under accident conditions.

The following Table 5-1 gives a summary overview of the electric power supply possibilities for Safety Layers 4 to 7 including the classified diesel equipment, supply from hydro-plants and Accident-Management-Equipment (AM- Equipment).

Table 5-1: Overview of diesel equipment and supply from Hydro plants

Safety Layer	Supply	KKB 1 / 2	KKG	KKL	KKM
4	Number of emergency diesels	2 per unit	4 *2	3	1
	Number of supply trains from hydro-emergency power supply	2 per unit	n.a.	n.a.	2
5	Number of special emergency diesel	1 per unit *1	2	2	2
6	Emergency supply connections from nearby hydro plant	n.a.	available *3	available *3	n.a.
	Number of local (on NPP site) available, large electric power supply-AM equipment	2 *4	2 *5	1	1
7	Number of AM-Equipment in Reitnau central emergency storage facility	3 *6	3 *6	3 *6	3 *6
	Additional AM-Equipment in the vicinity of the power plant	several may be procured from various locations	several may be procured from various locations	additional may be procured from a company	3 smaller ones located close to the installation

*1 1 special emergency diesel can supply both units 1 and 2

*2 in addition 2 other diesels for the 2. cooling water supply

*3 Built-in, cable and connectors available

*4 Since the end of October 2011

*5 Planned for 2012

*6 used in common by all NPP operators

5.1.1 Loss of off-site power (LOOP)

LOOP basically designates the loss of off-site operational grid (alternate current supplies, AC) and simultaneous loss of the auxiliary power supply from the power plant's own generators, so that the emergency electrical power supply bus bars classified as 1E − which were operationally supplied until this time − lose power and, as a result, the main AC emergency electrical power supplies, i.e. the emergency diesel generator and/or supplies classified as 1E from the nearby hydroelectric power plants (HPP), are activated. In other words, the LOOP event equates to emergency power conditions.

Operators' main results

As regards the emergency electrical power supply, the Swiss nuclear power plants have several staggered safety layers of electrical supply, in accordance with the defence-in-depth principle that is applied in nuclear technology. The off-site grid supplies for the Swiss NPPs comprise at least two connected high-voltage grids in each case, in addition to the generator-based auxiliary power supply. The LOOP event (emergency power conditions) only applies once these three possible supplies have failed.

In case of a loss of the main grid, the aim is to retain the generator-based auxiliary power supply with a rapid reduction of the generator power (load rejection to auxiliary power supply), before switching quickly over to the reserve grid (switchover to auxiliary power) and before starting the main AC emergency electrical power supplies. Following the load rejection to the auxiliary power supply, the power plant and its electrical supply are in island mode. The reserve grid is also used as an operational electrical reserve supply during the annual NPP outage or during inspections of the main grid, besides its safety-relevant role as auxiliary power grid.

For a scenario involving failure of the safety layers 1 to 3 mentioned above, the Swiss nuclear power plant operators have shown that the emergency electrical power supplies provided for in the design will guarantee a reliable and permanent supply for the safety systems and the important safety-relevant systems.

The KKB and KKM plants, which have direct and secured underground (buried) emergency power connections to the nearby HPP in each case, are not subject to any time restrictions in respect of their power supply. In addition, the emergency power and special emergency diesel systems available in these plants can be deployed if the emergency hydroelectric power supplies are impaired by external events such as flooding and the required power can no longer be made available.

In the other two plants, which are mainly supported by the stationary emergency and special emergency diesel generators in the LOOP scenario, a time restriction is imposed by the reserves of diesel fuel that are available locally; depending on the deployment concept for the safety-classified consumers with high energy consumption, different time restrictions are imposed on the autonomous local supply.

Under the assumption that there is as yet no impairment of the directly-connected emergency buried hydroelectric power supplies under LOOP conditions, the emergency electrical power supply for KKB and KKM is available without time restrictions. At KKG and KKL, the emergency diesel power generators start automatically and can be operated for periods of at least 3.5 or 5.3 days, respectively. This period is limited by the local stocks of diesel. Including the procurement of fuel from external diesel stocks after the first three days, for example from nearby fuel stores, all four Swiss nuclear power plants can be safely supplied with electricity for a very long period (weeks to months) under LOOP conditions. If the prepared emergency supply connections from the nearby HPPs to the Gösgen and Leibstadt NPPs are also included, an unlimited period of supply is available for all four plants, provided that the HPPs are able to function.

ENSI review

Based on conservative assumptions, all the Swiss plants fulfil the minimum period of autonomy of 72 hours (3 days) as stated in the ENSREG specification in case of a LOOP scenario. Thereafter, a very long period can be bridged by continued operation of the emergency hydroelectric power supplies or by procuring fuel from external stores until at least one of the redundant external grid feeds is restored. Thanks to the availability of directly connected buried emergency hydroelectric power supplies (KKB, KKM) or emergency power connections (KKG, KKL) from the nearby HPPs, a supply is also provided to each of the four Swiss nuclear power plants that is diversified from the fuel-dependent supply and is not subject to a time restriction. This is achieved by means of existing direct connections, and independently of the functional ability of the high-voltage grids. Hence, the LOOP scenario is covered by multiple and diversified supply options in all the Swiss plants.

5.1.2 LOOP and loss of the ordinary back-up AC power sources (SBO)

Operators' main results

When applied to the Swiss nuclear power plants, the SBO scenario not only involves the loss of all operational feeds (off-site operational grids and the plants' own generator-based supply) but also the loss of all safety-classified emergency diesel generators and - if available on the NPP site - of the emergency hydroelectric power supplies. In this scenario, the bunkered special emergency electrical supply provided for special external events is still available. This consists of special emergency diesel generators with the AC electrical supply equipment (switchgear, circuit breakers, equipment for electrical protection, displays, controls, manual operating devices, etc.) for the special emergency systems. On the basis of the Swiss requirements for the energy supply to nuclear power plants, the SBO scenario – in respect of the electricity supply – therefore entails a special emergency scenario that can only occur after the failure of the first four safety layers.

The availability of safety trains (ref to section 1.3) along with the necessary electrical power consumers in case of an SBO are treated in section 5.3.1 as is the combination of an SBO with the loss of the primary heat sink.

<u>Special emergency power supply</u>

In the Swiss NPPs, the special emergency electrical supplies are designed so as to satisfy the single failure criterion, i.e. in each case with doubled diesel and supply redundancy. As regards the KKB, which is a twin unit plant, it must be noted that this statement is valid in respect of both the power plant units. At KKB, one special emergency diesel is available for each unit, with the possibility of providing the supply from the special emergency diesel generator of the other unit by means of cross-coupling.

In all four Swiss nuclear power plants, the diesel supply for the operation of the special emergency diesel generators can be ensured for several days by using the plants' own local reserves of diesel fuel. The proven period of autonomy of more than five days for all the plants is sufficient to allow off-site diesel stocks to be procured.

The capacity of the batteries of the special emergency domain are not relevant to the SBO scenario since a recharge of the special emergency batteries is ensured by the special emergency diesels which are still operational in such a scenario. The capacity of the special emergency batteries is addressed in section 5.1.3 (Total SBO)

Non-special emergency DC power supply

DC supply supported by batteries feed to important consumers outside the special emergency domain. These important consumers consist in the emergency lighting, the safety lighting and the communications infrastructure which may still be used in the relevant accident situation (refer to section 6.1.5)

The NPP operators have carried out analyses of the autonomous battery supply period in case the quoted supplies from the batteries are still available outside the special emergency domain. After this period the batteries would have to be recharged by their supply bus bars in order for the important consumers to remain operational. A recharge of the batteries is possible by re-establishing the corresponding emergency power supply or through the use of mobile emergency power equipment. The period of autonomous supply in case of an SBO amounts to several hours for all Swiss NPPs in accordance with the ENSI Guideline HSK-R-101. In fact, the capacity available outside the special emergency domain reaches always a minimum of 4 hours and in most cases extends from 7 to 9 hours, in some case reaching even 19 hours. The single failure criterion is fulfilled for this supply, since the battery systems incorporate several redundant trains.

ENSI review

The SBO scenario (special emergency conditions in respect of the electrical supply) can be managed by the four Swiss nuclear power plants in accordance with their design and in compliance with the requirements of the Swiss regulations.

Even before the events at Fukushima, where several power plant units at the same site were simultaneously affected by a severe accident, potential for improvement regarding the special emergency supply had been identified at KKB. The major AUTANOVE project that has been in progress since the end of 2008 has the primary goal of replacing the existing emergency hydroelectric power supply for the KKB by four emergency diesel generators for the two units in two separate diesel buildings protected against earthquake and flooding.

All plants have emergency lighting supplied by emergency power for all important areas of the site as well as ununterruptible battery-supported safety lighting which are primarily used in command and control areas as well as for evacuation routes.

In overall terms, ENSI determines that the SBO case can safely be managed in the Swiss nuclear power plants and that, in addition, safety layers 6 and 7 remain in place to cope with accidents.

5.1.3 SBO and loss of any other diverse back-up AC sources (Total-SBO)

In the case of a total SBO scenario, the failure of the special emergency diesel supplies is assumed in addition to the SBO conditions. This extreme scenario, in which the failure of all non-battery-supported AC feeds for the first five safety layers of the electrical supply is assumed, falls within the scope of beyond-design-basis accidents. Depending on the severity of the accident, accident and emergency procedures must be applied, leading up to and including the decision-making aids for severe accidents (Severe Accident Management Guidance, SAMG) (also see the comments in section 6).

This section deals with the general availability of batteries, their capacity to ensure key functions for safety equipment (e.g. valve controls, availability of accident instrumentation) or safety-relevant functions (e.g. emergency lighting), and the availability of mobile emergency power units to recharge batteries. Section 5.3.1 covers the function of the exclusively battery-operated, steam-powered high-pressure injection systems (RCIC) for the Swiss boiling water reactors, which must also be considered in this context.

The availability in the case of a total SBO of the safety trains (see section 1.3) with the necessary large electrical consumers is considered in section 5.1.3, as well as the combination of the total SBO with the loss of the primary ultimate heat sink.

Operators' main results

In a total SBO scenario, only the safety-classified, interruption-free, battery-powered direct current (DC) supplies are still able to supply power, together with the interruption-free AC supplies provided by them via inverters (if these are available in the plant in question), as long as the battery capacities are sufficient.

In the case of a total SBO scenario, credit can also be given for the relevant accident management measures that are in place (Accident Management (AM) or Severe Accident Management Guidelines (SAMG)) and the equipment held in readiness for this purpose (local equipment in the plant as the sixth safety layer, and components stored at more distant locations, especially in the central Reitnau storage facility, as the seventh safety layer of the electrical supply).

Special emergency DC power supply

The operators have analysed the period of autonomous supply from the special emergency batteries. Important consumers on the battery-supplied bus bars in the special emergency domain are the accident monitoring instrumentation classified as 1E (the elements in the special emergency control room that are independent for supply and signalling purposes), the emergency lighting in the special emergency area (special emergency control room and special emergency sections of buildings) and the command and control feeds to individual control-related safety systems and individual components within the scope of emergency management, such as the pilot valves for main valves. The batteries can be recharged by restoring the special emergency diesel feeds or also by mobile emergency power units. At all the plants, the period of autonomous supply for the total SBO scenario is several hours, in accordance with the requirements of the ENSI guideline HSK-R-101. Specifically, the actual available capacities are always more than four hours, mostly in the range of five hours and in some cases up to the range of 20 hours. The battery systems for the special emergency systems incorporate two redundant systems, which meet the single failure criterion.

Non-special emergency DC power supply

The same considerations are valid for the Total SBO scenario as for the SBO scenario in section 5.1.2 regarding the non-special emergency DC power supply

Electrical power accident management measures

For accidents relating to the electrical supply, appropriate accident and emergency procedures have been produced in all Swiss nuclear power plants, including the decision-making aids for severe accidents (Severe Accident Management Guidance, SAMG) in accordance with the requirements stated in the guideline ENSI-B12. The SAMG includes components such as instrumentation that still functions fully or with restrictions in case of severe accident conditions. Part of this SAMG instrumentation makes use of passive mechanisms for measurement purposes, so it is independent of the electrical supply. The use of prepared SAMG measures and aids is basically covered in section 6.

In case the safety-classified battery systems can no longer be supplied with emergency power according to their design basis, all the operators of Swiss NPPs have stated (in corresponding procedures such as instructions for abnormal situations, emergency instructions, AM instructions, emergency manuals, etc.) how emergency supplies can be provided for these battery systems or for other important supply bus bars. At all the plants, the emergency supply measures include the deployment of available accident management emergency power units (AM diesel generators) and the connection of these units to multiple supply bus bars designated for them by means of prepared connection and supply cables. In all four plants, the special emergency and the non-special emergency domain can be supplied by the emergency feeds.

As regards the availability of AM diesel generators, one key question is how quickly they can be connected to the supply bus bars provided for this purpose. For the objective of battery recharge, the aforementioned period of autonomous supply by the batteries is available and, in all cases, this amounts to several hours. This period is regarded by the operators as sufficient in order to initiate the measures for the emergency supply.

In three plants, at least one medium-sized mobile AM emergency power unit (at least 120 kW / 150 kVA) is available locally, i.e. in the plant itself (status as at mid-2011). At KKG, units of this sort must first be requested from the immediate vicinity and transported to the plant because the previously available local KKG emergency power unit was relocated to the external Reitnau storage facility. Since the end of October 2011, two large mobile units (approx. 890 kW) have been available at KKB. According to additional information, KKG plans to procure local power generation units (size: approx. 500 kVA), and KKM plans to replace the current AM diesel generator with a substantially larger unit of the order of 1000 kVA. This provisional information will be confirmed and specified in more detail by the relevant plants during 2012 (see open point in section 5.1.5).

At all four Swiss NPPs, provision is made for recourse to the AM emergency power units at the central Reitnau storage facility. These are two fully transportable power generation units (167 kVA each) and one unit that must be assembled at the plant as its diesel motor (500 kW) and generator (500 kVA) must be transported separately on account of the transportation capacities of the available helicopters.

Based on the integration of staff with specialised knowledge of power engineering, as well as the measures prepared for the execution of simplified emergency electrical connections by the shift staff and their training in this regard, the operators conclude that sufficient qualified specialist staff will be promptly available to connect the emergency electrical supplies.

According to the present status, the fuel supply to operate the AM diesel generators from the plants' own local reserves of diesel fuel can be ensured for several days in all four Swiss NPPs. The autonomy period of at least twenty days is more than adequate in order to procure additional fuel from off-site diesel stocks.

ENSI review

The total SBO scenario as a beyond-design-basis accident can be controlled at all four Swiss NPP sites.

In case of a total SBO scenario, the available battery systems ensure on the one hand a sufficiently long bridging period until the supply from the AM diesel generators is established, and on the other hand, the locally available fuel stocks at the plant ensure a long period of autonomy for the operation of the AM diesel generators.

Taking account of the power generation units that can be procured in the vicinity, i.e. from the central Reitnau storage facility and (on a plant-specific basis) from other locations, multiple emergency electrical supply options are available at all the plants. Additional possibilities comprise the accident management measures to restore the design-basis power supplies in the special emergency area and the non-special emergency area, as described. Depending on the total SBO accident scenario, emergency electrical feeds are also possible from the HPPs or from nearby switchgear, either immediately or after some time, as additional electrical supply trains. These possibilities also ensure compliance in all four plants with the relevant requirement in the ENSI guideline HSK-R-101, according to which provision must be made for an appropriate emergency bus bar power supply in case of infrequent events.

According to the information at ENSI's disposal, additional mobile AM diesel generators with external air cooling are deployed for the emergency electrical measures as part of the total SBO scenario. This means that these units are not dependent on an external supply of cooling water. A cooling water supply for the diesel units would be an aggravating boundary condition for the accident management measures.

ENSI welcomes the fact that all the operators keep, or plan to keep, additional mobile AM diesel generators both on site and at the external Reitnau storage facility. These equipment, although they are primarily intended for the Total SBO case, can complement the supply in the non-special emergency domain in the case of an SBO. Given the importance of this equipment to bring the total SBO under control, ENSI regards a comprehensive strategy for the targeted deployment of this equipment as appropriate in order to secure selected direct current and/or AC consumers in the long term (see the open point in section 5.1.5).

5.1.4 Conclusion on the adequacy of protection against loss of electrical power.

To summarise, ENSI determines that the electrical supply for important safety consumers in the Swiss nuclear power plants is ensured for all the power supply failure scenarios that have been analysed (LOOP, SBO). Moreover, in the case of the scenario beyond the design basis (total SBO), selected important consumers can still be supplied with power for an adequate period.

5.1.5 Measures which can be envisaged to increase robustness of the plants in case of loss of electrical power

All operators keep, or plan to keep, additional mobile AM diesel generators both on site and in the external Reitnau storage facility. ENSI has not identified any additional improvement measures in the area of energy supply beyond the measures already implemented or planned for the future by the operators.

The reviews carried out by ENSI lead to the following open point: ENSI will follow up on the development of a comprehensive strategy for the targeted deployment of the mobile accident management emergency diesels in order to secure selected direct current and/or alternating current consumers in the long term under total SBO (resp. SBO) conditions (**open point 5-1**).

5.2 Loss of ultimate heat sink

Three different safety trains are considered for the presentation and assessment of protection of the heat sinks at the Swiss nuclear power plants. These are explained in section 1.3 of the current report. Depending on the design of the plant, multiple different heat sinks are available for these safety trains. Main cooling towers, such as those in place at the KKG and KKL plants, are not credited as heat sinks because they are irrelevant in terms of nuclear safety.

The operators' main results are largely based on D1 documents, and some D2 documents are used in addition.

5.2.1 Design provisions to prevent the loss of the primary ultimate heat sink

Operators' main results

At all the Swiss nuclear power plants, river water is used as the primary ultimate heat sink for the conventional safety systems (safety train 1). The respective cooling water intake structures are designed and positioned on the courses of rivers in such a manner as to provide them with basic protection against a failure due to flooding (blockage by bedload or floating debris). High availability of the cooling water intakes is achieved thanks to robust mechanical cleaning plants consisting of raking and screening systems.

The two units at the KKB are each equipped with their own cooling water intake structure that is physically separate from the other unit in order to supply the respective main cooling water system. The main cooling water ducts, which supply safety train 1 in each case in addition to the turbine condensers, can be regarded as qualified for the safe shutdown earthquake (H2) on account of their robust structural designs. In case of a failure of the cooling water intake for unit 2, it is possible to provide a shared supply by means of a cross-connection (emergency water cooling pipe) with river water from unit 1. In addition, safety train 1 can also be supplied via a well water system.

The KKG has two physically separate intake structures to supply cooling water to safety train 1. River water is taken from the headrace channel of the Gösgen hydroelectric power plant (HPP) via the first intake structure and, after mechanical cleaning, is gravity-fed to safety train 1. In case of a failure of the first intake structure, access to the river water is maintained thanks to an automatic switchover to the second intake structure located on the tailrace channel of the Gösgen HPP. This is equipped with redundant cooling water pumps; in addition to two pumps driven directly by their own diesel units, a third electrically-powered pump is available. The second intake structure is designed against flooding (H1) and also against the safe shutdown earthquake (H1). The latter statement also applies to the first intake structure. Due to the structural design and the positioning of the active components, maintenance of the function of the second intake structure is also assumed in case of a 10,000-year flood (H3).

At KKL, the Rhine is used as the primary ultimate heat sink for safety train 1 via a cooling water intake structure. This intake structure has a certain degree of importance in terms of safety, but heat removal via safety train 1 is also ensured by the emergency cooling water system that has an emergency cooling tower supplied from well water (see section 5.2.1). The intake structure is therefore only designed against the operating basis earthquake (OBE, H2).

At KKM, river water is used to cool safety trains 1 and 2. As its primary ultimate heat sink, safety train 1 uses river water from the main cooling water intake structure (SSE: H1, flood: H3). The cooling water supply for safety train 2 is provided by the special emergency intake structure (main cooling water outlet). It is also possible for safety train 2 to be supplied with cooling water from the main cooling water intake. Following submission of the proof required by ENSI of ability to withstand the 10,000 year flood /A-3/, the cooling water supply for safety train 2 was upgraded on the basis of new knowledge regarding blockages due to bedload (see section 3.2.2).

ENSI review

The review of all four nuclear power plants in connection with the last Periodic Safety Reviews (PSR) showed that the access to river water as the primary ultimate heat sink provides high reliability in each case. Over the 10-year operating period considered in each PSR, no faults that would have required a shutdown of the reactor system occurred in any of the Swiss nuclear power plants.

At the KKB and KKL plants, no special safety engineering requirements need to be specified for the protection of the primary ultimate heat sink because, in both plants, safety train 1 is ensured by cooling water systems that are independent of the river water supply.

Thanks to its two robust intake structures, KKG already has a high level of protection for the primary ultimate heat sink. However, the function of the second intake structure is, in ENSI's view, not necessarily protected in case of a 10,000- year flood (H3) /A-3/. This is because KKG has not supplied proof that safety against blockages is also ensured in case of an extreme event of this sort.

At KKM, special requirements must be specified for the intake structures because the function of both the first and the second safety trains depends solely on the river water supply. Following the measures implemented during the 2011 outage, ENSI considers that the reliability of the cooling water supply has been significantly improved, especially as regards protection against blockages.

5.2.2 Loss of the primary ultimate heat sink

Operators' main results

At the KKB and KKL nuclear power plants, the loss of the primary ultimate heat sink leads to failure of the service water systems. In this case, maintenance of the function of safety train 1 for core cooling via independent well water supplies as alternative heat sinks is basically guaranteed in both plants. This supply is flood-proof in both nuclear power plants and at KKL is also protected against earthquakes. The power supply is also available under emergency power conditions. Thanks to the special emergency wells that are protected against floods and earthquakes, both plants also have another alternative heat sink at their disposal, via which the specially protected safety train 2 is supplied with cooling water. At both KKB and KKL, the loss of the primary ultimate heat sink can be withstood according to the design basis.

At KKG, a loss of the primary ultimate heat sink (first intake structure) leads to an automatic switchover to the second intake structure. Safety train 1 therefore continues to be available. Maintenance of the function of safety train 2 at KKG is not dependent on the availability of the first and second intake structures because (as is the case at KKB and KKL) it is supplied with cooling water via a specially protected well water system.

In case of a failure of the primary ultimate heat sink (main cooling water intake) at KKM, safety train 1 is no longer available. In this case, according to the design basis, the plant is brought into a safe condition via safety train 2, which takes cooling water from the special emergency intake structure, and is kept in the safe shutdown state.

Provided that the emergency power or SBO cases do not occur simultaneously, none of the plants is subject to a time restriction as regards keeping them in a safe condition without external support. Otherwise, the available stocks of diesel fuel are the key factor for ensuring the emergency power or special emergency power supplies (see section 5.1.1, 5.1.2).

In this scenario, accident management measures to ensure core cooling are not required at any of the Swiss nuclear power plants, according to the operators' statements.

The cooling of the spent fuel pools (SFP) at the KKG and KKL plants is implemented via safety train 1 in the scenario under consideration here. At KKB and KKM, the SFP cooling systems used for operational purposes are dependent on the primary ultimate heat sink. At KKB, the alternative SFP cooling system (safety train 3) must be put into operation according to the emergency procedures[4] (see section 6.5). Accident management measures (safety train 3) must also be used for SFP cooling at KKM (see section 6.5). Due to the large water amount, an additional water injection to the SFP is only necessary in the long term (> 72 hours) in order to prevent damage to the fuel assemblies. In connection with its order of 5 May 2011 /A-4/, ENSI requested the implementation of upgrading measures for SFP cooling at both KKB and KKM. Among other measures, both plants plan to install a new independent SFP cooling system.

Depending on the design of the plants and according to their condition (power operation and/or hot shutdown or outage operation), the measures to deal with the scenario considered here take place automatically or are initiated manually. No special aggravating circumstances can be identified. For the measures to be implemented manually, the available time for operator action is adequate. The operators' emergency organisations ensure that sufficient specialist staff is available in case of both accidents and emergencies in order to implement the necessary measures promptly.

ENSI review

According to the operators' assessments, a failure of the primary ultimate heat sink can be withstood in compliance with the design basis at all the Swiss nuclear power plants. However, only the KKB and KKL plants have a possible cooling water supply for safety train 1 (in the form of emergency wells and/or emergency cooling towers) that can be classified as a full-scale alternative heat sink according to the ENSREG specifications. Generally speaking, KKM and KKG have two physically separate intake structures for the primary ultimate heat sink. As compared to the first intake structure, the second structure affords extended protection against flooding. According to present knowledge, however, a flood-induced blockage of both intake structures cannot be excluded. But in case of a failure of this sort, KKG also has a full-scale alternative heat sink for safety train 2 that is compliant with the ENSREG specification. At KKM, on the other hand, it is necessary to resort to an additional supply option that was back-fitted during the 2011 plant inspection and is ensured by means of mobile pumps. With a view to a long-term solution in connection with the investigations resulting from order /A-2/, ENSI required the installation of a new heat sink at KKM as a full-scale alternative to the river water supply. Taking account of the aforementioned upgrading measures, ENSI generally sees no further requirement for improvements regarding the cooling water supplies for safety trains 1 and 2 at the Swiss nuclear power plants.

[4] As per Technical Specification; cooling water supply from extinguishing water or from the drinking water mains network

ENSI agrees with the operators' conclusion that, without additional failures of the power supply (LOOP or SBO), fulfilment of the fundamental safety functions is ensured at all the plants for unlimited periods with the sites' own equipment.

5.2.3 Loss of the primary ultimate heat sink and the alternative heat sink

Operators' main results

At the KKB and KKL plants, safety train 1 is unavailable in case of a simultaneous failure of the primary ultimate heat sink (access to river water) and the first alternative heat sink (emergency wells and/or emergency cooling towers). A second alternative heat sink is available at both plants in the form of the specially protected special emergency wells in each case. Hence, heat removal from the reactor can be maintained via safety train 2 if there is a simultaneous failure of the river water and emergency well water cooling. As in the scenario of "failure of the primary ultimate heat sink", no time restriction applies in the case considered here as regards keeping the plants in a safe shutdown state without external support, provided that the total SBO case does not occur at the same time. In terms of the availability of the safety systems, this scenario is comparable to the SBO and is covered by it (see section 5.3.1). Prepared accident management measures (safety train 3) must be initiated for the SFP cooling in both plants (see section 6.5).

In case of a loss of river water cooling (first and second intake structure), safety train 1 is no longer available at KKG. In this case, core cooling and cooling of the SFP within the primary containment is ensured via safety train 2, for which a groundwater well with special emergency protection (special emergency well) is used as the heat sink. The cooling of the external wet storage facility is passive and is independent of the river water cooling and the special emergency well. There is no time restriction as regards keeping the plant in safe condition via safety train 2 with the mains connection available.

At KKM, the complete loss of river water cooling also leads to the failure of safety train 2. In this case, therefore, accident management measures must be initiated (safety train 3) to remove heat from the reactor. For this purpose, use is made of the filtered containment venting with heat removal via the outer Torus and then via the stack into the atmosphere. If the emergency electrical power supply from the Mühleberg HPP (which is not dependent on the cooling water supply) and the emergency diesel generator (air-cooled) are still available, safety trains 1 and 2 can continue to be used to supply the reactor, with the help of internal stocks of coolants (Torus and condensate water storage tank). Thanks to the internal stocks of coolant, sufficiently long times for operator action are available in order to utilise other water reserves (such as the hilltop reservoir, fire extinguishing network or river) so as to provide a further supply to the reactor (see section 5.3.1). The plant can be kept in a safe condition for 72 hours with operational resources kept available on-demand at the site. Due to the large water reserve for the SFP, fuel damage can be reliably excluded even after a total failure of the cooling lasting several days. In this case, the cooling is guaranteed by passive heat removal, vaporisation and/or evaporation via the secondary containment and then into the outer Torus. Depending on the charging status of the SFP, a heating rate of 0.2 to approx. 1.3 K/h would be available for accident management measures to cool the SFP (see section 6.5).

ENSI review

All Swiss nuclear power plants are designed so that the "failure of the primary ultimate and alternative heat sink" scenario can be withstood, both as regards core cooling and SFP cooling, without the need to rely on external support.

In general, KKB and KKL have two separate well supplies (emergency wells and special emergency wells). If the two well supplies are considered as separate, ultimate heat sinks, this scenario is covered by the SBO case. Otherwise, this scenario is covered at all Swiss nuclear power plants by the total SBO case (see section 5.3.1).

5.2.4 Conclusion on the adequacy of protection against loss of ultimate heat sink

With the exception of KKM, the Swiss nuclear power plants have alternative heat sinks in addition to the primary ultimate heat sinks so that, in case of a loss of the primary ultimate heat sink, at least safety train 2 remains able to function in order to cool the reactor core. These alternative heat sinks are specially protected against extreme naturally-induced events. KKM only has one primary ultimate heat sink as defined by the ENSREG specification. The cooling water supplies for safety trains 1 and 2 are physically separated, and the second intake structure has extended protection against flooding as compared to the first structure. However, a blockage of the intake structures cannot be excluded in case of extreme flooding. For this reason, ENSI has requested the installation of a full-scale alternative heat sink to increase the robustness of KKM. As a bridging measure, KKM has ensured an additional cooling water supply by means of mobile pumps.

In the newer nuclear power plants (KKL and KKG), cooling of the SFP is also ensured by alternative heat sinks. In the older nuclear power plants (KKB and KKM), SFP cooling is not secured by means of alternative heat sinks; in these cases, the large water reserve and the associated long time delays available to initiate accident management measures afford adequate protection. At ENSI's request, KKB and KKM will back-fit additional specially protected systems for SFP cooling.

In ENSI's view, the Swiss nuclear power plants basically have adequate degrees of robustness in case of loss of the primary ultimate heat sink. The loss of the primary ultimate and the alternative heat sinks is covered by the total SBO case.

5.2.5 Measures which can be envisaged to increase robustness of the plants in case of loss of ultimate heat sink

Operators’ main results

No measures are envisaged at the KKG and KKL sites to increase the robustness of the plants in case of loss of the ultimate heat sink.

At KKB and KKM, the installation of a new independent SFP cooling system is planned. At KKM, a full-scale alternative heat sink will also be installed.

ENSI review

Based on current knowledge, ENSI sees no need for any further action above and beyond the improvement measures already initiated.

5.3 Loss of the primary ultimate heat sink combined with SBO/Total-SBO

5.3.1 Internal actions foreseen to prevent fuel degradation

Operators' main results

For the purposes of ensuring core cooling in the Swiss nuclear power plants, an overlap of an SBO with a loss of the primary ultimate heat sink does not represent an additional aggravating condition as compared to the SBO. A scenario of this sort is covered by the special emergency conditions (also see section 5.1.2), in which compliance with the fundamental safety functions is ensured by the specially protected systems of safety train 2 (special emergency systems). At KKB, KKG and KKL, the special emergency wells serve as heat sinks for safety train 2; at KKM, the river water serves this purpose.

As regards SFP cooling, accident management measures (safety train 3) must be initiated in the aforementioned scenario at the KKB, KKL and KKM nuclear power plants in order to restore SFP cooling (see section 6.5). Due to the large water reserve for the spent fuel pools, damage to the fuel assemblies can be excluded for 72 hours in case of total failure of SFP cooling. The specific accident management measures to be initiated are described in greater detail in section 6.6. At KKG, however, cooling of the SFP can be implemented via safety train 2 according to the design basis.

In respect of the scenario mentioned above, the availability of diesel fuel is decisive in order to ensure a safe condition in the long term. In all Swiss nuclear power plants, the diesel fuel stocks are dimensioned so that the special emergency diesel units can be operated for at least 72 hours without additional measures. This time can be multiplied by having recourse to further fuel stocks belonging to the site itself. The necessary manual measures are described in procedures.

Likewise, if a total SBO overlaps with a loss of the primary ultimate heat sink, the loss of the primary ultimate heat sink does not represent an aggravating condition.

At the Swiss nuclear power plants, plant-specific accident management measures are prepared to bring a long-lasting (> 72 hours) total SBO under control (also see section 5.1.3). Following the occurrence of a total SBO during power operation, automatic measures come into play in the early phase in order to remove heat from the reactor. In the PWR plants (KKB and KKG), the decay heat can be discharged into the atmosphere via spring-loaded main steam safety valves, because of the water reserve in the steam generators (SG). In the BWR plants (KKL and KKM), heat is removed via the relief valves into the water reserve of the suppression pool (SP) respectively into the Torus, and the stock of coolant in the reactor pressure vessel (RPV) is automatically supplemented by steam-driven high-pressure feed systems (RCIC, reactor core isolation cooling) supplied by batteries.

Core damage is prevented by the initiation of accident management measures at an early stage, i.e. during the phase when the automatic measures are still in progress. The aim of the accident management measures is to use mobile operational resources belonging to the fire brigade and stored on site in order to inject into an SG (in the case of the PWRs) or into the reactor pressure vessel (in the case of the BWRs). Drinking water or fire extinguishing networks, or cooling tower basins (for example) may be used as water reservoirs.

At the PWR plants (KKB and KKG), an SG is vented in each case to enable it to be supplied from a mobile fire extinguishing pump or via a fire water tender vehicle (KKG). For this purpose, main steam relief valves are opened locally by hand. The supply to the SG is then implemented in several steps. As soon as the hot water in the feed water pipes is below saturation pressure, their content is propelled into the SG; as the venting continues, a large proportion of the hot inventory of the feed-water tank is gravity-fed into the SG. Several hours are bridged over in this way. This period is sufficient in order for the prepared mobile fire brigade equipment (pumps, hoses) available at the respective site to be made ready for operation, and to continue the SG injection without interruptions. The procedure is defined in emergency procedures. Thanks to these accident management measures, the KKB and KKG plants can be kept in a safe shutdown state for more than 72 hours.

Following a total SBO during power operation at KKL, automatic isolation of the primary containment and an automatic start of the RCIC are triggered by the decrease in the filling level in the RPV. The internal water reserves (SP and condensate water storage tank) are adequate for about 20 hours of continuous operation of the RCIC. The decay heat is fed into the SP via the relief valves, which are controlled by compressed air. In order to conserve the stocks of compressed air, the valves are left in the open position. Without this intervention, the stocks of compressed air would be exhausted after about 10 hours (with 100 opening/closing operations). At the same time, this strategy achieves rapid venting of the RPV before the batteries needed to operate the RCIC are discharged. In parallel with the RCIC supply, the fire brigade's mobile operational resources are made ready for deployment. After about five hours, a pressure level is reached after which an alternative supply can be implemented with mobile operational resources. In case of a failure of the RCIC, all the relief valves are opened in order to reduce the pressure rapidly, thereby enabling a passive supply from the feedwater tank that is subject to pressure (a time gain of about 150 minutes). The alternative injections are prepared at the same time. The filtered containment venting is initiated before the rupture disk in the parallel venting train bursts, so that the venting line that is used can be closed again if necessary. The procedure for venting the RPV and the primary containment, and for aligning the alternative supply, is stipulated in emergency procedures. A long-lasting total SBO (> 72 hours) can be withstood, with the prepared accident management measures. If filtered venting is used, no damage to the fuel assemblies is anticipated; the core remains constantly covered.

At KKM, a comparable strategy to the one implemented at KKL is followed in case of a total SBO. In the first phase, the stock of coolant in the reactor is automatically supplemented via the RCIC from internal reserves of water (condensate water storage tank, suppression pool/Torus), and in this case too, the battery capacity limits operation (14 hours, see section 5.1.3). The period during which the reactor is safely supplied via the RCIC is sufficient in order to enable the use of other water reserves such as the hilltop reservoir, the fire extinguishing network or river water. Depending on the supply variant to be used, different preparation periods are required before alignment of the alternative supply is ensured. Several minutes are required until a passive supply becomes possible from the hilltop reservoir or the fire extinguishing network via the RCIC pressure lines; the use of a mobile pump requires about 25 minutes. If these measures are implemented successfully, it is guaranteed that the plant can be kept in a safe shutdown state for more than 72 hours without external support.

In case of a total SBO, SFP cooling is implemented at all the Swiss nuclear power plants by accident management measures; adequate time is available to initiate these measures due to the long waiting periods. The individual plant-specific accident management measures to be initiated are described in greater detail in section 6.5.

In addition to the mobile operational resources of the fire brigade, other emergency equipment (as listed below) is available at the power plant sites in order to ensure core cooling in the long term (also see section 5.1.3):

- At the KKB, KKL and KKM sites, mobile AM diesel generators are kept available on-demand, for example to recharge batteries (KKL, KKM) and/or to enable the supply of consumers in safety train 2 (KKB) (time requirement: up to about 2 hours).
- At KKG, AM diesel generators can be procured within a short time from three different locations close to the site. One mobile AM diesel that was already present on site was relocated to the external storage facility in Reitnau. Procurement of mobile AM diesel generators that will be stationed on site has been initiated.
- At the Beznau site, it is possible to use a cross-connection to have the power supply for the special emergency system of the affected unit taken over by the adjacent unit.

The emergency equipment that is to be deployed at the respective sites in connection with the prepared accident management measures is stored at or near the operational locations. Appropriate connections are prepared for the mobile AM diesel generators.

All the additional accident management measures and the relevant responsibilities of the various organisational units for implementing these measures are stipulated in corresponding regulations. The administrative measures are covered in more detail in section 6. In all the Swiss nuclear power plants, the emergency organisation guarantees that expert staff is promptly available to implement the prepared accident management measures. If an accident occurs during non-power operation, considerably longer reaction times are generally available thanks to the relatively low decay heat power.

ENSI review

Numerous precautions have been implemented in the past at Swiss nuclear power plants in order to guarantee adequate core and SFP cooling in case of a long-lasting SBO as well as a total SBO (> 72 hours) so that core damage can be prevented.

A wide variety of robust precautions have been implemented as part of in-plant emergency management in order to bring a total SBO under control. In ENSI's view, adequate time for operator action is available in order to implement the necessary accident management measures, which are ensured (among other means) by the availability of individual items of safety equipment that can be operated without AC power. Thanks to the targeted deployment of mobile AM diesel generators available on the power plant sites, the equipment to manage a severe accident is also available in the long term. In overall terms, ENSI concludes that all Swiss nuclear power plants are adequately protected against a long-lasting SBO and total SBO.

5.3.2 External actions foreseen to prevent fuel degradation

Operators’ main results

All Swiss nuclear power plants can have recourse to mobile diesel units and additional mobile operational equipment that are kept available on-demand in the external Reitnau storage facility (where they are protected against earthquakes and flooding) and which can be transported by helicopter. In addition, KKM has an additional storage facility of its own with mobile operational resources in the immediate vicinity of the site.

In each case, the emergency organisation of Swiss nuclear power plants guarantees that adequate expert staff is present in case of need in order to enable prompt initiation and implementation of the prepared accident management measures.

ENSI review

In addition to the equipment available on the power plant sites, an external storage facility was set up by the operators at ENSI's request. Access to the additional equipment stored there results in a further improvement of the robustness of the Swiss nuclear power plants, should infrastructure at the plants and in the immediate vicinity be destroyed.

5.3.3 Measures, which can be envisaged to increase robustness of the plants in case of loss of primary ultimate heat sink, combined with SBO/Total-SBO

Operators' main results

In addition to the improvement measures that have already been mentioned, none of the operators except KKG lists any further improvement measures. In August 2011 KKG has already installed a larger diesel tank with a capacity of about 13,000 liters.

ENSI review

Other than the measures mentioned by the operators, ENSI has not identified any further measures to increase the robustness of the plants.

6 Severe accident management

6.1 Organisation and arrangements of the operators to manage accidents

6.1.1 Emergency Organisation

Operators' main results

Every Swiss nuclear power plant has its own emergency response organisation (ERO). In case of an emergency, the ERO replaces the line organisation which provides management during normal operation. At all the plants, the ERO comprises the emergency director, the emergency staff and additional emergency bodies. The emergency director is usually the director of the power plant. He is supported by a staff consisting of the heads of those specialist departments relevant for the purpose of dealing with emergencies.

As a minimum level of staffing with qualified personnel is stipulated for the plants on a 24-hour basis, it is ensured that adequate staff is present in the plant at all times in order to initiate alarms and the first measures required in case of an emergency. Moreover, all employees of Swiss nuclear power plants are members of the respective ERO, so the plants can always draw on a sufficiently large pool of specialists for their ERO.

In an emergency, all Swiss nuclear power plants can have recourse to technical support from the relevant reactor suppliers. This is ensured by agreements between the plants and the reactor suppliers.

The structure of the emergency response organisation is specified by the emergency preparedness procedures. In case of emergencies, the emergency staff is summoned by the standby engineer (the so-called *Pikett-Ingenieur*), together with the entire emergency response organisation.

The internal emergency response organisation in the power plants is provided with targeted support by means of infrastructure equipment and specified requirements for action in the form of emergency procedures, so that the necessary tasks can be undertaken if needed.

The behaviour of the operating staff in emergencies, the definition of types of emergency and the tasks, areas of responsibility and authority in case of an emergency are stipulated in the emergency preparedness procedures and the associated documents.

All the nuclear power plants have written decision-making aids for the management of severe accidents (Severe Accident Management Guidance, SAMG), which cover power operation (since 2006) as well as non-power operation (since the end of 2010). Except for KKM, which does not indicate the classification of the SAMG, the operators classify the SAMG as a D1 document.

The emergency documents (emergency preparedness procedures, power plant procedures, etc.) were mostly classified by the operators as D1 documents.

Training courses, education and exercises for members of the emergency response organisation are specified in the relevant instructions for the nuclear power plants. These activities take place regularly on the basis of training programmes and refresher courses.

In addition to the internal emergency exercises, one emergency exercise is carried out each year with ENSI as an observer. Within a cycle of four years, each element of the emergency response organisation must be practised at least once as part of the overall emergency response organisation. At longer intervals, the Federal emergency organisations participate actively in an emergency exercise within the scope of their respective remits, alongside the in-plant emergency response organisation.

Over a lengthy period, the scenarios for the emergency exercises cover all the types of emergencies defined in the emergency preparedness procedures; technical emergencies that originate from technical damage to the plant are included more frequently. However, security scenarios are also trained.

Exercise scenarios involving core damage are periodically included in the programme for the emergency exercises, in liaison with the supervisory authority.

Each emergency exercise is systematically evaluated and the results are used to optimise procedures, and for the training and development of members of the emergency response organisation.

Information is available from three operators (KKB, KKL, KKM) on emergency exercises involving loss of cooling for the spent fuel pool (SFP). KKB points out that experience gained from an emergency exercise was integrated into the AM procedures for restoring SFP cooling. KKL and KKM state that scenarios with a failure of SFP cooling have not yet been addressed in emergency exercises.

ENSI review

Organisational measures ensure that an appropriate management structure and sufficient staff are available to cope with an emergency. KKG assumes that staff can reach the plant at all times as the employees live in various localities surrounding the plant. KKM states that backup personnel for the emergency staff can be flown in by helicopter. However, no specific concepts for the case where access to the plant is not guaranteed are presented in the reports submitted. This point is taken into account in ENSI's forthcoming supervisory planning on the basis of the "Lessons Learned" from the Fukushima accident (/A-16/, checkpoint 18).

The plants have the possibility of obtaining technical support from the reactor suppliers in case of emergencies. However, the submitted documents do not indicate how communication with the suppliers is implemented if normal means of communication are unavailable due to external events. This point is already included in the “Lessons Learned” report on the Fukushima accident (/A-16/, checkpoint 17) and will be followed up in the frame of ENSI forthcoming oversight activities.

The emergency protection measures at the nuclear power plants are regularly assessed by the operators in the Periodic Safety Reviews. On the basis of its assessment, ENSI concludes that the emergency response organisation of the nuclear power plants meets the requirements of the ENSI guideline ENSI-B12 /A-20/, of the concept for emergency protection in the vicinity of nuclear plants (issued by the Commission for NBC Protection (ComNBC)) /A-24/ and those of IAEA Safety Standard GS-R-2 /A-25/, the Radiological Protection Ordinance (RPO) /A-23/ and the Nuclear Energy Ordinance (NEO) /A-7/, according to which the operator must identify and assess an accident, initiate appropriate measures to manage it, and quickly inform the responsible authorities.

The SAMG available in all the plants, which comprises decision-making aids for accident management and covers power operation as well as non-power operation, is based on international standards and plant-specific analyses of the phenomena to be expected in case of severe accidents (such as H_2 or steam explosions). In addition, knowledge gained from the Level 2 PSA (Probabilistic Safety Analysis), which examines the progression of an accident after the inception of core damage in terms of technical risks, was also incorporated into the development of the SAMG. To this extent, the SAMG also reflects the high degree of completeness (internal and external events as well as internal events affecting multiple systems; all operating conditions) of the PSA required according to the Swiss regulations. The SAMG is reviewed regularly, especially in connection with Periodic Safety Reviews (PSR) or emergency exercises, in order to identify potential improvements. ENSI regards the establishment of the SAMG in the Swiss nuclear power plants as an important contribution towards mitigating the consequences of severe accidents. ENSI is essentially in agreement with nuclear power plants' classification of the SAMG. In ENSI's view, the SAMG corresponds to D1 documentation.

The operators' classification of the emergency documents regarding the definition of an emergency, types of emergency, priorities in case of emergency, overview of emergency alarms, emergency response organisation, general and special tasks of severe accident management or of the emergency staff, radiological self-protection and checklists for correspondence with the authorities is generally regarded as correct by ENSI. The cited documents are classified as D1 documents.

Regular emergency exercises on scenarios with loss of SFP cooling are not carried out at any of the Swiss nuclear power plants. However, the existing SAMG includes instructions on checking and (where applicable) restoring SFP cooling. The emergency exercises based on scenarios with loss of cooling of the fuel located in the RPV also consider the conditions in the SFP. ENSI regards the level of such exercises as adequate; nevertheless, this point is also included in the “Lessons Learned” report on the Fukushima accident (/A-16/, checkpoint 16) and will be followed up in the frame of ENSI forthcoming oversight activities.

6.1.2 Emergency equipment

Operators' main results

The emergency equipment available on each nuclear power plant (NPP) site includes, in particular, mobile motor-driven pumps and standard fire brigade equipment (e.g. hoses) as well as radiation protection equipment (e.g. protective suits). Mobile emergency power units are also available on site at three nuclear power plants (KKB, KKL, KKM). All the nuclear power plants have permanently installed connectors for alternative injection into the reactor pressure vessel (RPV) and/or into the steam generators (secondary-side); all the plants except KKM also have permanently installed connectors for emergency injection into the spent fuel pool (SFP).

A flood-proof and earthquake-resistant external storage facility at Reitnau has been in place since June 2011, containing various operational resources for emergencies that can readily be called up. These resources notably include mobile motor-driven pumps, mobile emergency power generators, hoses and cables, radiation protection suits, tools, diesel fuel and boration agents.

For a situation where transport (from Reitnau) to the power plant by road (first priority) is prevented, there is the option of air transportation via military helicopter. According to the concept for the storage facility, about 8 hours should be planned as the time between calling up emergency equipment and its availability on site. At KKL, the details for calling up emergency operational resources from the external storage facility are already addressed in a written procedure.

Each NPP has adequate diesel fuel to operate the permanently installed emergency diesel generators and special emergency diesel generators for a period of at least 3 days. All the nuclear power plants refer to the possibility of supplementing these stocks from the external storage facility at Reitnau. KKL provides information on emergency stocks of borating agents.

ENSI review

The emergency equipment available at the sites and the prepared technical facilities (such as supply connectors) required for its use are appropriately coordinated with the prepared accident management measures established in written procedures on emergency operation and accident management (AM).

For KKG (where a total of six permanently installed emergency power units is available), it is planned to make a mobile accident management diesel generator available (see section 5.1).

The external storage facility at Reitnau increases the availability of the resources required for accident management measures, thereby creating additional safety reserves. The first introductory phase for the storage facility ended in May 2011 with the acquisition of the building and provision of the operational resources. Among other activities, the next phase includes the integration of the storage facility into the emergency operating and AM procedures.

ENSI regards a supply of diesel fuel for at least 3 days as adequate, also in view of the option of supplementing the stocks from the external storage facility within 8 hours.

ENSI regards the absence of information on the means of supplementing the available reserves of water to be of minor importance as all the nuclear power plants are located on rivers. Moreover, two nuclear power plants have water sources in the form of reservoirs at higher elevations that can be used in an emergency.

The borating agents available in the plants are coordinated with the AM measures to prevent recriticality as presented in section 6.3. Additional borating agents are located in the external storage facility at Reitnau.

6.1.3 Limiting radioactive releases

Operators' main results

The maximum possible retention of radioactivity in the plant in the event of core damage is one of the central objectives of the SAMG (Severe Accident Management Guidance). Elements of SAMG include, but are not limited to, the deployment strategy and the specific procedure if it becomes necessary to vent the containment with the Filtered Containment Venting System, FCVS. The FCVS in place in the nuclear power plants is conceived for accidents that exceed the design basis. It ensures that the primary containment does not fail due to excessive internal pressure, with the uncontrolled release of radioactive substances. A wet scrubber is integrated into the release train. Additional information from the operators regarding the FCVS and other elements of the SAMG are presented in sections 6.2 to 6.4.

ENSI review

Regarding the assessment of the SAMG, see also sub-section 6.1.1 and sections 6.2 to 6.4.

The filtered venting systems in Switzerland's nuclear power plants can be controlled remotely and also locally (e.g. in case of a total power failure). These systems were inspected again by ENSI in November and December 2011 as a follow-up measure after the severe accident in Japan. No significant deficiencies were identified during these inspections.

According to the guideline ENSI-B12 /A-20/, the timing of any filtered venting that may be required should be agreed with the responsible authorities, insofar as possible. The procedures in all Swiss plants appropriately include this requirement.

Guideline ENSI-B12 specifies among others requirements for the accident instrumentation to be kept avavilable to deliver the measured values that are needed to implement the SAMG. For example, this includes so-called accident monitoring displays to show the pressure, temperature and dose rate in the containment. Compliance with the requirements for accident instrumentation was (and is) reviewed as part of the Periodic Safety Reviews, and improvement measures are requested as necessary. For the assessment of the accident instrumentation in connection with accident management measures, see also sections 6.2 and 6.4.

6.1.4 Limiting exposure to the operating staff

Operators' main results

From the documents submitted by the Swiss nuclear power plants, ENSI highlights the following general descriptions of radiological measures to limit personal doses:

- The operators indicate that the radiological situation with respect to staff deployment is monitored by radiation protection staff who is integrated into the emergency response organisation. The potential radiological hazard in the operational area is assessed before deployment. Protective measures are implemented as necessary, for the operational staff. In the absence of measurement results, recourse may be had to information regarding the estimation of radiation exposures. This information also indicates the radiological conditions for persons present at special working locations on the power plant site.

- The operators provide information (with reference to the Radiological Protection Ordinance (RPO) regarding the maximum permissible radiation doses for the operational staff (persons subject to an obligation) deployed to deal with accidents, and to protect the public and save human life. For activities in connection with accident management, the limit for radiation exposure for mobilised personnel is 50 mSv. In order to protect the public and in particular to save human life, up to 250 mSv may be accumulated by a single individual who is mobilised.
- For work in high-dose areas, remotely readable dosimeters can be used to monitor the operational staff. In addition, the pre-defined and optimised work paths and procedures should be used for work involving intense doses. Dose maps of the affected buildings are further aids that are also available after an accident. These maps make it possible to determine optimised access routes with minimum radiation exposure.
- The operators of the nuclear power plants also make provision for evaluations using their own dosimeters (basically TL and DIS dosimeters) in other personnel dosimetry units that are not affected by the accident if their own personnel dosimetry units can no longer be operated.

ENSI review

ENSI is basically in agreement with these measures. Furthermore it is worthwhile to emphasize that the exposure of operating staff to radiation during emergencies has been addressed already by ENSI in the so-called post-LOCA studies. These studies resulted in a number of improvements (e.g. installation of radiation protection shields at critical locations).

However, ENSI expects the operators to continue developing the measures to limit personal doses by implementing organisational, administrative and technical improvements and optimisations. This point is also included in the “Lessons Learned” report on the Fukushima accident (/A-16/, checkpoints 31 to 36) and will be followed up in the frame of ENSI forthcoming oversight activities.

6.1.5 Communication systems

Operators’ main results

Multiple internal means of communication are available for operational and emergency-related purposes in all four Swiss nuclear power plants. For internal emergency communication, the focus is on radio telephone systems, including cordless telephone systems for the emergency teams, combined loudspeaker and alarm systems (for announcements and alarm signals), as well as selective voice connections via intercom(munication) systems (ICS) or telephone systems using conventional analogue technology (Stanofon systems, military telephones) with self-supplied / autonomously powered voice units and permanently installed connections with wiring boxes/sockets.

The information from the power plants regarding their communication equipment in respect of external connections is heterogeneous; essentially, this information states that a number of redundant / diverse connection options are available. KKG did not provide any information on this aspect.

ENSI review

The internal means of communication can be broken down according to their functions into alarm systems, paging systems and voice systems, whereby certain systems used in the

NPPs perform dual functions in this regard, and certain important functions (e.g. paging of personnel) are implemented redundantly. In Switzerland, the internal communication systems used for emergency communication in relation to nuclear safety are classified as safety-relevant (with electrical classification 0E), and they are subject to mandatory permits. On the basis of the information supplied by the operators in the final EU stress test reports, and with the help of documents available from earlier permits or by making enquiries, ENSI has obtained the necessary information for the review purposes. At all the plants, most of these systems (unless they are self-supplied from the equipment's own batteries) are connected to uninterruptible, battery-buffered supply bus bars, or else they have their own UPS (Uninterruptible Power Supply) feeds that are supplied via emergency power bus bars. In most of these systems, the fixed-position and mobile components are set up so as to protect them against flooding. Charging of the battery-powered systems is ensured by various supply options.

In respect of the accident management measures, the operators pursue a flexible operational strategy for emergency communication that is adapted to the accident conditions. The aforementioned internal means of communication and their supplies are basically assessed as suitable, and this assessment includes their use for accident management measures. At each Swiss NPP, some of the systems can be regarded as robust in the event of seismic impacts, as has been confirmed by specific studies and flanking measures.

Due to the events related to the accident at Fukushima in March 2011, the means of communication are being analysed again in relation to extreme natural events (see the “Lessons Learned” report on the Fukushima accident /A-16/ checkpoint 17).

Pursuant to Article 6, paragraph 2 of the Ordinance on Emergency Protection in the Vicinity of Nuclear Plants (Emergency Protection Ordinance, EPO) /A-21/, the operators procure and install appropriate means of emergency communication in order to communicate with:

a. ENSI

b. The National Emergency Operation Centre (NEOC)

c. The organisations designated by the cantons containing communities (communes) which are located wholly or partly in a Zone 1.

Each year, ENSI inspects the external means of communication in the nuclear power plants. These inspections are intended to show that documented equipment to send alarms to external organisations is available, that specified requirements for periodic functional tests are in place, and that proof of the implementation of these requirements is available. In addition, random functional checks are carried out on communication equipment to verify that it functions correctly, and also that it is used in the emergency exercises observed by ENSI.

All the nuclear power plants can reach ENSI, the NEOC and the cantonal organisations by means of the following external connections:

- *Fixed network* with diverse connection to two public exchanges for communication via telephone and fax with ENSI, the NEOC and the relevant canton
- Dedicated line (leased line) connection, *NPP Inland*, for communication via telephone and fax with ENSI, the NEOC and the other nuclear power plants
- With their security guards, all the nuclear power plants have an encrypted wireless connection (POLYCOM) for communication with external emergency services (BORS "blue light" organisations).

Thus, all the nuclear power plants can communicate with the designated organisations via the means of emergency communication required by the Emergency Protection Ordinance.

In an extreme event, a failure of all conventional means of communication is conceivable. The importance of introducing a redundant and/or fail-safe communication system has been taken up by the *Interdepartmental Working Group to Review Emergency Protection Measures in case of Extreme Events in Switzerland* (IDA NOMEX) and is emphasised in a report to the Federal Council (also see /A-16/, checkpoint 17).

6.1.6 Long-term measures after a severe accident

Operators' main results

The measures required in the long term following a severe accident generally depend on the specific initiating event and the accident development. For this reason, they should be implemented by the emergency staff in response to the situation and in liaison with the external emergency response organisation. In the plant itself, one key aspect will be the restoration of the fundamental safety functions for nuclear safety, and in particular ensuring the removal of decay heat and the confinement of radioactivity.

The Swiss NPP operators have undertaken to support one another with operational equipment, emergency materials or other resources in case of emergency situations. All the power plants have the possibility of access to external emergency support.

KKL also refers to the Emergency Protection Ordinance and the relevant Federal government regulations on emergency protection, pointing out that the Federal Council and its operational organisations are responsible for ordering protective measures and longer-term measures outside the site of the power plant.

ENSI review

The Emergency Protection Ordinance (EPO) /A-21/ describes the duties and tasks of the operators, of ENSI, of other Federal organisations, and of the cantons, regions and communes. Immediate measures to protect the public are ordered by the NEOC. As soon as the Federal NBCN Crisis Management staff is ready to deploy, it takes over coordination of the civilian and military operational units, as well as the development of proposals to protect the public for consideration by the Federal Council.

The need to develop concepts to deal with the long-term impacts of a severe accident outside the site of the nuclear power plant has been recognised at Federal level (also see /A-16/, checkpoints 21, 22 and 34). The longer-term tasks in order to accomplish the necessary severe accident management activities may be expected to include safeguarding the qualified staff required for this purpose, not only on the part of the power plant operators but also at ENSI and other emergency partners as mentioned above. The *Interdepartmental Working Group to Review Emergency Protection Measures in case of Extreme Events in Switzerland* (IDA NOMEX) set up by the Federal Council as a consequence of Fukushima has turned its attention, among other matters, to ensuring the operational readiness and sustainability of the Federal bodies involved in dealing with emergencies.

The issue of ensuring the availability of auxiliary resources for the subsequent phase of an emergency was already assessed in section 6.1.2.

6.1.7 Control and emergency rooms

Three operators (KKB, KKL, KKM) refer to the option of an emergency control room (ECR) as a replacement for the main control room (MCR). KKG refers to a study /A-19/ dating from 1993 regarding the assessment of radiological conditions for persons present at various working locations on the power plant site.

Active carbon filters to reduce airborne activity in the control rooms are mentioned by KKB and KKL. KKL refers to an emergency room as the place of work of the emergency staff (as part of the ERO); the air supply of this room is controllable to minimize the contamination by noble gases that can be present despite the filtered air supply. KKM refers to the protection of the MCR against flooding and the special protection of the ECRs against external impacts (such as earthquakes, flooding, aircraft crashes or direct radiation).

ENSI review

In addition to the MCR, at least one ECR is available as a standby control room for the shift team at all the Swiss NPPs. In three plants, this is the special emergency control room, whereas several protected emergency control rooms are available at KKL. The MCR or ECR can be used as well as place of work of the emergency staff.

Following a study of the consequences of the Chernobyl accident, the Swiss NPPs have already provided proof of sufficient protection against radiation exposure of the shift staff in the main control room (MCR) as well as the emergency staff in the emergency room (ER) or standby emergency room (SER). The protection of emergency buildings against external events such as earthquakes or floods is a point already included in the “Lessons Learned” report on the Fukushima accident (/A-16/, checkpoint 10) and will be followed up in the frame of ENSI forthcoming oversight activities.

The accessibility of other locations where action is taken is covered by section 6.2.2.

6.2 Accident management measures in place at the various stages of a scenario of loss of the core cooling function

6.2.1 Emergency procedures and measures

Operators’ main results

As part of Accident Management (AM) measures before occurrence of fuel damage are in place at all sites and are incorporated into the procedures. These measures include, for example, venting of the steam generators (SG) without external power, venting of the RPV via alternative trains, the supply (by means of fire brigade pumps) of borated water from the SFP into the RPV, coolant supply via the fire extinguishing system and cross-switching of power supply systems. The accident management measures established specifically for accidents during non-power operation (NPO) include similar measures, according to information from two operators (KKB and KKL). The closure of the containment material gate is mentioned by KKG and KKL as an accident management measure during NPO.

Measures as part of Severe Accident Management (SAM) after occurence of fuel damage are established and incorporated into the procedures (Severe Accident Management Guidance, SAMG) at all the nuclear power plants. Both the PWR plants (KKB, KKG) use SAMG entry criteria geared to the core exit temperature (CET). At KKG, additional provision is made for two entry paths based on an increased hydrogen concentration or dose rate in the containment. Information on NPO is available from KKB: the criteria are primarily based on the CET. Both the BWR plants (KKL, KKM) use SAMG entry criteria based on the level in the RPV and the chances of success for measures to maintain the level; at KKL, a similar criterion is also used for NPO. At KKM, provision is made for additional entry paths, e.g. due to an increased H_2 concentration in the containment or due to the failure of a requested RPV emergency depressurisation.

The measures ordered in the SAMG include, but are not limited to, filtered venting of the containment before or after an RPV failure. In each Swiss plant, provision is also made for a supply to the containment – preferably before, but also after the RPV failure. In the case of the BWRs, this is specifically intended to ensure that the core melt falls into a pool of water in case of an RPV failure. At KKB, on the other hand, this measure is intended for external cooling of the RPV, so as to prevent it from failing. If coolant is lost into the containment, the measures to supply the RPV would also contribute to the supply for the containment. Accident management measures in place to prevent fuel damage may also be utilised to mitigate the consequences of fuel damage. The accident management measures during NPO largely correspond to those during power operation.

The SAMG at three nuclear power plants (KKG, KKL, KKM) includes instructions for the identification of an RPV failure. Additional details on this aspect are also provided for KKM. Accordingly, an assessment of the condition of the RPV floor is undertaken on the basis of an overall assessment of measured values for the surface temperature of the RPV, the drywell pressure and the radiation in the containment.

The accident management measures after failure of the RPV are largely identical to those prior to such a failure. The differences relate to the priorities and objectives. After an RPV failure, for example, the supply of water to the suppression pool (SP) of the containment at KKL would have a lower priority than the supply of water for cooling the residual melt remaining in the core. After an RPV failure and the inception of damage to the containment foundation, flooding of the containment is used at KKG to decelerate the interaction between melt and concrete and to minimise discharges if the core melt reaches the containment sump area.

ENSI review

Accident management measures against fuel damage are in place in all the Swiss nuclear power plants and are incorporated into the procedures. ENSI regards these accident management measures as an important contribution towards minimising the risk due to accidents beyond the design basis. These are largely (preventive) measures to avert fuel damage. Important exceptions are as follows:

- Verification of the automatically triggered containment isolation (ordered in the accident or emergency procedures of all the operators) and
- Closure of the containment material gate in an emergency during NPO (ordered in the accident or emergency procedures of three operators before damage to fuel assemblies).

The review of the SAMG documents showed that entry into SAMG – and the associated change of priority from preventive to mitigative treatment of the accident – is regulated to a large extent at all the nuclear power plants.

The SAMG for the Swiss plants is symptom-oriented, and it provides strategies and associated measures. Accident management measures following fuel damage are in place for all the nuclear power plants and are systematically integrated into the SAMG. These are measures to terminate incipient fuel damage, to maintain the integrity of the containment and to minimise radioactive releases. ENSI regards these accident management measures as an important contribution to the mitigation of the consequences of accidents beyond the design basis.

6.2.2 Cliff-edge effects

Operators' main results

Specific information on cliff-edge effects in relation to accident management measures is available from two operators (KKB and KKL). This includes the period of utilisation for the batteries in case of a total SBO, namely a minimum of 5 hours for KKL resp. 8 hours for KKB. KKB also refers to the negative concomitant effects (such as non-availability of the approach routes) of flooding of the site or of an earthquake; reference is additionally made to the stocks of diesel fuel. KKL lists the times that limit the success of accident management measures, e.g. 8 hours until RPV failure after total failures of cooling and venting.

As regards the instrumentation required for accident management measures, KKB and KKL refer to the possibility that the power supply to the instruments required in an SBO can be ensured by means of mobile emergency power units. The operator of the Leibstadt nuclear power plant points out that the selection of the measured values for the accident instrumentation was made in accordance with the US NRC Regulatory Guide 1.97, and that a manual is available in the plant which deals with instrumentation failures or errors. In case of a failure of the reactor level measurement related to the measurement principle, the KKL accident procedures provide for flooding of the RPV. KKM indicates how the instrumentation equipped with a special emergency supply can be used to diagnose incipient fuel assembly damage and an RPV failure.

The operators' main results on the ability to use the control rooms were already presented in section 6.1. Information on the accessibility of the other locations where action is undertaken is available from KKB and KKL. KKB refers to individual measures to protect the staff working on the site against airborne contamination. KKL shows that no major monitoring or accident mitigation measures are impeded by radiation after a core meltdown accident.

The same information regarding the adequacy and ability to implement the accident management measures regarding impairments due to H2 accumulations in buildings outside the containment is available as for the accident management measures after the loss of containment integrity (section 6.4).

ENSI review

There is no comprehensive listing (including indications of time) of conditions that weaken accident management measures (e.g. destruction of the access routes preventing the replacement of staff who have already been working on the site for more than 8 hours − relevant for accident management measures required in the subsequent progression of the accident) or which limit their effectiveness and/or success (e.g. RPV failure – limits the success of RPV venting).

Further comments regarding cliff-edge effects are limited to the aspects of instrumentation and accessibility of locations where actions must be performed, on which substantial information from the operators is available.

- Instrumentation: No comprehensive evaluation of the instrumentation required in order to initiate and implement the individual accident management measures (prior to a containment integrity failure) was undertaken by any of the operators in the final EU stress test report. However, all the plants have met the requirement (as per guideline ENSI-B12 /A-20/) to examine and take account of the behaviour of the instrumentation under severe accident conditions in the course of the introduction of SAMG. ENSI therefore regards the instrumentation as generally adequate. Continuous review and improvement is included in supervisory activities such as the Periodic Safety Reviews (PSR) or inspections. The availability of the instrumentation required for accident management measures is also included in the “Lessons Learned” report on the Fukushima accident (/A-16/, checkpoint 5) and will be followed up in the frame of ENSI forthcoming oversight activities.
- Accessibility of operation areas: Comprehensive evaluations within the frame of the EU stress test, in particular from KKL, are available regarding restricted accessibility to operation areas on account of inadmissibly high radiation doses. In addition, the comment by ENSI on the so-called post-LOCA studies in section 6.1.4 applies. Other aspects, such as prevention of access due to destroyed buildings or flooding, are not presented in systematic form by any of the operators. The accessibility of operation areas is covered by the HRA (Human Reliability Analysis), which is undertaken as part of the PSA for each plant. In turn, the PSAs and hence also the HRAs are regularly reviewed by ENSI as part of the PSR. The issue of accessibility of premises is also included in the “Lessons Learned” report on the Fukushima accident (/A-16/, checkpoint 11) and will be followed up in the frame of ENSI forthcoming oversight activities.

As accident management measures are usually implemented outside the containment, ENSI considers it appropriate to consider the hydrogen issue for the accident phase after the loss of containment integrity (section 6.4) – it is only after the loss of containment integrity that there is a possibility of an accumulation of hydrogen (induced by core damage) outside the containment.

6.3 Maintaining the containment integrity after occurrence of significant fuel damage (up to core meltdown) in the reactor core

6.3.1 Hydrogen control, containment venting and containment isolation

Operators’ main results

In order to prevent hydrogen deflagrations or detonations in the primary containment, all the nuclear power plants have systems such as igniters, thermal or passive autocatalyic recombiners or mixing systems. The KKM containment is inerted with nitrogen.

All the plants have a system for venting the containment which, according to the relevant safety analysis reports, is fitted with filters with decontamination factors of at least 100 for iodine and 1000 for aerosols. The containment venting systems all have (at least partly) a two-train contaminated gas piping, of which one train is sealed with a rupture disk. The shut-off valve upstream of the rupture disk is closed during normal operation at KKG but is open at the other plants.

At all the plants, the containment venting systems are used not only to prevent hydrogen deflagrations or detonations but also to prevent a containment overpressure failure.

KKB and KKG provide no information about the need for alternate/direct current power or compressed air supplies to maintain containment integrity. KKL presents the available supplies of energy and compressed air for various items of equipment in order to ensure containment integrity (e.g. filtered containment venting, hydrogen igniters) in case of a Station Blackout (SBO). In addition to certain other systems, KKM mainly considers the shut-off valves of the containment and, in summary, concludes that power and control air are not necessary to guarantee the integrity of the primary containment.

ENSI review

In studies on hydrogen combustion, pressures were until now mainly calculated on the basis of complete adiabatic isochoric combustion in the primary containment. It is standard that the computer codes normally used for this purpose model combustion with a hydrogen concentration of 10% in the relevant control volume. This procedure largely corresponds to the international state-of-the-art. Nevertheless, it neglects, for example, the fact that hydrogen may accumulate locally in higher concentrations, which can lead to more energy-rich combustion and hence to higher pressures. Further analysis is therefore required. This point is also included in the “Lessons Learned” report on the Fukushima accident (/A-16/, checkpoint 7) and will be followed up in the frame of ENSI forthcoming oversight activities.

In ENSI's view, the systems for filtered venting generally correspond to the state-of-the-art. In case of a failure of manual alignment of the containment venting system, however, automatic passive alignment via the rupture disk cannot always be assumed at all plants. This is because the shut-off valve upstream of the rupture disk is normally closed at KKG; at KKB, this valve is closed as an immediate measure in case of an accident; and at KKM, a leak in the drywell cover seal at high temperatures can occur earlier than rupture of the disk. Clarification is still required regarding an optimised deployment strategy for the containment venting systems, e.g. as regards blocking off the rupture disk. Therefore from the point of view of risk minimisation, ENSI will follow up on the extent to which the current deployment strategies for the venting systems in severe accidents should be retained (**open point 6-1**).

The absence of information from KKB and KKG (within the frame of the EU stress test) regarding the supply of power and compressed air prevent a conclusive assessment on maintaining containment integrity without these supplies. Information from KKL shows the various protective measures for maintaining containment integrity, although the lack of statements about the containment isolation does not allow for a conclusive assessment of this aspect. The issue of power and air supply support for maintaining containment integrity, especially in case of a long-lasting total SBO, is also included in the “Lessons Learned” report on the Fukushima accident (/A-16/, checkpoint 16) and will be followed up in the frame of ENSI forthcoming oversight activities. In this context see as well the ENSI review on the total SBO in section 5.3.

6.3.2 Prevention of recriticality

Operators’ main results

KKG provides no information regarding the prevention of recriticality. KKB and KKM present reasons supporting that recriticality after a core melt is unlikely, whereby the use of non-borated water is permitted for Severe Accident Management. KKL describes an Accident Management measure to prevent recriticality in case of reflooding of the reactor core (which may have been damaged) in the RPV.

ENSI review

The KKG emergency manual indicates that, on account of the recriticality risk, non-borated water should only be fed into the RPV when all the sources that could supply borated water are unavailable and the core has melted. Information from KKB, KKL and KKM refers to different conditions of the reactor core (damaged core, core melt within the RPV, core melt outside the RPV (RPV failure)). Borated water is always preferred if it is available. According to the latest knowledge and current SAMG strategies, it is also generally appropriate to cool a core melt with non-borated water in an emergency. It should also be noted that additional stocks of boron are kept available on-demand for accident management measures at the external storage facility in Reitnau. ENSI regards the measures to prevent recriticality after core damage as adequate.

6.3.3 Prevention of basemat melt through

Operators' main results

KKB, KKL and KKM each refer to their accident management measure of flooding the containment. For the case of failure of both core cooling and RPV depressurization (e.g. within the course of a total SBO), KKL emphasizes that the pressure build-up in the containment pushes a large amount of water from the suppression into the drywell to fill the drywell and pedestal to the top of weir wall level. KKG describes the decelerating effect of filtered venting on the reaction speed of the concrete-melt interaction, the supply of emergency cooling medium to form a melt crust on the corium surface, and the importance of a high sump water level.

ENSI review

Flooding of the containment is an appropriate measure in order to prevent melt-through of the containment foundation as far as possible. The measures at KKG are appropriate to the reactor type.

6.3.4 Cliff-edge effects

Operators' main results

KKG provides no information about cliff-edge effects. KKB identifies the failure of the power supply from the Beznau hydroelectric power plant as an aggravating circumstance, but one which nevertheless presents no danger to the protection of containment integrity. KKL identifies the non-availability of all emergency coolant injection trains and (during shutdown) an open material gate as cliff-edge effects in relation to containment flooding. It is also stated that flooding the drywell until the lower section of the RPV is covered is more difficult than flooding the containment up to the level of the weir wall as the drywell atmosphere must also be vented. KKM identifies an error in the transition from the accident procedures to the SAMG as a cliff-edge effect. Another potential cliff-edge effect is a containment venting system activation error. The KKM's "Defence-in-depth" concept nevertheless takes account of the passive operation of the containment venting system so that controlled, filtered release takes place if there is no manual activation.

ENSI review

The effects identified by the plants make it more difficult to bring accidents under control. It can generally be stated that the primary and/or the secondary containment are open in certain phases during shutdown.

ENSI will follow up on whether restoring containment integrity during shutdown in the case of a total SBO represents a time-critical measure (**open point 6-2**).

6.3.5 SAMG and instrumentation

Operators' main results

KKG does not deal directly with the topics of SAMG and instrumentation. The other plants assess their SAMG as suitable in order to maintain containment integrity. As regards statements on instrumentation, KKB and KKL refer to preceding sections, KKM describes the availability of measurements of the RPV filling level, the drywell pressure, the water level in the drywell/in the inner Torus and the flow rate through the venting duct for the containment venting system.

ENSI review

The plants' statements regarding the suitability of their SAMG to maintain containment integrity are assessed by ENSI as plausible. No additional measures are described by any of the plants. The instrumentation at KKM is assessed as fit-for-purpose because KKM has appropriate 1E-classified measuring instruments on the one hand, and also has passive, power-free measuring instruments on the other. Reference should be made to section 6.2 for the assessment of the requisite instrumentation at KKB, KKL and KKG.

6.3.6 Accumulations of hydrogen outside the containment

Operators' main results

KKB postulates the integrity of the containment. KKB regards H_2 accumulations outside the containment as unlikely. KKL puts forward one case involving H_2 accumulations in the secondary containment. This would happen if a core meltdown occurred during plant shutdown and, at the same time, an open material gate linking the primary and secondary containments cannot be closed promptly. At KKM, H_2 accumulations are not expected to reach a hazardous limit. Possible leaks from the primary containment are diluted in those parts of the building, which then absorb them to such an extent that explosive gas mixtures are not expected to develop. KKG does not examine this topic.

ENSI review

In its order of 5.5.2011 /A-4/, ENSI already required an assessment of protection against hydrogen deflagrations and detonations in the area of the spent fuel pools. The relevant reports must be submitted to ENSI by 31.3.2012. Reference is also made to /A-16/, checkpoint 7 (also see section 6.3.1), which will be followed up in the frame of ENSI forthcoming oversight activities.

6.4 Accident management measures to restrict the radioactive releases

6.4.1 Emergency measures after loss of containment integrity

Operators' main results

At all the nuclear power plants, some of the accident management measures (e.g. SG injection, RPV injection, containment venting, containment injection) requested before the loss of containment integrity are also used to limit radioactive releases after loss of containment integrity. In this context, the BWR operators (KKL, KKM) refer to measures specified in instructions on monitoring the secondary containment. KKL mentions the verification of containment isolation and RPV venting as two measures for this purpose, which are ordered in the quoted instructions. KKM emphasises that these instructions must also be worked through after the transition to SAMG. At both the PWR plants (KKB, KKG), special measures to limit radioactive releases after the loss of containment integrity are integrated into the SAMG.

ENSI review

Provision is made at all the nuclear power plants for accident management measures to limit radioactive releases after the loss of containment integrity. There are minor differences regarding the integration of individual measures into the procedures.

6.4.2 Cliff-edge effects

Operators' main results

With the exception of KKG, specific information is available from the operators on cliff-edge effects in relation to accident management measures. KKB emphasises the restriction of mobility on the site and within the buildings. KKL mentions the period (about 19 hours) from total failure of the cooling until reaching the rupture pressure (3.1 bar) of the rupture disk for the containment venting system, and argues that this rupture pressure still provides a large safety reserve in relation to the containment failure pressure. KKM states that no cliff-edge effects are identifiable.

The aforementioned operators assess the instrumentation in respect of accident management measures to mitigate radioactive releases after the loss of containment integrity. KKB refers to the possibility that the power supply for the necessary instruments can be ensured by means of mobile emergency power units. KKL refers to the possibilities for identifying a loss of containment integrity, e.g. with the 1E-qualified instrumentation of the leakage monitoring system in the annulus. KKM assesses the relevant instrumentation for containment venting and flooding. Particular prominence is given to the passive measurement (without external energy) of the containment pressure, water level and venting flow rate.

As regards the ability to use and access the operation areas, the same information is available as for the accident management measures before the loss of containment integrity (section 6.2).

Information from the aforementioned operators is available regarding potential impairments of accident management measures due to H2 accumulations outside the containment. In all this information, the long timeframe available for preventing of the release of H_2 from the SFP is emphasised. Two operators (KKB, KKL) consider an impairment by H_2 after the loss of containment integrity. KKB highlights the open containment material gate during NPO as a potential cause of this loss. KKM shows that the containment venting system is designed for the exposures to be anticipated in case of accidents in those areas where an explosive atmosphere can be expected.

ENSI review

As appropriate, see the comments by ENSI on this subject in section 6.2 (regarding instrumentation and accessibility) and section 6.3 (regarding hydrogen) are applicable.

6.5 Accident management measures in place at loss of the spent fuel pool cooling

Operators' main results:

In case of a failure of the systems used in operation for cooling the spent fuel pools (SFP), staggered (defence-in-depth) measures come into play. Initially, their aim is to use permanently installed alternative systems (e.g. the shutdown cooling system at KKM) to restore a cooling circuit. For this purpose, the relevant sections of the first safety train (at KKG, KKL and KKM) are available and, at KKG, those of the second safety train are also available for SFP cooling. In this case, some manual measures may have to be implemented by the plants' operating staff. Operation of the systems as such is handled from the main control rooms (KKG, KKL, KKM) or from the emergency control room (at KKG only). The respective measures are stipulated in accident procedures. After loss of the operationally utilised SFP cooling system at KKB, it is necessary to deploy the alternative pool cooling system that is assigned to the third safety train. Safety trains 1 to 3 are explained in section 1.3.

If it proves impossible to reconnect a cooling circuit, heat is removed by vaporisation and/or evaporation cooling. In this case, prepared accident management measures are implemented whereby the vaporisation and/or evaporation volume is compensated by re-injecting water into the SFP. These accident management measures (safety train 3) are implemented with the help of mobile operational equipment kept available on-demand on site, such as fire extinguishing pumps, fire water tender vehicles and fire brigade hoses. At the KKB, KKL and KKM plants, it is necessary to implement manual measures in the storage pool area, e.g. to establish hose connections as far as the SFP or to operate valves. By contrast, the injection into the SFP at the KKG plant is effected by means of a connection that is permanently installed in the annular space and then via pipes in the independent pool cooling system. Due to the dimensioning of the SFPs, sufficiently long time is available after the failure of SFP cooling at all the plants, in every operating condition (power operation or shutdown with full core discharge), in order to implement the prepared accident management measures. As the SFPs at the KKB and KKL plants are located in separate buildings, the accident management measures for SFP cooling can be implemented there regardless of conditions in the containment.

Incipient evaporation of the SFP inventory is quoted by all the operators as a cliff-edge effect. Depending on the reactor type and plant configuration, the time until this occurs (after a failure of SFP cooling) is of the order of several hours for the PWR plants (KKG: 6 hours; KKB: 13 hours) or several days for the BWR plants. Three operators (KKB, KKL, KKM) point out that incipient evaporation of the SFP inventory would substantially impair accident management measures (for restoration of SFP cooling), and they announce back-fitting measures to counteract this impairment (e.g. SFP filling level indicators in the main control room and in the emergency control room).

In those plants where the SFPs are located outside the primary containment (KKB, KKL, KKM), no specific measures have currently been prepared in order to counteract the release of H_2 following a Zr-water reaction in the SFPs. In case of a total failure of SFP cooling, KKL and KKM do not expect any uncovering of the fuel assemblies in the storage pools that could lead to major releases of activity, on account of the large water reserve for the SFPs and the prolonged periods thereby available to bring alternative water injections into operation. At KKB, no release of H_2 is expected as long as the fuel assemblies remain covered and the fuel does not heat up beyond 800℃. Regarding the point "H_2 releases outside the primary containment", reference is made here to section 6.3.6.

In the event that a water injection into the SFP at the KKG plant is impossible even with accident management measures, isolation of the containment can be implemented in order to minimise the release of activity. A pressure failure of the containment within 72 hours of the occurrence of the event is excluded by KKG. An H_2 mixing and reduction system is installed within the containment. In addition to the SFP inside the containment, KKG also has an external wet storage facility for spent fuel assemblies. Heat removal here is ensured by inherently safe passive natural circulation via two parallel cooling circuits[5]. In an emergency, this pool can also be supplied by prepared fire brigade resources.

The responsibilities of the individual organisational units for implementing the accident management measures are stipulated in the respective emergency preparedness procedures. The procedure for making use of the prepared operational resources is regulated in accident instructions and emergency procedures. Temperature and filling level measurements are used for ongoing monitoring of SFP cooling. On the basis of ENSI's order of 5 May 2011 /A-4/, measurement devices are being upgraded in all the plants and accident-resistant designs are being introduced where these are not yet present. One element of this upgrading measure is that the SFP temperatures and filling levels across extensive measurement ranges will also be displayed in the emergency control rooms and/or special emergency control rooms.

In compliance with ENSI's order of 18 March 2011 /A-2/, provision must be made in all plants by 31 December 2012 for two physically separate connections for the external SFP supply so that accident management measures can be implemented without the need to enter the storage pool area. This upgrading measure is either in the planning stage or has already been partially implemented at the plants. In addition, further improvement measures to upgrade the SFP cooling systems are planned in the KKB and KKM nuclear power plants. These measures include, but are not limited to, the extension of the existing systems for direct injections to the storage pools and the installation of new, independent cooling systems that are supplied with cooling water from the protected area and can also supply the SFPs directly in case of an emergency.

ENSI review:

As a reaction to the events in Fukushima, ENSI carried out inspections related to key issues in all the Swiss nuclear power plants in order to assess the respective precautionary measures for SFP cooling in case of design-basis accidents and accidents beyond the design basis, among other aspects. In this regard, ENSI has established that the relevant accident and emergency procedures in all the plants basically cover the available technical possibilities and the requisite measures. Selective improvements were identified in the procedures of KKB /A-26/ and KKL /A-27/. ENSI also determined that the measures to be implemented on site are articulated in a practical and complete manner in the procedures. The interaction between the relevant accident and emergency procedures is generally regulated

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5 In a second phase of the extension (depending on the decay heat to be removed) the external wet storage facility at KKG will have four cooling circuits.

by means of criteria enquiries or cross-references. ENSI was also able to ascertain that accessibility is ensured in all plants to those locations where auxiliary technical resources are prepared and where measures must be implemented. Likewise, the nature and scope of the measures to be initiated on site and of the auxiliary technical resources are such that the time required to restore cooling is well within the available time. The most restrictive conditions regarding the time available in case of a failure of SFP cooling occur during outages when the core is discharged. Here as well, ENSI regards the available waiting times as adequate.

Temperature and filling level measurements are used as the criterion for initiating accident management measures for SFP cooling, or for the ongoing assessment of their effectiveness. In order to avoid the need to enter the storage pool areas (possibly under aggravated conditions) to carry out and monitor the accident management measures on an ongoing basis, ENSI has directed that appropriate back-fitting measures must be implemented. All the operators are under obligation to install accident-resistant displays to monitor the temperature and filling level of the spent fuel pools in the main control rooms (KKL, KKM) and also in the specially protected emergency control rooms and/or special emergency control rooms (KKB, KKG, KKL, KKM) by 31 December 2012, where these facilities are not already in place. Likewise, in its first order of 18 March 2011 /A-2/, ENSI already stipulated that two physically separate injections for the external supply of the SFP must be back-fitted by 31 December 2012 where they are not already in place.

The orders issued following the events at Fukushima also placed an obligation on the operators to report to ENSI on whether SFP cooling in each plant is a specially protected safety function and whether such cooling can take place via the second, specially protected safety train. At the KKG plant, SFP cooling is also possible via the second safety train. However, weak points were identified in this respect at the KKB and KKM plants. In ENSI's view, the in-plant accident management measures to remove decay heat in case of a failure of SFP cooling at KKB and KKM do not provide adequate coverage. Improvement measures in this regard were to be submitted to ENSI by 31 August 2011. ENSI has reviewed these measures and assessed them as basically adequate and appropriate /A-28/, /A-29/. The implementation of these measures will be staggered over time until 2015 (see table 7-2).

Against the backdrop of the events in Fukushima, ENSI has given renewed attention to two topics: "Development of hydrogen in the SFP area" and "Accumulation of hydrogen outside the containment". In order to clarify the importance that should be accorded to the hydrogen problem, on 5 May 2011 /A-4/ ENSI directed that (among other requirements) the operators must assess protection against hydrogen deflagrations and explosions in the SFP area and report to ENSI by 31 March 2012 (see section 6.3.6).

In overall terms, ENSI concludes that the prepared accident management measures in respect of SFP cooling at all the Swiss plants are expedient and appropriate, and that they basically cover the requirements. Sufficiently long waiting times are available in the Swiss plants in order to implement these measures. Fulfilling the subsidiary fundamental safety function of "Cooling of fuel assemblies in the storage pools" is also ensured for 72 hours without external technical support in case of extreme naturally induced impacts leading to a total failure of the SFP cooling systems (see section 5).

7 General conclusion

7.1 Key provisions enhancing robustness

Results of the review relating to ENSI's orders and the EU stress test have shown that the Swiss nuclear power plants guarantee a very high degree of protection against the consequences of earthquakes, flooding, other natural hazards, loss of electrical power and ultimate heat sink. In respect of all the events that were analysed, the statutory requirements are met, taking account the hazard assumptions that are currently valid (at least H2), hence the fundamental safety functions are fulfilled. In addition, safety margins exist, in particular as regards control of reactivity, cooling of the fuel assemblies and confinement of radioactive material (containment integrity).

One key reason for the robustness of the Swiss nuclear power plants is the implementation of the precautionary "defence-in-depth" safety concept. Up to three safety trains are available in Switzerland in order to achieve and maintain a safe plant condition in case of events such as analysed in conjunction with the EU stress test. In addition to the conventional safety systems, these include the specially protected special emergency systems and the accident management measures required at statutory level.

Determining the safety margins provided confirmation in particular of the robust design of the special emergency systems that are in place at all the Swiss nuclear power plants. These systems are designed to be safe against flooding and earthquakes; they have their own special emergency/emergency power supplies and (except for one nuclear power plant) a full-scale alternative supply of cooling water from groundwater wells. In case of need, the safety functions for reactor shutdown, core cooling and removal of decay heat are performed automatically and autonomously for at least 10 hours; switching operations by the operating staff are required in the longer term.

In order to prevent and mitigate the consequences of accidents, all Swiss nuclear power plants have extensive accident management measures at their disposal, which are reviewed and improved at regular intervals by the operators and ENSI, especially during the course of emergency exercises. In addition, the central external storage facility at Reitnau was set up as a consequence of the events at Fukushima. The emergency resources stored there can be made available by helicopter in addition to the equipment already available at the NPPs to deal with severe accidents.

Two further aspects which have proven their merits are the continuous review of the plants on the basis of the PSR (Periodic Safety Review, every 10 years) and the annual evaluation of operating experience, from which numerous back-fitting measures have resulted (see the examples in section 1.2).

7.2 Safety issues

During the re-assessment of the degree of protection against flooding (order of 18 March 2011 /A-2/), KKM determined that it was impossible to exclude a blockage of the special emergency intake structure by bedload in case of a flood (H3). KKM therefore decided to shut down the plant early, prior to the 2011 planned outage, in order to carry out back-fitting measures.

On the one hand, three intake pipes (periscopic pipes) were installed in two physically separate positions on the special emergency intake structure, so that an adequate inflow of cooling water to the special emergency cooling water pumps is guaranteed even in the event that bedload is deposited. On the other hand, a fixed injection point for mobile fire brigade pumps was back-fitted, via which adequate cooling water is fed to the special emergency cooling water pumps if the special emergency intake structure is blocked. In the medium term, KKM's safety will be improved by back-fitting an additional heat sink.

Apart from these measures, the analyses in connection with the EU stress test have shown that no relevant safety deficits are present in any of the Swiss nuclear power plants.

7.3 Potential safety improvements and further work forecasted

A summary is given below of the measures which will result in a further improvement of plant safety in addition to the required safety provisions.

The safety improvements required on the basis of the first three orders /A-2/, /A-3/, /A-4/ which have still to be implemented are shown in Table 7-1.

Table 7-1: Safety improvements based on the orders

Order	Subject	Date	NPPs affected			
			KKB	KKG	KKL	KKM
3	Back-fitting of accident-proof filling level and temperature instrumentation for the spent fuel pools (SFP)	By 2014 at the latest	X	X	X	X
3	Back-fitting of a diversified heat sink	By 2015 at the latest				X
3	Back-fitting of a new SFP cooling system	By 2015 at the latest	X			X
1	Back-fitting of a physically separated additional feed for the SFP (accident management measure)	By 2012 at the latest	X	X	X	X
3	Improvement of earthquake resistance of the SFP storage building	By 2014 at the latest	X			
3	Back-fitting of a venting duct to remove heat from the SFP storage building	By 2014 at the latest	X			

ENSI has also analysed the event sequences and causes pertaining to the accidents at Fukushima, and has published the findings (/A-14/, /A-15/, /A-16/, /A-17/). 37 checkpoints were derived.

In addition to the safety improvements mentioned in Table 7-1, ENSI has derived eight open points − which may lead to further improvement measures – within the EU stress test (see Table 7-2).

Table 7-2: Open points (OP) derived within the EU stress test

OP no.	Subject	NPPs affected			
		KKB	KKG	KKL	KKM
2-1	ENSI will follow up on the question as to whether in the Swiss nuclear power plants automatic scrams should be triggered by the seismic instrumentation.	X	X	X	X
2-2	In respect of seismic proof that has still to be supplied, ENSI will follow up on a more detailed examination of the seismic robustness of the isolation of the containment and the primary circuit.	X	X	X	X
2-3	ENSI will follow up on measures to improve the seismic stability of the containment venting systems in case of beyond-design basis accidents for KKG and KKL.		X	X	
3-1	ENSI will follow up on the impacts of a total debris blockage of hydraulic engineering installations.	X	X		X
4-1	ENSI will follow up on the proofs of protection against extreme weather conditions, including combinations thereof.	X	X	X	X
5-1	ENSI will follow up on the development of a comprehensive strategy for the targeted deployment of the mobile accident management emergency diesels in order to secure selected direct current and/or alternating current consumers in the long term under total SBO (resp. SBO) conditions.	X	X	X	X
6-1	From the point of view of risk minimisation, ENSI will follow up on the extent to which the current deployment strategies for the venting systems in severe accidents should be retained.	X	X	X	X
6-2	ENSI will follow up on whether restoring containment integrity during shutdown in the case of a total SBO represents a time-critical measure.	X	X	X	X

All the aforementioned points (checkpoints and open points from the EU stress test review) will be followed up on the basis of key thematic issues in the frame of ENSI forthcoming oversight activities. It is planned to complete the processing of all these points by 2015.

8 List of abbreviations

Table 8-1: List of abbreviations

AC	Alternate Current
AM	Accident Management
BBC	Brown, Boveri & Cie
BWR	Boiling Water Reactor
CET	Core Exit Temperature
DBE	Design Basis Earthquake
DBF	Design Basis Flood
DC	Direct Current
DETEC (UVEK)	Department of Environment, Transport, Energy and Communication (Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation)
ENSI	Eidgenössisches Nuklearsicherheitsinspektorat, Swiss federal Nuclear safety Inspectorate ENSI
FA	Fuel Assembly
FN (AN)	File Note (Aktennotiz)
GE	General Electric
GLA	General License Application
HPP	Hydro(electric) Power Plant
IAEA	International Atomic Energy Agency
ICS	Intercommunication System
IDA-NOMEX	Interdepartementale Arbeitsgruppe zur Überprüfung der Notfall-schutzmassnahmen bei Extremereignissen in der Schweiz
KWU	Kraftwerk Union AG
LOOP	Loss Of Offsite Power
MCR	Main Control Room
NPO	Non-Power Operation
OBE	Operating Basis Eartquake
PSA	Probabilistic safety analysis

PSR	Periodic Safety Review
RB	Reactor Building
RPV	Reactor Pressure Vessel
SAMG	Severe Accident Management Guidelines
SBO	Station Blackout
SFOE	Swiss Federal Office of Energy
SFP	Spent Fuel Pool
SP	Suppression Pool
SSC	Structures, Systems, and Components
SSE	Safe Shutdown Earthquake
SSHAC	Senior Seismic Hazard Analysis Committee
TB	Turbine building
Total-SBO	Total Station Blackout
TS	Technical Specification
UPS	Uninterruptible Power Supply
W	Westinghouse

9 References

Italics = only in German

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/A-3/ ENSI
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/A-4/ ENSI
Formal order of 05.05.2011: Comment on your report dated March 31st 2011

/A-5/ ENSI
Formal order of 01.06.2011: Re-evaluation of the safety margins for the Beznau nuclear power plant pursuant to the EU stress tests

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