Transactions, SMiRT-22
San Francisco, California, USA - August 18-23, 2013
Division IX (include assigned division number from I to X)

CONSEQUENCES OF POST-FUKUSHIMA SAFETY EXAMINATIONS

Rainer Kaulbarsch[1]

[1] Dr.-Ing. Department for Safety Analysis, Nuclear Power Plant Gösgen, Switzerland

ABSTRACT

The Swiss Authority decreed several provisions after the Fukushima event. Due to these provisions many examinations and safety increasing measures had to be done in a very short time. The result is the use of safety systems to show the control of Fukushima like events which were originally designed for other special events like aircraft crashes or explosion pressure waves. At the end of such ad-hoc measure the safety systems and the events controlled by using these functions are mixed up. Another effect of these ad-hoc measures is the prohibition of larger safety improvements with a concept that fits to the existing safety concept of the power plant.

INTRODUCTION TO THE POWER PLANT

Location

The nuclear power plant Gösgen (KKG) is located in the north of Switzerland close to the village Däniken in canton Solothurn. The next cities close to KKG are Aarau (approx. 4 km, 20 000 citizens) and Olten (6 km, 17 000 citizens). Larger cities in the neighborhood are Zürich (42 km, 395 00 citizens), Basel (36 km, 200 000 citizens) close to the German border and Bern (61 km, 135 000 citizens). The area of the KKG is approximately 1 km^2 large and limited by the river Aare at the north-west to north-east side.

Environment

There are 32 industries or civil locations (like paper, energy, coloring and waste disposal industries, swimming pools) within a radius of 8 km around KKG which are taken into account for several events -like earthquakes- as more or less relevant. Approximately 1 km south of KKG the railway from Olten to Aarau is used for transportation of hazardous goods, see report of AF-Consult (2013). The next larger airports are Zürich Kloten, Grenchen, Buochs and Bern, AF-Consult (2012). Another hazard potential results from a gas transit pipeline passing by in the north-west of the KKG area in a minimal distance of 225 m.

Main Data

The nuclear power plant KKG was build up by the German supplier Kraftwerks Union (KWU). The plant was put into operation in the year 1979. The reactor type is a pressurized light water reactor with three cooling loops. Actual the capacity is of thermal 3002 MW_{th} and electrical 1035 MW_{el}. Up to the year 1992 the thermal capacity was extended in two steps from originally 2808 MW_{th} up to today's capacity, KKG (2011).

The reactor core is build up by uranium fuel elements. New fuel elements have an enrichment of 5.01% U-235, AREVA (2012). In the year 2013 the core is again MOX free after burning MOX fuel elements for several years due to the Swiss regulatory body which forbids fuel recycling in 2006 for 10 years, see Swiss nuclear energy law KEG (2003). As a special characteristic the core currently consists of five regions.

The core is cooled by three main loops during normal operation. The three steam generators supply the secondary circuit with steam (62 bar, 278°C) to operate the 1035 MW_{el} power island. As ultimate heat sink for waste heat a cooling tower is installed and is fed by water of the river Aare.

In the KKG fuel elements may be

a) set in in the reactor core for power production or during outage,
b) stored in the spent fuel pool inside the reactor building,
c) handled in the fuel element loading and service pool in the annulus building or
d) stored in the separate wet storage pool (separate building).

The loading and service pool is only temporary used for refueling or fuel element inspection. The safety systems for residual heat removal from the primary circuit are connected to the three main cooling loops, the spent fuel pool, and the fuel element loading and service pool.

Safety Concept

The general objective is to secure the safety objectives, see UVEK (2009):

1. Control of the reactivity.
2. Cooling of fuel elements and radioactive waste.
3. Enclosure of radioactive materials.
4. Limitation of radiation.

Therefore several classes of systems are installed:

- Operational systems
- Limiting systems
- Unsecured safety systems
- Secured safety systems
- Emergency equipment

Operational systems try to operate the plant within the limiting conditions of operation (LOC). By injuring a LOC, the limiting system will try to restore a plant status within the LOC. The limiting system also has the function to ensure discrete plant conditions in case of a design base event. These discrete plant conditions mark the worst starting point for measures by the safety systems. The safety systems themself are divided into a secured and an unsecured safety systems. The unsecured safety systems are to control design base events like internal events (loss of coolant, reactivity accident …) and external events (earthquake, loss of power grid, smaller air plane crash …). Secured safety systems are designed to control external beyond design base events like large aircraft crashes or pressure waves. Emergency equipment will be used to support the control of the event or to limit radioactive release.

Two power plant conditions are defined as “save” conditions:
“hot shutdown” and
“cold shutdown”.
In case of a design base event, the safety systems will try to reach the condition “hot shutdown”. So the plant will be set into save conditions automatically within 30 minutes in all design base events and also aircraft crashes and explosion waves. After that, the plant will be cooled down to the condition “cold shutdown” by manual measures in most of all cases.

To control events, KKG has an operation manual with a floating transition into the emergency manual. The transition is done by the control of the safety objectives. If safety objectives are not kept or will be violated soon, measures of the emergency manual will be used to control the event and to limit radioactive release.

Depending on the kind of event itself and the strength of the event the different classes of systems are used. In general KKG is a pressurized water reactor with a 3-loop primary circuit. That means that all cooling, feed water and borating safety trains are connected to one of the main cooling loops. The following list presents the main character of the system classes and the safety functions of the system classes.

Safety systems

The safety systems are built up in a secured and an unsecured part. The unsecured part of the safety systems are built up in the reactor building and the auxiliary building as well as in some buildings needed to operate the cooling chains close to the reactor building. Its general characteristics are

- 3 (4) redundant process safety trains
- 4 redundant diesel trains EY
- 4 I&C trains

The functionality of process train No.4 is limited. The train is used while another train fails. The secured systems are installed inside reactor building and the so called ZX-Building, which is a special, bunkered building next to the annulus building with strong protection against aircraft crashes, flood, and explosion pressure waves. Its general characteristics are

- 2 redundant process safety trains
- 2 redundant diesel trains FY
- 3 I&C trains

The main available safety functions of these part of the safety system are to

- shut down the reactor,
- cool down the primary circuit by steam relief and refilling the steam generators,
- secure undercriticality and compensation of thermal contraction,
- closure of the primary circuit,
- cooling of the primary circuit by one of two available cooling chains and
- cooling the spent fuel pool by one of two available cooling chains.

All in one, that means that the safety systems are designed to control the more seldom events like aircraft crashes and pressure wave by a limited amount of necessary safety functions and systems and more manual intervention.

Ultimate heat sinks

One advantage of the strict separation of secured and unsecured parts of the safety systems outside the reactor building is the use of diverse heat sinks or water sources also separated by distance. The KKG has three water sources which can be used to operate the cooling chains:

- River Aare M0
- River Aare M5
- 2 wells under the ZX-building

All three water sources are separated from each other by distance. The M0 and M5 water inlet are operated together with the unsecured part of the safety systems. Therefor the M5 water intake has additional two diesel generators to operate pumps and necessary electrical equipment. The two wells under the ZX-building are only used by the secured safety systems. They can be used to operate a cooling chain for spent fuel pool cooling, rector cooling and also to refill the steam generators. The last option may be necessary when one redundancy of the two process trains of the secured systems fail e. g. by a single failure. In that case, the remaining process redundancy is used to cool the primary circuit by steam relief and refilling of a steam generator and operating a decay cooling chain to cool the spent fuel pool.

Protection against earthquakes and flood events

Up to the time before the Fukushima event the KKG was in a very comfortable situation. All design base events were controlled also in case of a single failure. In nearly all design base events (except aircraft crash and pressure wave) no failure of several safety systems had to be suspected. Especially earthquakes and high water levels of the river Aare were controlled by the safety systems.

After the Fukushima event much higher levels of earthquake loads and flood waves were discussed and at the end stipulated by the Swiss legislation. Most important was the ongoing SSHAC level 4 process to establish a new earthquake hazard spectrum for Swiss nuclear power plant and the generation of new scenarios for dam bursting during the new build process for nuclear power plant in Switzerland. The preliminary earthquake loads determined in the PEGASOS project had to be used for detailed evaluations on earthquake control. Increased loads by a factor of approximately two had to be taken into account. Flood waves resulting from time discrete sequential break of dam were taken into account and increase the resulting water wave up to level higher than the power plant area. Corresponding evaluations to assess the security of event control were mandated by the Swiss regulation authority ENSI.

REACTION OF THE AUTHORITIES

After the pictures of the Fukushima event the Swiss regulator ENSI decreed ad-hoc measures to proof security of Swiss nuclear power plants. They also decided to take part at the EU-Stresstest and to build up their own program to determine the power plant security with respect to the Fukushima accident. Therefore the Swiss regulator decreed the following provisions:

1. March 18th, 2011, Measures because of the Fukushima event, ENSI (3/2011)
2. April 1st, 2011, Guidelines to examine the design regarding earthquake and flood, ENSI (4/2011)
3. May 5th, 2011, Statement to the KKG report from March 31st, 2011, ENSI (5/2011)
4. June 1st, 2011, Re-examination of the safety margins of the KKG in the framework of the EU-Stresstest, ENSI (6/2011)
5. January 10th, 2012, Provision Statement to the report for EU-Stresstest (Report of KKG), ENSI (1/2012)

Provisions like that are positioned in the Swiss legislation. With reference to the edicts of the UVEK (2008) and UVEK (2009) the regulator is authorized to decree such examinations and in case of negative results to shutoff the power plant. The criteria which have to be examined are given by the Swiss decree KEV (2003). The named criteria apply to fuel element cooling, integrity of the primary circuit and integrity of the containment. The examination points of the five named provisions above had to be done within a specified time frame without an option to extend the available time regarding to VwVG (2011). An overrun of the given time limit for an examination would be rated like a negative result and may lead to a shutoff of the plant. The resulting outage may be as long as it takes to finish the examination or till necessary safety improvement are implemented. The license owner of KKG had to follow these provisions. At least the license owners of Swiss nuclear power plant tried to do everything to answer all points of these provisions in time and sufficiently. Otherwise the economic losses in case of a decreed shutoff would immense and in most cases higher than technical measures for safety improvement.

In the center of attention of the named provisions there are three types of events: earthquake, flood and dam rupture due to earthquakes. These events correspond with the Fukushima event type. The examination of these three events should cover the worst case of all possible loads due to earthquake, flood or combinations of them. As a starting point of all examinations the probabilistic frequency of exceeding was postulated by the regulator to be 10^{-4} per year. The effect is that these events are located at the boarder of 10^{-4} per year between category 2 and 3 of the UVEK (2009) edict. For category 2 it has to be shown that the radioactive dose limit of 1 mSv in the environment is not exceeded without any postulated single failure of a necessary safety system. For category 3 it has to be shown that the radioactive dose of 100 mSv in the environment is not exceeded. But in the examinations one single failure at the worst point of occurrence has to be considered.

Due to the guidelines and boundary conditions of the regulator the license owner had at first to evaluate the hazardous impacts of an earthquake and flood on its power plant site. Second he had to show the control of both events with and without single failure and with available equipment. For the determination of an earthquake with destruction of dam an earthquake with a 10^{-4} per year frequency of exceeding is postulated as a starting point. Instantaneous and complete dam destruction of all dam with a negative impact on the power plant site had to be taken into account. The impact on the nuclear power plant will be destruction due to the earthquake and a short time later one or more flood waves with additional destruction to the power plant. To ensure that all important points were considered many examination points were given in the provisions of the Swiss regulator ENSI.

POST FUKUSHIMA EXAMINATIONS AND ACTIONS

After giving an overview of the post Fukushima provisions and their placement in Swiss legislation, the more detailed view on the examination points and resulting actions shows some effects of the whole ongoing process. The following list is a list of decreed examination and action point of all named provisions above. The date in brackets is the time limit for that action point.

Examination of the design to control earthquakes and flood (immediately)

A report was written that shows the control of earthquakes, flood and combinations. Available systems were listed and accident management measures documented.

Buildup of an external storage of safety equipment (2011-06-01)

The owners of all nuclear power plants in Switzerland build up one external storage facility with mobile emergency power supply systems, fuel, batteries, cables, mobile pumps, flexible tubes, borating equipment and necessary tools. Also measures and routines were developed to transport the external equipment to each nuclear power plant.

Connection point for external equipment (2012-12-31)

Connecting points were installed to be able to make use of the external equipment, such as connectors to refill steam generators, connectors to refill spent fuel pool and connectors for electricity supply from the external diesel generators.

Examination of earthquake loads and fragility analysis for necessary safety systems (2011-11-30)

An analysis based on intermediate results of the Swiss PEGASOS project was done. The resulting loads were used for a detailed fragility analysis of all structures and systems necessary for event control. The examinations included the whole reactor building inclusive the spent fuel pool. The most important result was that event control has to be shown by using the secured safety systems in the ZX building because some unsecured safety systems located in the auxiliary building ZE would not withstand the new seismic loads spectrum. That means, only two process redundancies will be available for fuel element cooling in best case (no single failure). Worst case there will be only one process train be available to cool the primary circuit and spent fuel pool. The earthquake dampers of the diesel generators of the secured safety systems were identified as a weak point by the KKG itself. They were exchanged during the first shutdown after the Fukushima event.

Earthquake - deterministic analysis of event control (2012-03-31)

A deterministic approach was used to show event control by only using the secured safety systems. Therefore all necessary components were listed. For each component inclusive buildings the calculated HCLPF (high confident in low probability failure) value was given to demonstrate the availability in case of an earthquake.

Flooding - deterministic analysis of event control (2011-06-30)

The hazard loads which had to be used were extracted from the new build licensing process, a process to build a new nuclear power plant next to the existing KKG. Based on these data the examination came to the conclusion that such flood scenarios only will be controlled by the secured safety systems. That means again that only to process trains will be available, in worst case only one.

Earthquake and flooding – deterministic analysis of event control (2012-03-31)

As a starting point the occurrence of an earthquake with a frequency of exceeding of 10^{-4} per year was postulated. Two different ways were depicted by the authority how to show event control. The first way was to show consistency of dams in case of earthquake. This option was not feasible for KKG. The second option was to examine the maximum flood wave and the availability of all necessary structures and systems after earthquake and instantaneous and complete destruction of all relevant dams.

Technical solutions how to monitor temperature and water level of the spent fuel pool (2011-08-31)

A technical solution to display the spent fuel pool temperature and water level was proposed. After getting the acceptance of the authority KKG started to implement the claimed measurement systems as secured safety systems with availability of this information in the secured ZX building.

Examination of the design of the spent fuel pool, its building and cooling systems (2013-03-31)

An additional examination had to be done to show that some passive operating draining and cooling systems with existing seismic design will withstand the new interim seismic hazard spectrum. In detail the draining system of the reactor room above the reactor had to be examined. The draining system is of importance only during power plant outages and is closed manually by a disc. Also to be examined was the operational cooling systems which are connected to the spent fuel pool at the upper end of the pool. In case of rupture only am minimum of water may be lost. Fuel elements will be covered with several meters of water. As result no additional installations became necessary.

Examination of the protection against hydrogen deflagration and explosion (2012-03-31)

KKG has a very robust containment which may withstand pressure loads more than 10 bar depending on the liner temperature. It could be shown that the atmosphere inside the containment may allow deflagration processes but no detonation process. Installed hydrogen recombiners were not taken into account.

Examination of margins in case of an earthquake, participation at the EU-Stresstest (2011-08-15/ 2011-10-31)

KKG took part at the EU-Stresstest and got a good feedback. No additional actions were necessary.

Examination of the seismic robustness of the containment isolation (2012-09-30)

The containment isolation in case of earthquake or flood is not necessary because no leakages especially of the primary circuit and connected systems have to be expected. These systems have a robust seismic design. Although no leakages have to be expected an analysis of the robust seismic containment isolation was claimed by the authority and could be performed successfully.

Examination of the seismic robustness of containment venting system (2012-09-30/ 2012-12-31)

Parts of the venting system which are used for a controlled release in case of high containment pressure had to be examined. After getting the results, some measures had to be done to increase the robustness against seismic loads.

Examination of log jam of the Aare water inlet systems (2012-09-30)

The unsecured safety systems take water from the river Aare to operate cooling chains and unsecured emergency diesel generators. Cooling chains and diesel generators of the secured safety systems get water from the wells under the secured ZX building. So, possible log jam will not affect the availability of the used secured safety systems.

Examination of severe weather conditions and analysis of event control (2013-12-31)

The hazard of extreme weather conditions have to be re-examined. A common project of the Swiss nuclear power plant operators is ongoing.

Up to now, all decreed retrofit measurements could be realized in time. One of the decreed examinations needed more time to be worked out.

PLACEMENT INTO CURRENT SAFETY CONCEPT

Regarding the general safety philosophy one important thing is obvious. Systems installed and designed to help controlling seldom events like extreme aircraft crashes or explosion pressure waves are now stressed to show the control of design base events which were controlled by the unsecured safety systems before. The result is a mismatch of event classification and the corresponding safety systems used to control them. Due to that the control of events is not endangered. Assumed the implementation of retrofit measures is done very carefully. But the likelihood to make mistakes is increased.

RESUMEE

As résumé two things are obvious: the high time pressure for measurements and examinations and the use of systems to control events they are not originally designed for. The first thing –time pressure- was never good for development and implementation of measurements in technical systems. But public pressure on actions after events like Fukushima leads to very short handling times and as a result to higher failure rates. It would be recommendable to make use of normal adequate handling times in future. The second thing is in many cases a result of time pressure. If the requirements of a system or system functions increases so that the system cannot fulfill its function any more someone has to look for a quick solution to ensure the availability of the safety function also under increased loads. Under those circumstances it is only natural to make use of other systems designed to control events of other classes if their use guarantees the safety function. This reduces the shutdown duration in an environment where decreed shutdowns are probable. But the chance for large safety improvements which fit to the safety philosophy of the existing plant is getting smaller.

Beside the provisions KKG itself started a study how to extend the secured safety systems to get larger safety increases. Additional the hydrogen situation is re-examined over the next month followed by the exchange of the recombiner systems. A KKG internal collection of ideas was done directly after the Fukushima event and lead to punctual improvements.

REFERENCES

AF-Consult (2013). “Kernkraftwerk Gösgen-Däniken AG Unfälle in der Nachbarschaft” Technical report 2252.3300, Rev. 1, Switzerland

AF-Consult (2012). “Kernkraftwerk Gösgen-Däniken AG Aircraft crash frequency evaluation for the site of nuclear power plant Gösgen” Technical report 2252.3500.12.07, Rev. 1, Switzerland

AREVA (2012). “KKGG-Reaktorphysikalische Rechnungen für den 35. Zyklus; vorläufiger Umsetzplan für den 34. BE-Wechsel (Stand: 22.11.2912)”, AREVA Report FS1-0008878, Rev. 2.0, Germany

ENSI (3/2011). “Verfügung: Massnahmen aufgrund der Ereignisse in Fukushim”, ENSI provision, March 18th, 2011

ENSI (4/2011). “Verfügung: Vorgehensvorgaben zur Überprüfung der Auslegung bezüglich Erdbeben und Überflutung”, ENSI provision, April 1st, 2011

ENSI (5/2011). “Verfügung: Stellungnahme zu Ihrem Bericht vom 31. März 2011”, ENSI provision, May 5th, 2011

ENSI (6/2011). “Verfügung: Neubewertung der Sicherheitsmargen des Kernkraftwerks Gösgen im Rahmen EU-Stresstests”, ENSI provision, June 1st, 2011

ENSI (1/2012). “Verfügung Stellungnahme zu Ihrem Bericht zum EU-Stresstest”, ENSI provision, January 10th, 2012

KKG (2011). “EU Stresstest: Beurteilung der Sicherheitsmargen des KKG, Bericht des Genehmigungsinhabers”, KKG Report BER-D-54731, Switzerland

KEG (2003). “Kernenergiegesetz (KEG)”, Swiss law SR732.1, Actual Revision March 21th, 2009, Switzerland

KEV (2003). “Kernenergieverordnung (KEV)”, Swiss decree , Actual Revision December 10th, 2004, Switzerland

UVEK (2008). “Verordnung des UVEK über die Methodik und die Randbedingungen zur Überprüfung der Kriterien für die vorläufige Ausserbetriebnahme von Kernkraftwerken”, Swiss Regulation SR732.114.5, Actual Revision May 1st, 2008, Switzerland

UVEK (2009). “Verordnung des UVEK über die Gefährdungsannahmen und die Bewertung des Schutzes gegen Störfälle in Kernanlagen”, Swiss Regulation SR732.112.2, Actual Revision August 1st, 2009, Switzerland

VwVG (2011). “Bundesgesetz über das Verwaltungsverfahren”, Swiss law SR732.021, Actual Revision January 1st, 2011, Switzerland