Research on the vulnerability of NPP Borssele in situations comparable to the Fukushima accident

Commissioned by Greenpeace Netherlands
Antonia Wenisch, (in collaboration with Oda Becker)
Vienna, Hannover
August / September 2011

1 SUMMARY AND CONCLUSIONS

The NPP Borssele in the Netherlands is the only pressurized water reactor (PWR) of design lines 1 and 2 developed and constructed by the German company Siemens/Kraftwerksunion (KWU) that is still operating. And yet: Plans foresee an almost doubling of the operation time of this old reactor to 60 years.

However, in 1993 after 20 years operation the first 10-yearly periodic safety review (PSR) of Borssele NPP took place. This resulted in a major back-fitting and design modification program worth 200 million euro to be implemented in the following 10 years until 2003. The second 10-yearly periodic safety review of 2003 resulted in some fine tuning of the safety concept rather than in major design changes.

The third 10-yearly periodic safety review is foreseen for 2014. The original design of the plant is based on an operating period of 40 years beginning from 1973. Therefore the Dutch utility EPZ must apply for a long term operation (LTO) license.

WENRA (Western European Nuclear Regulator's Association) published a paper on LTO stating that "for existing reactors, WENRA safety objectives for new nuclear power plants and other relevant modern standards should be used as a reference with the aim of identifying reasonably practicable safety enhancements." [WENRA, 2011]

A safety review comparing Borssele with the safety objectives for new nuclear power plant as recommended by WENRA should be carried out in a transparent manner with participation of the interested public during the LTO licensing procedure.

Besides safety improvements the economic efficiency of the plant was enhanced by replacing the turbine and switching to MOX fuel and higher enriched fuel to achieve higher burnup. These measures certainly are profitable, but the use of MOX fuel and longer fuel exploitation (high burn-up) complicates the control of incidents and results in higher radioactive releases in case of an accident.

According to the Dutch ministry of environment [VROM 2010] also safety culture seems to be an issue for Borssele. Safety culture in old plants which are planning long-term-operation (LTO) must be of high quality, because of the aging processes of diverse components of the plant. In LTO regime many small failures can occur. Even if each of these faults seems to be minor, they must not be neglected.

Borssele invested in a total renewal of the control room and improvement of man-machine-interface, including a process presentation system helpful in diagnosing emergency situations. Nonetheless the safety management and training of people operating and maintaining the plant is of high relevance. Experience from German NPPs (Krümmel) showed that deficiencies in safety culture and management can result in undetected deficits. Because of these deficits a small incident can develop into a severe accident.

According to the Nuclear Energy Agency [NEA 2007] external hazards dominate the severe accident risks for Borssele.In August 2011 the operator of Borssele NPP EPZ published a document called 'Progress Report – Complementary Safety margin Assessment' [EPZ 2011]. This progress report lists the issues to be discussed in the stress test but does not contain a discussion on the safety margins of Borssele NPP yet. However, the PSA (probabilistic safety assessment)results in EPZ 2011, are very different from the results of the PSA from 2004 presented in NEA 2007. Because the 2011 PSA data are presented by the operator without verification, we refer in this study to the PSA from 2004.

Power supply

NPP's are dependent on a continuous electric power supply, even when they are not operating. Heavy storms can lead to multiple damage to the transmission lines and hence to loss of off-site power. But the grid could also collapse due to a regional overload. If load rejection via the turbine control fails, an automatic scram shuts off the reactor and the emergency diesel generators (EDG) start automatically.

Every nuclear power plant has emergency power supplies, often diesel-driven. These generators provide power to supply emergency pumps, valves, fans, and other components that are required to operate to keep the plant in a safe state by removal of the residual heat.

Borssele has three identical 4.3 MW EDG's located around the nuclear plant. Each of these three EDG's is able to provide enough power to remove the decay heat from the core. In 1986, two extra 'station blackout' diesel power generators were built in bunkers. Each of these 0.85 MW DG can keep the NPP in a safe controlled state [EPZ 2010].

Without electricity the operator looses instrumentation and control power leading to an inability to cool the reactor core. Counter measures (accident management) are practically impossible. If the blackout lasts for a long time, not only the reactor, but also the fuel in the spent fuel pool can overheat, leading to radioactive releases [Hirsch et al. 2005].

Inside the plant electrical connectors and electronic control devices could be damaged by humidity and water leading to shortcut and interrupting power supply for the core cooling pumps.

According to NEA 2007, flooding is the largest contribution to core damage frequency at Borssele NPP. If the three EDG'ss fail, the two bunkered SBO (station black out) diesels should be able to keep the plant in a safe state. With the current amount of stored diesel fuel the plant can sustain 72 hours, within which a refilling of the diesel tanks should take place. However, in case of a dike break which is likely to be accompanied by harsh weather conditions and the plant surroundings being flooded this refilling cannot be guaranteed [NEA 2007].

A lesson from Fukushima is that in an extreme flooding, the emergency equipment at the plant site itself could be hit by the flood or the emergency crew cannot reach and use it.

Flood

Flooding is the most important hazard for the Borssele site. Scientists have found out that the sea wall is not strong enough to protect Borssele NPP in case of a superstorm which occurs once every 4000 years.

Projectbureau Zeeweringen is reinforcing the dikes of Zeeland. The cladding of many dikes along the Oosterschelde and Westerschelde is not strong enough. In case of a so-called superstorm, some stones and concrete could break away although the stone cladding should be strong enough to safely stem the waves of a superstorm. Reinforcement is necessary to protect Zeeland and other parts of the Netherlands against flooding. The Flood Defence Act regulates the sturdiness of dikes and stone cladding. The standard depends on the damage a storm can cause in an area. In Zeeland the safety standard is 1:4000. This means that a dike should be able to withstand a superstorm which could happen once in 4000 years. The Ministry announced that the dikes at Borssele will be strengthened in summer 2012. For comparison: statistically the North Sea flood of 1953 happens once every 250 years [PZ 2011]..

According to current international design requirements a NPP should be able to withstand at least a ten-millennial flooding. This is an even stronger superstorm exceeding the flood of the superstorm which on average happens once every 4000 years. After strengthening of the dikes at Borssele is finished the NPP would not be further endangered by a four-millenial flood. But in case of a ten-millennial flood the dike could fail and the NPP could be faced with a flood for which it is not designed to withstand.

The flood level for vital components is 7.3 m. In 2006 the flood protections of the station blackout (SBO) diesel generators (DG) were increased from 7.3 m to 9.8 m by installing snorkels at the air inlet [EPZ 2010]. But detailed instructions how to supply the fuel from the additional storage tanks to the DG in case of flooding are missing.

The German RSK (Reaktorsicherheitskommission) requires large safety margins for floods: 1 meter or better 2 meters. As long as the dike withstands the flood the reactor should be safe, but a break of the dike would inevitably lead to a disaster because of the design deficiencies of Borssele NPP.

Moreover it is not enough to have the SBO diesels running if there are electric connections in the plant that could be flooded (e.g. electrical supply connections to the ground water pumps which are located below the flood level). If these connections fail removing the residual heat from the core would be impossible. The result could be a core melt accident as in Fukushima.

Earthquake

An earthquake was not considered in the original Borssele design, as in all other KWU reactors of this age. The design basis earthquake[1] (DBE) of Borssele according to the license is MSK VI with a peak horizontal acceleration (PGA) of 0,06g. This is nonconforming with the actual IAEA's (International Atomic Energy Agency) recommendation for a minimum design basis earthquake of PGA = 0,1g. [IAEA, 2003]

1 DBE: seismic level 2 guarantees safe shutdown of the plant and removal of decay heat.

Even if the earthquake risk at Borssele is assumed to be low a re-evaluation of the design earthquake according to state-of-the-art methods should be considered. At several NPP sites worldwide, the design earthquake estimated decades ago was found to be insufficient based on new scientific insights. In the EPZ progress report of August 2011 it is stated that extensive earthquake measures have been implemented as part of the backfitting project of 1997 [EPZ 2011]. Earthquake protection is not mentioned in all other documents and the progress report [EPZ 2011] gives no details on these measures.

Aircraft crash

Aircraft crashes have not been considered in the design of the first KWU PWRs. The vulnerability of Borssele NPP concerning air plane crashes is probably the same as for the old German PWR of design line 1 and 2: withstanding the accidental crash of a small military plane, the Starfighter. Strengthening the reactor building is not possible.

In Borssele separated trains of safety systems are placed at different locations, like the two bunkered diesel generators and pumps and there are redundant systems for decay heat removal. But from the published documents it cannot be proved if all redundant trains are totally physical separated. According to the CNS (convention of nuclear safety) report it is not clear that all essential emergency systems are fully functional and physical separated.

In the progress report [EPZ 2011] EPZ describes that the next airport is 10 km from the plant and is intended for small civil airplanes (maximum weight <5.7 tons). Flight corridors for commercial aircraft are said to be in a distance of 20 km from the NPP and the closest military base is in a distance of 40 km. The restricted area for military air traffic has a diameter of 7.2 km and a height of 500 meters. Flight exclusion zones can mitigate the risk of an accidental air-crash impact to the NPP. But they are no protection against a terror attack.

Terrorist attack & external explosions

In case of terrorists hijacking an aircraft and targeting the plane into the NPP the attack could result in major damage to the plant because the containment is not able to withstand the impact of a commercial aircraft which has a minimum weight of 40 tons.

Older German NPP containments are designed to withstand a pressure wave created by explosive gas mixtures of maximal 0.45 bar. However, impacts of a hydrogen detonation could create a pressure wave a factor 10 to 20 higher . For this reason the German Reactor Safety Commission[2] recommended a re-evaluation of the protection capability of the NPP's [RSK 2011]. Several different hazards are possible: fire, smog, toxicity, explosions. An explosion could also be caused by terrorists. For older German NPP's back-fitting has been required.

The Borssele site is in an industrial area where also an industrial harbor is located. A cargo ship gas explosion makes up a significant portion of the risk to Borssele NPP. The gas explosion could for example damage the reactor building and debris penetrating the steel containment could fail the primary systems. The gas explosion could also cause demolition of the bunkered buildings where the diesels and pumps for station blackout are located, In this case no systems would be available to mitigate the accident resulting in a core melt accident.

Water supply

We understand that EPZ has implemented several effective safety upgrades in Borssele NPP. The description of the back-fitting program shows that physical separation of redundant systems is not an overall design principle. This might be due to former requirements and plant design which does not allow for additional spatial separation. It could prove to be a serious disadvantage because a failure in an essential system could simultaneously disturb the redundant system too.

However, none of those measures can work reliably under conditions like internal or external flooding unless all systems and components are waterproof. In particular electrical and electronic devices are vulnerable to water and humidity and might fail. An external flooding of the plant site could make refilling the SBO diesels impossible which would be necessary if the site stays underwater longer than three days (72 hours).

2 Reaktorsicherheitskommission (RSK)

Reactor coolant pressure boundary

Borssele is an old plant. Material deficiencies and aging phenomena of vessels and pipes could cause cracks and ruptures which could induce problems eventually resulting in accidents. A singular pipe break can most likely be controlled and a release into the environment prevented. However, each leak of radioactive coolant causes contamination and additional exposure to plant personnel. Incidents caused by fire, shortcut or explosion are specific loads which can create cracks in the pipes. This can eventually lead to partial or complete system failure, which can cause a severe accident.

Severe Accidents

A major weakness of Borssele NPP concerns external impacts like flooding, earthquakes and explosions. The dominant contributors to the total core damage[3] frequency (CDF)[4] according to the probabilistic safety assessment (PSA)[5] are the flooding scenarios. In NEA 2007 internal events contribute 81% to the CDF, external events 19%. In the progress report EPZ presents a new version of the PSA [EPZ 2011] with results very different from the results given in NEA 2007. In EPZ 2011 internal events have the largest contribution to core damage frequency for power operation (92 %) and external events contribute only 8 %. It is not explained which measures could have improved the resistance of the NPP so dramatically that the contribution of external impacts could be mitigated that far. The following citation from EPZ 2011 could be an explanation of this difference:

> "The external events PSA has been conducted based on a successive screening process. First, the external events scenarios were identified, the initiating event frequency quantified, and the impact on the plant determined. If the frequency was low, then the scenario has been screened out. If the frequency was above the truncation frequency, then the plant response and other factors were considered." [EPZ 2011]

If screening out the severe external impact scenarios justifies the minor role of external impacts by the PSA results in EPZ 2011, this is a misinterpretation of the ENSREG (European Nuclear Safety Regulators Group) stress-test specifications which claims:

> "The approach should be essentially deterministic: when analyzing an extreme scenario, a progressive approach shall be followed, in which protective measures are sequentially assumed to be defeated. The plant conditions should represent the most unfavorable operational states ..."[ENSREG 2011]

EU Stress test

Rare events as earthquakes, flooding, extreme weather and also man-made events (plane crashes, cyber attacks, terrorism, sabotage, etc.) can heavily affect a NPP. If loss of power, station blackout and/or loss of main heat sink are caused by external impacts safety margins compared to the design basis have to be proven.

From a safety point of view it is more convenient to have more lines of defense available (more configurations) and larger time margins for plant recovery. There are no fixed acceptance criteria which could be applied to the stress test because there are no reference values specified for extreme situations which are not considered in the existing international safety standards. Therefore, principal robustness and diversity of safety systems and functional and spatial separation of these systems have to be investigated.

The internal emergency measures (accident management) should be described in general as well as taking into account the events and subsequent failures mentioned above. The following issues deserve special attention:

---

3 Core damage accidents are considered serious because damage to the core may prevent control of the nuclear reaction, which can lead to core (partial) meltdown.

4 The chance that the reactor core gets damaged possibly leading to radioactive releases or meltdown

5 PSA's are used to calculate the probability of damage to the core as a result of sequences of accidents identified by the study. PSA's are also used to assess the size of radioactive releases from the reactor building in the event of an accident, as well as the impact of such releases on the public and the environment.

- Accident management measures for the different stages of loss of core cooling
- Accident management measures for preserving containment integrity after fuel damage (core or spent fuel pond),
- Accident management measures for the storage of spent fuel.

A lesson from the Fukushima accident is that extreme external events (flood, earthquake, extreme weather) can challenge a nuclear power plant. Extreme events can result in cliff edge effects. The goal of the ENSREG stress test is to find out the robustness of the plant, the cliff edge effects which could threaten the plant's safety and the time the plant can be safe without support from outside. Therefore, an unlikely event cannot be excluded solely based on probabilistic assessments. This is even more valid, as insecurities of probabilistic risk analyses can amount to a difference of one or two orders of magnitude for the internal events alone. Moreover such analyses always remain incomplete, because not all relevant factors can be included.

Prevention of possible 'cliff-edge-effects' needs to be investigated where issues of organization, of availability of equipment and supplies (fuel for the diesel-generators, cooling water etc.), prevention of radioactive releases , impacts of a far-reaching destruction of the infrastructure of the plant and, contamination of the plant site need to be taken into account.

Even if early releases are unlikely to occur they would have the biggest impact on environment and health. At Borssele NPP, accidents with early releases would most likely be caused by external events such as air-plane crashes or explosions.

However, an unlikely event cannot be excluded solely based on probabilistic assessments. This is even more valid, as insecurities of probabilistic risk analyses can amount to a difference of one or two orders of magnitude for the internal events alone. Moreover such analyses always remain incomplete, because not all relevant factors can be included.

Fukushima is a prove that exclusion criteria, which are based on low probability of occurrence only, must be supported by additional deterministic safety assessments. More attention needs to be devoted to event chains of external impacts; in particular cumulative effects caused by common mode failure (including the failure of several systems) will have to be assessed.

After Fukushima a WANO (World Association of Nuclear Operators) mission published the Significant Operating Experience Report of Borssele which named 15 gaps regarding capabilities to mitigate conditions that result from beyond design base accidents. Even if most of these gaps could be closed in time and the procedures will be defined properly, design deficiencies and aging problems remain unsolved. Borssele will hardly achieve a modern safety standard.

2 INTRODUCTION

The goal of this study is to investigate the vulnerability of the Nuclear Power Plant (NPP) Borssele in situations comparable to the accident at Fukushima. Critical issues are total loss of electrical power (e.g. by flooding) and loss of ultimate heat sink.This study focuses on the most important design deficiencies of the almost 40 years old Borssele NPP and points to the weaknesses which cannot be substantially improved by additional safety upgrades.

Borssele is a 2-loop Pressurized Water Reactors (PWR) constructed by the German company Siemens/KWU. Borssele NPP (484 MWe) started commercial operation in 1973 and is of the same age as the old KWU PWRs of design lines 1 and 2[6]. Design line 1 includes prototypes: in Germany itself only two PWRs of this design line - Obrigheim and Stade - have been operating but both have been permanently shut down. Obrigheim (357 MWe) was operating from 1968 to 2005, and Stade (672 MWe) from 1972 to 2003. Starting with design line 2 only 4-loop reactors were constructed by KWU with one exception: Neckarwestheim 1 which is a 3-loop PWR of the second design line[7]. As a reaction to the severe accident at Fukushima all 4 PWRs of construction line 2 have been permanently shutdown because of insufficient safety margins[8]..

Borssele NPP in the Netherlands is the only still operating NPP of the first KWU design lines. And yet plans foresee almost doubling the operation time of this old reactor to 60 years. In 1993 after 20 years of operating Borssele NPP the first 10-yearly periodic safety review (PSR) took place. This resulted in a major back-fitting and design modification program worth 200 million euro to be implemented in the following 10 years until 2003 [NEA 2007].[9]

Periodic safety reviews

The first 10-yearly Periodic safety review resulted in the following measures [VROM 2010]:

- Measures to strengthen the emergency cooling system:
    - Functional and physical separation of redundant emergency core cooling system (ECCS) trains.
    - Addition of a single train reserve cooling water system to strengthen the decay heat removal capability. This system consists of a reserve decay heat removal system and a reserve emergency cooling water system including deep-well groundwater pumps.
    - Functional separation of the closed component cooling water system trains and the addition of a fourth pump to this system.
    - Increase in the discharge head of the pumps of the bunkered primary side reserve suppletion system (reserve injection system) to 168 bars.
    - Connection of the bunkered primary reserve suppletion system (reserve injection system) to the pressuriser (spray) to make it easier to decrease pressure in the event of an steam generator tube rupture.
    - Functional separation of the auxiliary and emergency cooling water system trains.
- Replacement of main cooling water pipes by piping qualified as 'leak before break':
    - Replacement of the existing lines inside the containment and annular space (between the inner and outer containment) and partially in the turbine hall by qualified 'leak before break' piping; steam flow limiter at the containment penetration location and guard pipe round steam and feed water lines in the auxiliary building.
- Accident management measures:
    - Replacement of the primary power-operated relief valves (PORV's) on top of the pressuriser to improve the Bleed & Feed capability and to improve reliability in the event of ATWS situations (tandem principle).

---

6 KWU designed a series of pressurized water reactors, classified as design lines in German "Baulinie" often translated as construction line the design lines (DL) go from DL1 to DL4

7 There are 2 more 3 loop KWU reactors in Europe: Gösgen/CH and Trillo/E, which started operation much later in 1979 and 1988 respectively.

8 Neckarwestheim-1, Biblis A&B, Unterweser.

9 At the same time a similar reconstruction program of Euro 256 million was carried out at the German NPP Obrigheim, which was shut down in 2005.

- o Installation of a filtered containment venting system.
- o Installation of a catalytic hydrogen recombiner to enhance the capacity for preventing or mitigating hydrogen burn, deflagration or detonation.
- o Automation of the cooling-down of the primary system by means of steam generators (SG) in case of minor break loss of cooling accidents (LOCA).
- o Replacement of one of the two turbine-driven emergency feed water pumps by a motor-driven pump, to increase the reliability of the emergency feed water system.
- o Installation of check valves on inundation tank lines (low-pressure ECCS) to eliminate a failure mode in sump operation.
- o Complete renewal of the control room.
- o Installation of a new reactor protection system and second control room in a new external events hardened building.
- o Replacement of emergency power diesel generators to increase the electrical output.

The second 10-yearly periodic safety review of 2003 resulted in some fine tuning of the safety concept rather than in major changes. Specific attention was paid to the following items [VROM 2010]:

- International developments and views relating to e.g. back-fitting programs and other reactor designs;
- Aging management, including selection of the Structures, Systems and Components to be reviewed;
- State-of-the-art PSA analyses;
- Evaluation of good practices;
- Safety analyses with respect to external conditions;
- Accident management and severe accidents;
- Fire protection.

The third 10-yearly periodic safety review is foreseen for 2014 [VROM 2010]. The original design of the plant is based on a operating period of 40 years beginning from 1973. Therefore the Dutch utility EPZ must apply for a long term operation (LTO) license. This application should be submitted to the regulators for review in the second half of 2011, in order to complete the procedure before the end of 2013. The LTO project will cover among others (VROM 2010):

- The so called preconditions referenced in IAEA Safety Report Series 57, like adequate programs for maintenance, in-service inspection, surveillance, chemistry and equipment qualification;
- The assessment of design calculations and safety analyses containing time related (40 years) assumptions;
- The aging assessments and aging management programs;
- A number of non-technical issues in the area of organization, administration and human factors.

Long term operating license

As part of the coming periodic safety review the whole set of deterministic safety analyses will be renewed with state-of-the-art thermohydraulic and severe accident codes. The Western European Nuclear Regulator's Association published recently a paper [WENRA 2011] concerning LTO where it is stated that:

` "As for safety, two most common limiting factors for long term operation are identified in WENRA countries: aging of key systems, structures or components (in particular, those that are not replaceable) and fulfillment of modern safety requirements. New reactors will be commissioned which are designed to meet higher level of safety than the existing ones. Despite the fact that existing reactors undergo periodic safety reviews as a result of which safety enhancements are implemented, it is likely that there will remain a difference between the safety level of oldest and newest reactors" [WENRA 2011]

"Whether this difference is acceptable or not in the long term implies not only technical judgment but also political, economical and financial considerations which are clearly out of the scope of the Reactor Harmonization Working Group (RHWG) work. However, the RHWG can provide indications about what is technically feasible and foster harmonization of the regulator's positions on this issue across WENRA countries." [WENRA 2011]

"In periodic safety reviews for existing reactors, WENRA safety objectives for new nuclear power plants and other relevant modern standards should be used as a reference with the aim of identifying reasonably practicable safety enhancements." [WENRA 2011]

Modifcations to improve economical efficiency

Besides safety improvements the economical efficiency of Borssele NPP was enhanced, too. In 2003, the fuel modification was licensed [VROM 2010]. Special emphasis was put on issues associated with high burn-up fuel in relation with prevention of reactivity insertion accidents. The license was updated to allow EPZ to use 4,4% enriched fuel and a burn-up limit for fuel rods averaging 68 MW day/kg U by using the new Niobium-Zirconium cladding material M-5 made by Framatome with an improved corrosion behavior. Up to now the average burn-up of the fuel never exceeded 60 MW day/kg U due to the constraints (heat, radiation) imposed by the specifications of the spent fuel containers. Borssele NPP will conduct additional tests of the fuel quality before switching from 60 to 68 MW day/kg U for the whole core.

In 2006, EPZ increased the Borssele NPP capacity by 35 MWe: The turbine replacement to upgrate the power output by 7.3% from 452 to 485 MWe costed 43 million euro. The project involved a new inner casting, including new rotor blades for the turbine, new water separators, replacement of the turbine's instrumentation control and safety system and replacing the generator stator by way of a precaution.

In July 2011 EPZ has received permission from the government to use mixed-oxide (MOX) fuel at the Borssele nuclear power plant. The Ministry of Economic Affairs, Agriculture and Innovation informed EPZ of its decision to approve its fuel diversification plan in a letter dated 27 June 2011. The draft permit was available to public inspection until 11 August 2011. Unless appeals were lodged with the Administrative Law Division of the State Council by that date, the permit takes effect. EPZ submitted its application in May 2008 to use MOX (with 5.4% fissile plutonium content) as 40% of the fuel load. At that time, the company said that the use of MOX fuel would reduce its dependency on the volatile natural uranium market. As part of its fuel diversification plan for Borssele, EPZ also plans to "improve its use of recycled uranium" which it has been loading into the Borssele reactor for the past few years. The company aims to replace 4.4% enriched fuel with compensated enriched reprocessed uranium (c-ERU) which will be 4.6% enriched to compensate for the U-236 content. Used nuclear fuel from Borssele has been recycled at Areva's La Hague facility in France and a contract exists to continue this until 2015 [WNA news 2011].

Safety culture

According to VROM 2010 safety culture seems to be relevant problem for Borssele:

> "In the years 2004-2006 it was concluded that the safety culture program should have an extra effort. This was based on the increasing number of small incidents and reported incidents to the regulator, but also on the results of evaluations that came to the conclusion that root causes of incidents are mainly work practices, non-compliance with procedures and communication, and that this has been the case for years without improvement." [VROM 2010, Appendix 4]

The NPP Borssele in the Netherlands is the only still operating NPP of the first KWU design lines. And yet plans foresee doubling the operation time of this old reactor to 60 years. Therefore a safety review comparing Borssele with the safety objectives for new nuclear power plant as recommended by WENRA should be carried out during the LTO licensing procedure for Borssele in a transparent manner with participation of the interested public.

Borssele invested in a comprehensive restoration program. Besides safety upgrades measures the program included measures to enhance the efficiency of the plant. These measures certainly are profitable but the use of MOX fuel and longer fuel exploitation (high burn-up) complicates the control of incidents and results in higher radioactive releases in case of an accident.

Safety culture in old plants which are planning long-term-operation must be of high quality, because of the aging processes of different plant components. In LTO regime many small failures occur. Even if each of these faults seems to be minor they must not be neglected.

Borssele invested in a total renewal of the control room and improvement of man-machine-interface, including a process presentation system helpful also in diagnosing emergency situations. Nonetheless safety management and training of people operating and maintaining the plant is of high relevance.

Experience from German NPPs (Krümmel) showed, that deficiencies in safety culture and management result in undetected deficits. A small incident can eventually develop into a severe accident.

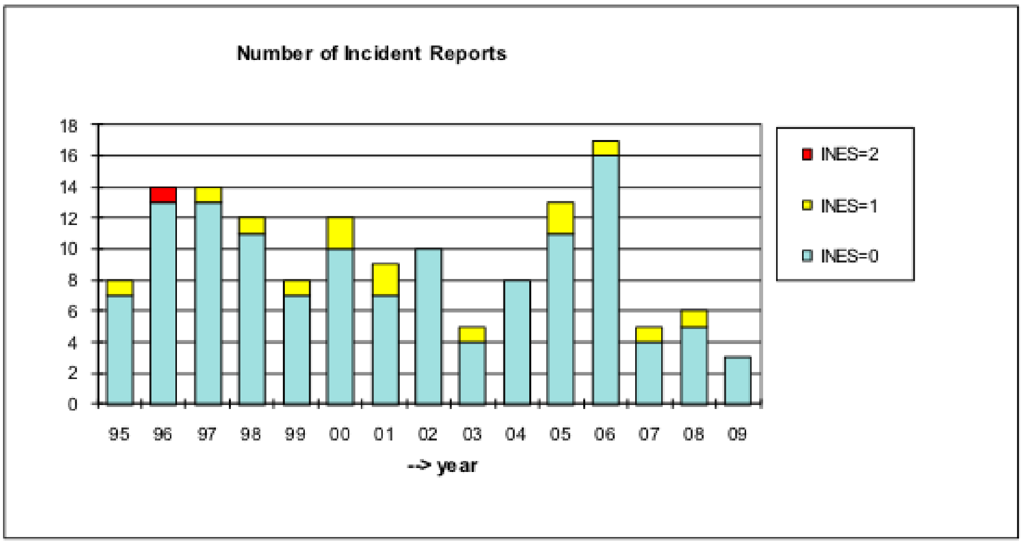

Figure 1: Incident reports [VROM 2010, Annex 1]

3 COMPARING BORSSELE PWR TO GERMAN PWR

3.1 Protection against external impacts

3.1.1 Floods

German KWU PWR

Since 1982, the requirements for flood protection measures have been specified in nuclear safety standard, revised in the years 1992 and 2004. Pursuant to this standard a permanent flood protection is to be provided. Under special boundary conditions, protection against the difference between the water levels of the flood with an exceedance probability value of 10^{-2}/year and the design basis water level of 10^{-4}/year may also be provided by temporary measures.

The sites of the nuclear power plants are mostly located inland at rivers and in some cases at estuaries with tidal influences. In most cases, sites have been selected which are located sufficiently high. In all other cases, the structures important to safety are sealed for water tightness and were built with waterproof concrete. Furthermore, the openings (e.g. doors) are located above the level of the highest expected flood. If these permanent protective measures should not be sufficient, mobile barriers are available to seal the openings [BMU 2010].

The re-examinations on flood protection in the years 2000 to 2002, initiated by the BMU, showed that the plant-specific specifications on the design basis flood as well as on the technical and administrative protection measures generally were in compliance with the safety standards applicable at that time.

In order to standardize the procedure for flood protection the safety standard was revised and has been available since November 2004 in an updated version. The changes compared to the previous version concern in particular the specification and determination of the design basis flood. It is now consistently based on an exceedance probability of 10^{-4}/year. Since then the amended safety standard has been applied to all modification licenses where flood protection is concerned. Moreover, it is used as assessment criterion for any kind of deterministic safety review, e.g. within the scope of the legally required safety review.

NPP Borssele

Flooding is the most important hazard for the Borssele site. Scientists have found out that the sea wall is not strong enough to protect the Borssele NPP in case of a super storm which occurs once every 4000 years. Projectbureau Zeeweringen is reinforcing the dikes of Zeeland. The stone cladding of a dike should be strong enough to safely stem the waves of a superstorm, however the cladding of many dikes along the Oosterschelde and Westerschelde is not strong enough. In case of a so-called superstorm, some stones and concrete could break away. Reinforcement is necessary to protect Zeeland and other parts of the Netherlands against flooding. The Flood Defence Act regulates the sturdiness of dikes and stone cladding. The standard depends on the damage a storm can cause in an area. In Zeeland the safety standard is 1:4000. This means that a dike should be able to withstand a superstorm which could happen once in 4000 years [PZ 2011].

The flood level for vital components is 7.3 m. In 2006 the flood protections of the station blackout (SBO) diesel generators (DG) were increased from 7.3 m to 9.8 m by snorkels fitted to the air inlet [EPZ 2010]. The Ministry announced that the dikes at Borssele will be strengthened in summer 2012.

According to current international design requirements Borssele NPP should be able to withstand at least the ten-millennial flood. This would be an even bigger superstorm exceeding the flood of the superstorm which on average happens once every 4000 years. After strengthening the dikes Borssele NPP should be protected from the four-millenial flood. As long as the dike withstands the flood, the reactor could be safe. But a ten-millennial flood would inevitably lead to a disaster if the dike fails. Than the NPP would be faced with a flood for which it is not designed to withstand.

Even if the station blackout (SBO) diesel generators (DG) are improved, it is not enough to have the SBO diesels running, if there are electric connections in the plant, which could be flooded (e.g. electrical supply connections to the ground water pumps, which are located below the flood level), then removing the residual heat from the core would be impossible. The result could be a core melt accident as in Fukushima.

An example for the problems a beyond design flood creates in a NPP is described in Hirsch et al. 2005 In 1999 a flood caused by the confluence of the rising tide with exceptionally strong winds resulted in the partial submergence of the Blayais site in France. The flood started two hours before the tidal peak. A high water alarm for the Gironde was transmitted to unit 4. It is noteworthy that the information concerning the high level was not transmitted to units 1, 2, and 3. The winds pushed the water over the protective dike. Invading the site through underground service tunnels, the water flooded the pumps of unit 1 essential service water system (ESWS), and one of the two trains (with two essential service water system pumps each) was lost because the motors were flooded. Furthermore, other facilities were flooded; most notably:

- the bottom of the fuel building of Units 1 and 2 containing the rooms of the two low head safety injection pumps and the two containment spray system pumps. The nuclear operator considered that the pumps were completely unavailable.
- some utility galleries, particularly those running in the vicinity of the fuel building linking the pump house to the platform;
- some rooms containing outgoing electrical feeders. The presence of water in these rooms indirectly led to the unavailability of certain electrical switchboards.

3.1.2 Earthquake

German KWU PWR

The earthquake design of components is in accordance with the site specific load assumptions for all design lines [BMU 2010]. The design basis earthquake has the largest intensity that, under consideration of scientific findings, could occur in a wider vicinity of the site up to a radius of about 200 km. Depending on the site, the intensity of the design basis earthquake varies between less than VI and a maximum of VIII on the MSK scale. In the power plants of older construction lines, the seismic qualification of civil structures, components and plant equipment was partly based on simplified (quasi-static) methods which delivered the basic values for the corresponding design specifications. In more recent nuclear installations the newly developed dynamic analyses were also applied [BMU 2010].

For some nuclear installations at sites with considerable seismicity a re-evaluation of the seismic safety has been performed due to the ongoing development of methods for seismic hazard analysis and for design verification. In general, the re-evaluations with regard to the design of components showed that, on the basis of more precise seismic input and modern verification methods, the technical equipment of the plants partly has considerable margins with respect to seismic loading. At plants for which a need for upgrading was identified despite of this, comprehensive safety retrofits were performed on the basis of these re-evaluations.

NPP Borssele

An earthquake was not considered in the original Borssele design as in all other KWU reactors of this age. In the EPZ progress report of August 2011 it is stated that extensive earthquake measures have been implemented as part of the backfitting project of 1997 [EPZ 2011]. Earthquake protection is not mentioned in all other documents, and the progress report gives no details on these measures.

The design basis earthquake[10] (DBE) of Borssele according to the license is MSK VI with a peak horizontal acceleration (PGA) of 0,06g. This is nonconforming with the actual IAEA's (International Atomic Energy Agency) recommendation for a minimum design basis earthquake of PGA = 0,1g. Even if the earthquake risk at Borssele is assumed to be low, a re-evaluation of the design earthquake according to state-of-the-art methods should be considered. At several NPP sites worldwide, the design quake estimated decades ago was found to be insufficient based on new scientific insights.

For German NPPs basic design safety is proven for an earthquake with a frequency of occurrence exceeding > 10^{-5}/year. Following the assessment of German NPP's according to the German stress test [RSK 2011] the plant should have safety reserves to resist a quake of 1 or 2 higher levels of intensity. For achieving the highest safety level an earthquake of 2 levels higher than the design earthquake should be practically excluded.

3.1.3 Aircraft crash

German KWU PWR

Aircraft crashes and pressure waves from explosions have not been considered in the design of line 1 and 2. Design line 2 has a different design and separated emergency systems and line 3 and 4 have a design where emergency systems are integrated in the safety system [BMU 2010].

Protection against aircraft crashes concerns the accidental crash of a military aircraft onto safety-relevant plant areas. The protection measures were taken against the background of the increasing number of nuclear power plants in Germany in the 1970s and a high crash rate of military aircrafts in those years. The general basis was the analysis of the crash frequency (the exceedance probability for impacts on safety-relevant buildings is about 10^{-6}/year and plant) and of the loads on the reactor building that would be caused by such a crash. From the mid-1970s onwards, load assumptions were developed for the event of an aircraft crash which were then applied to the design of preventive measures in the nuclear power plants built in the following years for further risk minimization. Since the end of the 1980s, the crash rate of military aircraft has decreased considerably. This has the effect that the crash frequency today can be assumed to be smaller by about one order of magnitude.

For older design lines, protection by system design against the consequences of a small military

10 DBE: seismic level 2 guarantees safe shutdown of the plant and removal of decay heat.

aircraft (Starfighter) crash was improved by the design of buildings and components in interaction with additional auxiliary emergency systems physically separated from the actual reactor building. The second-level emergency systems can ensure the safe confinement of radioactive material in the reactor even if important plant components would be destroyed due to external hazards. The spatial arrangement of the buildings ensures that the safety systems and equipment located in the central reactor building and in the second-level emergency systems do not become inoperative due to the postulated events at the same time. The effectiveness of the protection of these plants against aircraft crashes was demonstrated by subsequent reviews of the design margins of the safety-relevant buildings and extended within the framework of back-fitting measures. New buildings were designed according to the increased requirements and the measures against induced vibrations improved.

For the newer German KWU PWR design lines, the design against airplane crashes of a bigger military plane (Phantom) covered not only the reactor building itself but also the structures containing systems necessary for the control of this external hazard (e.g. the emergency feed-water building in newer PWRs). Furthermore, protective measures were taken to account for the vibrations in components and internals induced by pressure waves from aircraft crash, e.g. by uncoupling the ceilings and inner walls from the outer wall or by a special design [BMU 2010].

The design differences between old and newer German reactors regarding accidental crash of military aircraft onto a NPP result in different protection levels against deliberate terror attack with a commercial aircraft.

Because of the fact that the wall thickness of the older constructions lines 1 and 2 is only 0.60 to 1 meter, the vulnerability of the reactor building is very high. The reactor building of construction lines 3 and 4 have a wall thickness of 1.60 to 2 meter.

NPP Borssele

In the progress report of EPZ [EPZ 2011] information is given on the location of airports near the Borssele site:

- The Airport Midden Zeeland is situated at about 10 km north of the site. This airport is intended for small civilian aircrafts with a maximum weight of less than 5.7 ton.
- For large civil aircrafts with a maximum take-off weight of more than 5.7 ton[11], the so-called en-route flying must be carried out in prescribed airways.
- The airway A5 for flights from southern direction to Schiphol Airport and airway B29 for flights from Brussels to London are located 20 km east respectively and 20 km south of the NPP.
- The closest military airbase is at a distance of 40 km

Aircraft crashes have not been considered in the design of the first KWU PWRs The Borssele containment has a wall thickness 0.60 m, which corresponds to the German design line 1 reactors. These withstand the aircrash of a small military plane.

In Borssele separated trains of safety systems are at different locations, as the two bunkered diesel generators and pumps and there are also redundant systems for decay heat removal. But from the published documents it cannot be proved whether all redundant trains are totally physical separated. According to the CNS report [VROM 2010] it is not clear if all essential emergency systems are fully functional and physical separated.

The vulnerability of Borssele concerning air plane crashes is probably the same as for the old German PWR's of design line 1: withstanding only the accidental crash of the small military plane.In the EPZ progress report [EPZ 2011] the next airport is10 km from the plant, it is intended for small civil airplanes (maximum weight < 5.7 tons). Flight corridors for commercial aircraft are said to be in a distance of 20 km from the NPP and the closest military base is in a distance of 40 km. Restricted area for military air traffic has a diameter of 7.2 km and a height of 500 meters. Flight exclusion zones can mitigate the risk of an accidental aircrash impact to the NPP, but they are no protection against a terror attack.

3.1.4 Terror attacks and explosions outside the NPP

11 A large commercial airliner (A320) has a minimum weight of 40 tons and up to 80 tons with fuel .

German KWU PWR

The requirements for protecting nuclear power plants against pressure waves from chemical explosions in case of an accident outside the plant area were developed in the 1970s based on specific situation of nuclear power plants located on rivers with corresponding ship traffic and transport of explosive goods. The load assumptions - based on a maximum overpressure of 0.45 bar - are specified in regulatory guidelines and are applied since its publication independently of the individual site. Furthermore, with respect to possibly larger peak pressure at the accident location itself, a sufficient safety distance is kept from potential sources of explosions (e.g. traffic routes, industrial complexes).

NPP Borssele

The Borssele site is situated in an industrial region where also an industrial harbor is located. A cargo ship gas explosion makes up a significant portion of the risk to Borssele NPP. In the distance of 3 km from the Borssele site an oil refinery, a phosphor production and an aluminum industry is located. In a distance of 500 m to the NPP are a railway line and a road.

In the second 10-yearly periodic safety review from 2003 equipment to deal with gas clouds from industrial or transport accidents near the plant was installed at the NPP site boundary: detectors and igniters which shall counteract external gas clouds.A gas explosion could, for example, damage the reactor building, debris penetrating the steel containment could fail the primary systems. The gas explosion could also cause the demolition of the bunkered buildings where the diesels and pumps for station blackout are located. In this case no systems are available to mitigate the accident resulting in a core melt accident. Older German PWR containments are not designed for more than 0.45 bar, caused by a pressure wave created by explosive gas mixtures.

However, impacts of hydrogen detonation could create a pressure wave a factor 10 to 20 higher [RSK 2011]. For this reason, the German Reactor Safety Commission recommended a re-evaluation of the protection capability of the NPPs. Several different hazards are possible: fire, smog, toxicity, explosions. An explosion could be also caused by terrorists.

In case of Terrorists hijacking an aircraft and targeting the plane into the NPP the attack could result in major damage to the plant, because the containment is not able to withstand the impact of a commercial aircraft which has a minimum weight of 40 tons.

3.2 System failures

3.2.1 Containment

German KWU PWR

The principal design of the KWU PWR containment is for all design lines the same: a spherical steel vessel with surrounding concrete enclosure, annular gap and internal subatmospheric pressure. Differences exist in the design parameters as is shown in table 1 [BMU 2010].

	DL1	DL2	DL3	DL 4
Design pressure in bar	3 (1 NPP) 3.8 (1 NPP)	4.7	5.3	
Temperature in °C	125 (1 NPP) 135 (1 NPP)	135	145	
Containment wall in m	0.6 – 1.0		1.6 -2	
Wall thickness of steel vessel in mm	≤ 25 (1 NPP)	≤ 29	≤ 38	

Table 1 design parameters [BMU 2010]

German Konvoi PWR's (design line 4) have a single concrete shell (reactor building) with thickness of about 2 m, plus a separate steel shell inside. Newer Generation II reactors often have a double containment. Current French PWR's of the type P4, P'4 and N4 have a double containment with the following wall thicknesses: inner hull 0.9-1.2 m (cylinder), 0.9–0.95 m (dome); outer hull 0.55 m (cylinder), 0.4 m (dome) [COSTAZ 1983]. For the Russian VVER-1000/V466, the wall thickness of the inner hull is reported as being 1.2 m (cylinder), 1.0 m (dome); for the outer hull as between 0.6 and 2.2 m [NEK 2004].

Borssele NPP

The containment of Borssele NPP consists of a spherical steel vessel (25 mm) with a surrounding concrete enclosure with wall thickness 0,60 m. This containment was improved in the first 10-yearly periodic safety review (1993) by:

- Installation of a filtered containment venting system.
- Installation of catalytic hydrogen recombiners to enhance the capacity for preventing or mitigating hydrogen burn, deflagration or detonation.

The same modernization measures as in Borssele have been implemented at the German PWRs. But these measures are no compensation for the weakness of the structure. In case of an accident in an old reactor earlier and more often a release of pressure is needed in order to keep the containment intact. Each pressure release causes a release of radioactive gases and particles into the environment. As far as active components are used, failures of these components and a consequential containment breach cannot be excluded. An example for such negative consequences is that venting can cause hydrogen explosions in the reactor building as happened in Fukushima. The containment of the German reactors of the similar age and design line are not able to withstand the crash of a commercial airplane; at best they withstand a crash from a small military plane (Starfighter).The major weakness of NPP Borssele, which cannot be upgraded, is the containment. This concerns mainly impacts from external natural and man-made events.

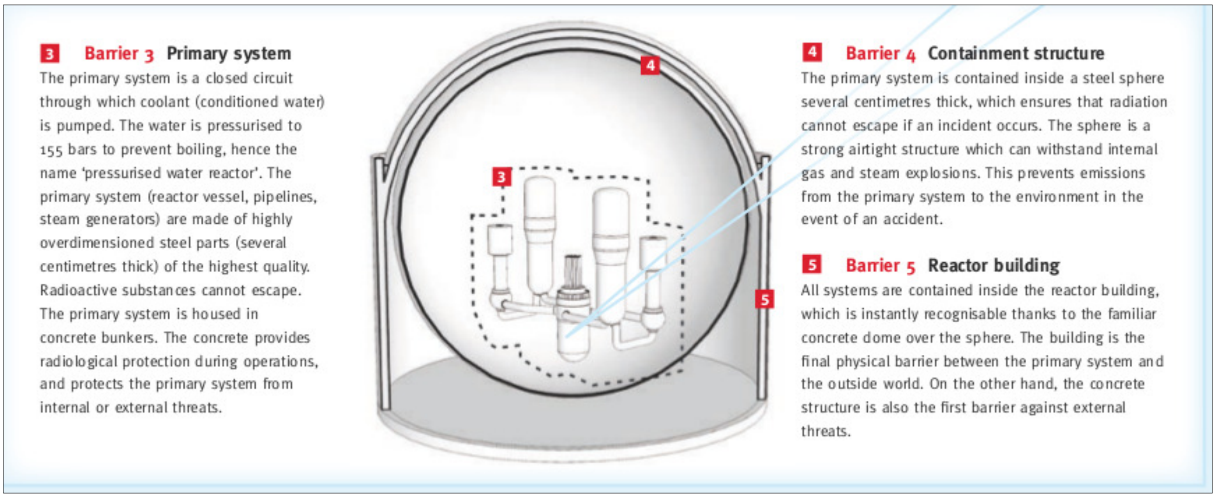

Figure 2: Containment structure and reactor building [Source: EPZ 2010]

3.2.2 Electric power supply

NPP's are dependent on a continuous electric power supply, even when they are not operating. Heavy storms can lead to multiple damage of the transmission lines, and hence to loss of off-site power. But the grid could also collapse due to a regional overload. If load rejection via the turbine control fails, an automatic scram shuts off the reactor, and the emergency diesel generators (EDG) start automatically.

Every nuclear power plant has emergency power supplies. These generators provide power to supply emergency pumps, valves, fans, and other components that are required to operate to keep the plant in a safe state (removal of the residual heat).

Apart from the diesel generators, there are also batteries that supply direct current in case of an emergency; however the batteries cannot provide electricity for large components such as pumps and have only very limited capacity (typically for about 2 hours).

German KWU PWR

In principal the design of KWU PWR provides at least three independent off-site power supplies, auxiliary station supply in case of off-site power loss and emergency power supply and protected DC power supply for two hours [BMU 2010].

	Design line 1 and 2	Design line 3 and 4
Emergency power supply (EPS)	2 trains with 3 diesel generators (DG)	4 trains with 1 DG each
Additional for external impacts	2 trains	4 trains with 1 DG each
Uninterruptible DC power	2 x 2 trains	3x 4 trains
Separation of trains	Intermeshed EPS physical separation of the EPS grids	Largely not intermeshed EPS physical separation of the EPS grids

Table 2: electric power supply [BMU 2010]

NPP Borssele

Two adjustments where made to the power supply system of Borssele NPP after construction in 1973:

- Replacement of emergency power diesel generators (EDG) to increase the electrical output after the first 10-yearly periodic safety review (1993).
- Increasing the supply of diesel oil in the bunkered systems from 24 hours to 72 hours after the second 10-yearly periodic safety review (2003).

Borssele contains batteries for the no-break power supply with a capacity for at least 2 hours. Borssele has three identical 4.3 MW EDG's located around the nuclear plant. Each of these three EDG's is able to provide enough power to remove the decay heat from the core. In 1986, two extra 'station blackout' diesel power generators (SB DG) were built in bunkers. Each of these 0.85 MW DG can keep the NPP in a safe controlled state [EPZ 2010].

Flooding is the largest contribution to core damage frequency at Borssele. If the 3 EDG's fail, the two bunkered SBO diesels should be able to keep the plant in a safe state. With the current amount of diesel fuel the plant can sustain 72 hours, within which a refilling of the diesel tanks should take place. However, in case of a dike break which is likely to be accompanied by harsh weather conditions and the plant surroundings being flooded, this refilling cannot be guaranteed [NEA 2007].

Without electricity the operator looses instrumentation and control of the reactor, leading to an inability to cool the reactor core. Counter measures (accident management) are practically impossible. If the blackout lasts for a long time, not only the reactor, but also the fuel in the spent fuel pool can overheat, leading to radioactive releases [Hirsch et al. 2005].

A lesson from Fukushima is that in an extreme flooding, the emergency equipment at the plant site itself could be hit by the flood or the emergency crew cannot reach and use it.

Inside the plant electrical connectors and electronic control devices could be damaged by humidity and water thus (shortcut) interrupting power supply for the core cooling pumps.

3.2.2 Water supply

Water is needed in the NPP for cooling the reactor core and the spent fuel pool. In a PWR water is used in the steam generators. Water is also used to cool pumps, condensers and heat exchangers. Several systems are used for emergency cooling and for injection of borated water to control the fission process. Water supply is as essential as electricity supply in a NPP.

Cooling is necessary not only if the NPP is operating at power, but also after shutdown. If the plant can not be cooled after shutdown, the temperature of the fuel increases and if cooling can't be restored the fuel will be overheated and start melting – as in Fukushima.

German KWU PWR

Emergency core cooling systems in German PWR have 4 trains of at least 50% capacity in all PWR. For flooding the core with borated water at least 3 tanks are provided in design line 1. In design line 2-4 there are 4 twin tanks.For emergency water injection into the core 1 hydro-accumulator is provided per loop in design line 1. In design line 4 there are 2 per loop.The main water supply of the NPP is provided by the cooling water intake building. Destruction of the cooling water intake building alone already has the effect that all cooling chains of the power plant are interrupted. However, a critical situation is slow to develop in this case, since there are various water reservoirs available at the plant area. Thus, there is time for improvised measures – unless those are hindered by further destructions at the site. It is a lesson from Fukushima that an alternative water supply could be a good investment for emergency situations.

NPP Borssele

We understand that EPZ has implemented several effective safety upgrades. As result of these measures Borssele has several redundant cooling systems for emergency, some with diverse equipment and power supply.

During the first 10-yearly periodic safety review (1993) the following upgrades were implemented [VROM 2010]:

- Functional and physical separation of redundant ECCS trains.
- Addition of a single train reserve cooling water system to strengthen the decay heat removal capability. This system consists of a reserve decay heat removal system and a reserve emergency cooling water system including deep-well groundwater pumps.
- Functional separation of the closed component cooling water system trains and the addition of a fourth pump to this system.
- Increase in the discharge head of the pumps of the bunkered primary side reserve injection system to 168 bars.
- Connection of the bunkered primary reserve injection system to the pressurizer (spray) to make it easier to decrease pressure in the event of an steam generator tube rupture.
- Functional separation of the auxiliary and emergency cooling water system trains.
- Replacement of one of the two turbine-driven emergency feed water pumps by a motor-driven pump, to increase the reliability of the emergency feed water system.
- Installation of check valves on inundation tank lines (low-pressure ECCS) to eliminate a failure mode in sump operation.

During the second 10-yearly periodic safety review (2003) the following upgrades were implemented [VROM 2010]:

- Installation of improved seals for the pumps in the low pressure injection system;
- Installation of a second reserve cooling water (TE) pump;
- Automatic starting of the bunkered primary reserve injection system if the level in the RPV becomes too low during midloop operation[12];

Borssele has an alternative water supply for removal of the decay heat from the core and for the spent fuel pool by well water. This is very important as the cooling water intake building is not earthquake resistant.

The description of the back-fitting program shows that physical separation of redundant systems is not an overall design principle; this might be due to former requirements and plant design, which does not allow for additional spatial separation. This could prove to be a serious disadvantage because a failure in an essential system could simultaneously disturb the redundant system, too.

However, none of those measures can work reliably under conditions like internal or external flooding

12 During certain phases of the shutdown period, maintenance operations be performed while the water level in the primary system is lowered. The water level may be reduced to the mid-point of the outlet leg (hot leg) of the primary coolant system, and thus the term midloop applies.

unless all systems and components are waterproof. In particular electrical and electronic devices are vulnerable to water and humidity and might fail. An external flooding of the plant site could make refilling the SBO diesels impossible, which would be necessary if the site stays underwater longer than 3 days (72 hours).

3.2.3 Reactor coolant pressure boundary

In the main cooling system of a pressurized water reactor coolant has high temperature and is under high pressure, which prevents boiling of the cooling water in the reactor core. All parts of the primary cooling system are under high pressure, including the primary side of the steam generator. The components of this system have to safely enclose the radioactive cooling water under high temperature and pressure. Qualification on the material of the components must be high.

German KWU PWR

The pressure boundary of design line 1 and 2 has several disadvantages compared to state-of the-art PWR. Most of the disadvantages are due to material used which is of lower quality compared to later design lines:

- Seamless forged rings are standard for reactor pressure vessel (RPV), steam generator (SG) and pressurizer in design line 3 and 4, but is restricted in design line 1 and 2; (pressurizer and SG secondary side do not achieve this standard)
- Seamless pipes in the whole main coolant line are standard in design line 3 and 4 PWRs, design line 1 and 2 has some restrictions in this respect.
- Material quality of big pipes (diameter Ø > 400 mm) in design line 1-3 reactors are of lower quality compared to design line 4.
- The original SG tube material in desing line 1 is not as corrosion resistant as in later design lines
- Non-destructive testing suitability is restricted in design line 1 and 2
- Application of the break preclusion concept has not been included in the design of design line 1, but afterpost commissioning qualification is used.
- Reduction of neutron flux embrittlement of RPV has to be provided by dummy elements which protect the reactor vessel wall. Later design lines use optimized materials and welding as well as a wider water gap in the RPV.

NPP Borssele

Borssele is an old plant. Material deficiencies and aging phenomena of vessels and pipes could cause cracks and breaks, which could induce events eventually resulting in accidents. A singular pipe break can most likely be controlled and a release into the environment prevented. However, each leak of radioactive coolant causes contamination and additional exposure to plant personnel.

Incidents caused by fire, shortcut or explosion are specific loads which can create cracks in the pipes. This can lead to partial or complete system failure and cause a severe accident.

There are no improvements mentioned in the CNS Report by VROM (2010).

4 SEVERE ACCIDENTS

Probabilistic Safety Assessment

During several years Borssele has carried out a comprehensive Probabilistic Safety Assessment (PSA) in 3 Levels. PSA is used to calculate the probability of damage to the core as a result of sequences of accidents identified by the study. PSA's can also be used to assess the size of radioactive releases from the reactor building in the event of an accident, as well as the impact of such releases on the public and the environment. These studies are referred to as level 2 and level 3 PSAs respectively (level 1 corresponding to the assessment of the risk of a core damage). Level 3 analyses are used for emergency planning. A PSA analyses the generation and consequences of failures in the complex system of the NPP and can be used to find out the week points of the plant.

The first PSA was carried out at Borssele between 1990 and 1994 followed by a model update in 2004. In general a PSA results also in some probabilistic indicators which can be used to compare the safety of NPP's: core damage frequency (CDF), early and late large release frequency (LRF) and for Borssele the life time individual risk.

As a consequence of the PSA's severe accident management measures have been implemented at Borssele During the first 10-yearly periodic safety review (1993):

- Replacement of the primary power-operated relief valves (PORVs) on top of the pressurizer to improve the Bleed & Feed capability and to improve reliability in the event of an accident for which the initiating event is an
- anticipated operational occurrence in which the fast shutdown system of the reactor fails to function.
- The relief valves are used to reduce overpressure in the core cooling system. To improve the reliability of the PORVs function the valves must be able to open and close safely with water, steam and a mix of both.
- The number of PORVs has been reduced, thereby reducing the LOCA frequency due to spurious PORV opening
- Complete renewal of the control room
- Installation of a new reactor protection system and second control room in a new external events hardened building.
- Automation of the cooling-down of the primary system by means of steam generators (SG) in the event of incidents or accidents such as minor break LOCAs.

During the second 10-yearly periodic safety review (2003):

- Duplicating the control panel of the fire extinguishing system for the main coolant pumps located in an area outside the containment.

Probabilistic safety analysis is often used to verify the safety status of a plant. It also can help to find out the weaknesses of the NPP and thus indicate potential improvements. These improvements had a positive impact on safety of the Borssele plant; as it is documented by the PSA results. Core damage frequency (CDF) has decreased from about 10^{-3}/year to 2.65 10^{-6}/year.

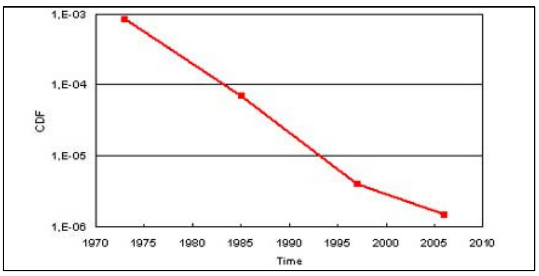

Figure 3: Changes in core damage frequency as a result of safety improvements [ENS 2007]

Major weakness of Borssele NPP concerns external impacts. The dominant contributors to the total CDF are the flooding scenarios. This is the result of the relatively large failure rate of the surrounding dikes and the fact that with the current amount of diesel fuel the plant can sustain 72 hours, within which a refilling of the diesel tanks should take place. In the second 10-year review period the diesel supply in the bunkered system was increased to serve 72 hours [EPZ 2010]. Because dike failure is likely to be accompanied by harsh weather conditions and together with the surroundings being flooded, this refilling cannot be guaranteed [NEA 2007].

In the power operating status of the plant upon loss of all cooling, core uncovery comes between one and a half and three hours after the initiating event, with vessel breach at 5 to 16 hours. The containment does not over-pressurize, even during a loss of coolant accident (LOCA), until after 5 to 6 days. Additionally, success of one pump of the bunkered primary reserve injection system is sufficient to delay the onset of core damage.

Results of PSA Level 2 are published in [NEA 2007]: early releases account for 1.5% of total release frequency, with induced failure of steam generator tubes contributing to 60% of these cases. Leakage of the containment occurs in 30% of these cases. Containment rupture in the early phase is dominated by external events, which fail containment directly and account for 5 % of the early releases. An early failure of the containment results probably in a large release of radioactive substances.

WANO mission 2011

In March 2011 the World Association of Nuclear Operators (WANO) launched a verification process of the capabilities to mitigate conditions that result from beyond design base accidents (BDBA). Findings and recommendations for NPP Borssele are documented in the Significant Operating Experience Report [SOER 2011-2]. The following gaps were found and should be closed until end of 2011:

- The bunkered high pressure (HP) emergency core cooling systems (ECCS) pumps are not routinely tested for cases where the highest pressure is required.
- Availability of required key to unlock chains (used to lock safety related valves in the required position for the actual plant status) is not guaranteed.
- H3BO3 stock (in bags), related to refilling the bunkered ECCS tanks, could be lost after flooding.
- Radiation shielding material is stocked near ground level and could be lost after flooding.
- On-site transportable DG could be lost due to the storage location, which might prove to not be safe enough e.g. in flooding situations
- Power recovery procedure has to be updated to reflect the current plant design.
- Accumulator injection valves are automatically closed to prevent N2 injection into the primary system. A step by step work instruction to bypass this automatic interlocks (in case N2 is required for inertisation) is not available.
- Spent Fuel pool is inside the containment. Procedure for refilling the spent fuel pool without entering the containment is feasible but required materials and methods are nor defined
- Dedicated fuel depots are sufficient to run all 5 diesel generators for 72 hours. Other fuel depots are available close by, however detailed operating instructions are lacking.
- Flooding resistance of the electrical supply connections to the deep well (ground water) pumps, used for the alternative heat sink, is not verified under the surveillance program.
- The wall, a part of the flooding barrier for the auxiliary reactor building, contains an undocumented and untagged seal, which is opened during outages; the flooding resistance is lower when this seal is open or not correctly closed.
- Check valves used for the level protection of the cooling water intake building are not part of the tests required under the surveillance program
- All installed fire suppression systems can fail as a result of seismic events. The same is true for the on site fire trucks and crash tender, as storage locations (buildings) and water tanks are not designed to withstand these seismic events. Damage from fire after seismic events is limited by fire barriers and the redundant and independent design of the relevant

buildings and safety systems. Their operability is monitored by the surveillance program.

- Principal equipment designed to mitigate flooding will also withstand the design seismic event for the site. The plant water intake building is not designed to withstand seismic events, therefore only the alternative heat sink is taken into account as a mitigation measure.

EU stresstest specifications

Major weakness of the Borssele NPP concerns external impacts. The dominant contributors to the total core damage frequency (CDF) according to the probabilistic safety assessment (PSA) are external events (67.5%), particularly flooding scenarios.Early releases account for 1.5% of total release frequency contributing to 60% of these cases. Even if early releases are unlikely to occur, they would have the biggest impact on environment and health.

A lesson learned from the accident at Fukushima shows that fuel supply for the diesel generator's operation of 72 hours is no guarantee to keep the plant in a safe state..In the progress report EPZ presents a new version of the PSA [EPZ 2011] with results very different from the results given in NEA 2007.

	EPZ 2011	**NEA 2007**
CDF (for power operation)	1.02 10^{-6}/a	2.16 10^{-6}/a.
Internal hazards in % of total	92 %	19 %
External hazards in % of total	8 %	81 %

Table: Comparison of CDF results of the PSA from 2011 and 2007. Low power and shutdown states contribute about 20-30 percent to the total CDF.

In the EPZ progress report it is stated that:

> "The external events PSA has been conducted based on a successive screening process. First, the external events scenarios were identified, the initiating event frequency quantified, and the impact on the plant determined. If the frequency was low, then the scenario has been screened out. If the frequency was above the truncation frequency, then the plant response and other factors were considered."

If screening out the severe external impact scenarios justifies the minor role of external impacts by the PSA results in EPZ 2011, this is a misinterpretation of the ENSREG (European Nuclear Safety Regulators Group) stress-test specifications which claims:

> "The approach should be essentially deterministic: when analyzing an extreme scenario, a progressive approach shall be followed, in which protective measures are sequentially assumed to be defeated. The plant conditions should represent the most unfavorable operational states ..." [ENSREG 2011]

The operator of the German NPP Unterweser had assumed that the dike protecting the plant from flooding could not break because of a low frequency of occurrence. The German nuclear safety authority had not accepted this screening out and demanded an analysis. Meanwhile the plant has been finally shutdown.

A lesson from the Fukushima accident is that extreme external events (flood, earthquake, extreme weather) can challenge a nuclear power plant. Extreme events can result in cliff edge effects. The ENSREG stress test is to find out the robustness of the plant, the cliff edge effects which could threaten the plant's safety and the time the plant can be safe without support from outside. Therefore, an unlikely event cannot be excluded solely based on probabilistic assessments. This is even more valid, as insecurities of probabilistic risk analyses can amount to a difference of one or two orders of magnitude for the internal events alone. Moreover such analyses always remain incomplete, because not all relevant factors can be included.

Fukushima is a proof that exclusion criteria, which are based on low probability of occurrence only, must be supported by additional deterministic safety assessments. More attention needs to be devoted to event chains of external impacts; in particular cumulative effects caused by common mode failure (including the failure of several systems) will have to be assessed.

After Fukushima a WANO mission published the Significant Operating Experience Report of Borssele, which named 15 gaps regarding capabilities to mitigate conditions that result from beyond design base accidents.

Even if most of these gaps could be closed in time and the procedures will be defined properly, design deficiencies and aging problems remain unsolved. Therefore Borssele will hardly achieve a modern safety standard.

5 REFERENCES

BECKER (2009): Becker Oda; Studie zu den Gefahren von Laufzeitverlängerungen; erstellt im Auftrag des BUND.

BMU (2010): Convention on Nuclear Safety - Report by the Government of the Federal Republic of Germany for the Fifth Review Meeting in April 2011 Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) Division RS I 7, Nuclear Regulatory Framework, Multilateral Regulatory Cooperation , Bonn 2010, Website: www.bmu.de/english

COSTAZ (1983): Costaz, J.L et al.: Evolution of the Concrete Containment in the French PWR Program; Transactions of SMiRT 7 – 7th International Conference on Struc-tural Mechanics in Reactor Technology, Chicago, IL, August 22–26.

DELTA (2008): Working together with water - A living land builds for its future: Findings of the Deltacommissie 2008.

ENS (2007): European Nuclear Society, e-news Issue 17; http://www.euronuclear.org/e-news/e-news-17/borssele.htm

ENSREG (2011): European Nuclear Safety Regulators Group; EU "Stress tests" specifications, 2011

EPZ (2010): "Clear as a cristal ball..". http://www.kerncentrale.nl/

EPZ (2011): Progress Report – Complementary Safety margin Assment; August 15 2011 www.kerncentrale.nl/media/downloads/Progress-report-CSA.pdf

IAEA (2003): SAFETY STANDARDS SERIES No. NS-G-1.6 Seismic design and qualification for nuclear power plants : safety guide. —Vienna : International Atomic Energy Agency, 2003.

IAEA (2008): Safety Reports Series No. 57: Safe Long Term Operation of Nuclear Power Plants International Atomic Energy Agency, Vienna 2008

HIRSCH et al. (2005): Nuclear Reactor Hazards - Ongoing Dangers of Operating Nuclear Technology in the 21st Century Report Prepared for Greenpeace International by by Helmut Hirsch, Oda Becker, Mycle Schneider, Antony Froggatt; April 2005

NEA (2007): NEA/CSNI/R(2007)12 , Nuclear Energy Agency- Committee on the Safety of Nuclear Installations: Use and development of probabilistic safety assessment - CSNI WGRISK 2007

NEK (2004): Bulgarian National Electric Company (NEK): Investment Proposal for Construction of Belene Nuclear Power Plant; Environmental Impact Assessment Report BNPP-EIA-PEC-NEK-0001-E3, March 2004.

PZ (2011): Projectbureau Zeeweringen- http://www.zeeweringen.nl/english/,

RSK (2011): Anlagenspezifische Sicherheitsüberprüfung (RSK-SÜ) deutscher Kernkraftwerke unter Berücksichtigung der Ereignisse in Fukushima-I (Japan); Reaktorsicherheitskommission beim BMU

VROM (2010): Convention on Nuclear Safety National Report of The Kingdom of the Netherlands; To be presented at the Fifth Review Meeting (April 2011) Ministry of Housing, Spatial Planning and the Environment , Ministry of Social Affairs and Employment ,. Ministry of Economic Affairs , Ministry of Foreign Affairs , Ministry of the Interior and Kingdom Relations, The Hague, September 2010

WANO (2011): World Association of Nuclear Operators - Fukushima Daiichi Nuclear Station Fuel Damage Caused by Earthquake and Tsunami Response Template- (SOER 2011-2):Station Borssele: http://www.kerncentrale.nl/

WENRA (2011): Pilot study on Long term operation (LTO) of nuclear power plants; Study by the Western European Nuclear Regulator's Association- Reactor Harmonization Working Group, March 2011

6 ACRONYMS

CDF	Core damage frequency
DL	Construction line
CNS	Convention of nuclear safety
DG	Diesel generator
ECCS	Emergency core cooling system
EPS	Emergency power supply
LOCA	Loss of coolant accident
LTO	Long term operation
NPP	Nuclear power plant
POS	Plant operational state
PSA	Probabilistic safety assessment
PSR	Periodic safety review
PWR	Pressurized water reactor
RHRS	Residual heat removal system
RHWG	Reactor Harmonization Working Group (WENRA)
RPV	Reactor pressure vessel
SBO	Station black out
SG	Steam generator
SGTR	Steam generator tube rupture
SSC	Structures ,systems and components
TE	2. reserve cooling water
TW	Reserve injection system
WANO	World Association of Nuclear Operators
WENRA	Western European Nuclear Regulator's Association