The VGB Technical Committee “Nuclear Plant Operation” has been exchanging operating experience about nuclear power plants for more than 30 years. Plant operators from several European countries are participating in the exchange. A report is given on the operating results achieved in 2016, events important to plant safety, special and relevant repair, and retrofit measures from Belgium, Germany, Finland, the Netherlands, Switzerland, and Spain.

In 2016 the German nuclear power plants generated 84.63 billion kilowatt hours (kWh) of electricity gross. No nuclear power plant ceased operation in 2016 due to the revision of the German Atomic Energy Act in the political aftermath of the accidents in Fukushima, Japan, in 2011. Eight nuclear power plants with an electric gross output of 11,357 MWe were in operation on 31 December 2016 (in 2015, see Table, including KKG Grafenrheinfeld, nine plants: 12,702 MWe).

Six power plants in operation until 31 December 2016 achieved operating results with a gross production greater than 10 billion kilowatt hours and again four power plants even produced more than 11 billion kilowatt hours.

German nuclear power plants (see also page 88) achieved three of the world’s ten best production results in 2016. At the end of 2016, 450 reactor units were in operation in 31 countries and 65 were under construction in 15 countries. With 450 units the most quantity of plants has been in operation for the first time in the history of peaceful use of nuclear power in energy generation than in any other year before. The share of nuclear power in world electricity production was around 11 %. German nuclear power plants have been occupying top spots in electricity production for decades thus providing an impressive demonstration of their efficiency, availability and reliability.

The Palo Verde 2 nuclear power plant in the United States of America (capacity: 1,414 MWe gross) achieved the world record in electricity production in 2016 with 12,495,000 MWh. The German nuclear power plants Isar 2 (KKI 2, 11,990,925 MWh) Brokdorf (KBR, 11,503,003 MWh) and Neckarwestheim II (GKN II, 11,391,770 MWh) took the third, sixth and eighth place.

*The reports with additional operating results of European nuclear power plants will be published in a further issue of atw.

German nuclear power plant

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The Brokdorf nuclear power plant remained in constant power operation with the exceptions of the annual outage and an 11.5 h period to repair a leakage on the generator circuit breaker AQ01H001. On order of the grid operator grid supporting services were often provided. With an annual output of 11,503,003 MWh (gross) Brokdorf nuclear power plant achieved a top result.

Planned shutdowns
The plant was shut down on 11 June 2016 after a 21-day stretch-out operation for the 28th overall maintenance inspection and refuelling.
Focus points were:
- Reactor cooling system
  Complete core discharge, inspection of fuel elements, etc., plug testing DE10, eddy current testing DE30/40.
- Reactor coolant pumps YD10
  Ring exchange of e-motor at main coolant pump, eddy current testing of pump shaft, inspection of the axial bearings.
- Generator
  Exchange of generator rotor.
- Cooling water
  Maintenance of the pump channel head VE30/40, pressure test of secured secondary cooling water pipes, return flow line and lead flow line.
- Transformer
  Exchange of the low-voltage auxiliary power transformer CS42/CT21.
- Block protection
  Optimisation of the phase failure detection.

Unplanned shutdowns and reactor/turbine trip
On 27 February 2016, during the period from 03:54 until 15:33 h the generator was taken from the grid for removing a leak from one of the coolant hose screw connections of the generator circuit breaker AQ01H001. The reactor was shut-down to the minimum load point.

Power reductions above 10 % and longer than for 24 h
See operating diagram: Load following for grid supporting.

WANO Review/Technical Support Mission
From 29 February 2016 until 18 March 2016 the World Association of Nuclear Operators (WANO) carried out a Peer Review at the Brokdorf nuclear power plant.

Delivery of fuel elements
During the reporting year 32 fresh uranium fuel elements were delivered.

Waste management status
By the end of the year 2016 29 loaded CASTOR© casks were located at the on-site intermediate storage Brokdorf.
Operating data

Review period 2016

Plant operator: PreussenElektra GmbH
Shareholder/Owner: PreussenElektra GmbH (80 %), Vattenfall Europe Nuclear Energy GmbH (20 %)
Plant name: Kernkraftwerk Brokdorf (KBR)
Address: PreussenElektra GmbH, Kernkraftwerk Brokdorf, 25576 Brokdorf
Phone: 04829 752560, Telefax: 04829 511
Web: www.preussenelektra.de

First synchronisation:
Date of commercial operation:
Design electrical rating (gross):
Design electrical rating (net):
Reactor type:
Supplier:

The following operating results were achieved:
Operating period, reactor:
Gross electrical energy generated in 2016:
Net electrical energy generated in 2016:
Gross electrical energy generated since first synchronisation until 12-31-2016:
Net electrical energy generated since first synchronisation until 12-31-2016:
Availability factor in 2016:
Availability factor since date of commercial operation:
Capacity factor 2016:
Capacity factor since date of commercial operation:
Downtime (schedule and forced) in 2016:
Number of reactor scrams 2016:

Licensed annual emission limits in 2016:
Emission of noble gases with plant exhaust air:
Emission of iodine-131 with plant exhaust air:
Emission of nuclear fission and activation products with plant waste water (excluding tritium):

Proportion of licensed annual emission limits for radioactive materials in 2016 for:
Emission of noble gases with plant exhaust air:
Emission of iodine-131 with plant exhaust air:
Emission of nuclear fission and activation products with plant waste water (excluding tritium):
Collective dose:

Collective radiation dose of own and outside personnel in Sv

Availability factor in %
Capacity factor in %

Collective radiation dose of own and outside personnel in Sv
Emsland

Operating sequence in 2016

Apart from the overall maintenance outage in May and June and the refuelling outage by the end of the year the Emsland nuclear power plant has been operating uninterruptedly and mainly at full load during 2016. Producing a gross power of 11,113,993 MWh with a capacity factor of 94.13 %, the power plant achieved again a very good operating result.

Planned shutdowns
28th refuelling and overall maintenance inspection:
The annual outage was scheduled for the period 21 May to 6 June. The outage took 15.9 days from high-voltage breaker opening to breaker closing. In addition to the replacement of 16 fuel assemblies the following major maintenance and inspection activities were carried out:
- Inspection of core and reactor pressure vessel internals.
- Inspection of a reactor coolant pump.
- Inspection of pressurizer valves.
- Pressure test on different coolers and tanks.
- Inspection of a main condensate pump.
- Maintenance works on different transformers.
- Different automatic non-destructive examinations.

29th refuelling outage:
By the end of the year, KKE stopped operation for a second refuelling outage, starting on 21 December 2016. Main task was the replacement of 24 fuel assemblies.

Unplanned shutdowns and reactor/turbine trip
None.

Power reductions above 10 % and longer than for 24 h
Stretch-out operation from 20 March to 21 May.
Stretch-out operation from 11 October to 26 December.

Delivery of fuel elements
- 24 Uranium-fuel elements.

Waste management status
During 2016 no CASTOR© cask loading was carried out. There were still 38 loaded casks in the local interim storage facility at the end of the year.

General points
On 22 December 2016 an early license application according to §7.3 Atomic Law on closing and dismantling of the KKE nuclear power plant was submitted to the ministry from Lower Saxony of Environment, Energy and Climate Protection. Planned shutdown date is 31 December 2022.
Operating data

Review period 2016

**Plant operator:** Kernkraftwerke Lippe-Emms GmbH  
**Shareholder/Owner:** RWE Power AG (87.5%), PreussenElektra GmbH (12.5%)  
**Plant name:** Kernkraftwerk Emsland (KKE)  
**Address:** Kernkraftwerk Emsland, Am Hilgenberg, 49811 Lingen  
**Phone:** 0591 806-1612  
**Web:** www.rwe.com

First synchronisation: 04-19-1988  
Date of commercial operation: 06-20-1988  
Design electrical rating (gross): 1,406 MW  
Design electrical rating (net): 1,335 MW  
Reactor type: PWR  
Supplier: Siemens/KWU

The following operating results were achieved:

Operating period, reactor: 8,285 h  
Gross electrical energy generated in 2016: 11,113,993 MWh  
Net electrical energy generated in 2016: 10,539,681 MWh  
Gross electrical energy generated since first synchronisation until 12-31-2016: 323,999,579 MWh  
Net electrical energy generated since first synchronisation until 12-31-2016: 307,163,345 MWh  
Availability factor in 2016: 94.25 %  
Availability factor since date of commercial operation: 94.07 %  
Capacity factor 2016: 94.13 %  
Capacity factor since date of commercial operation: 93.93 %  
Downtime (schedule and forced) in 2016: 5.75 %  
Number of reactor scrams 2016: 0

Licensed annual emission limits in 2016:

Emission of noble gases with plant exhaust air: $1.0 \cdot 10^{15}$ Bq  
Emission of iodine-131 with plant exhaust air: $5.0 \cdot 10^{9}$ Bq  
(incl. H-3 and C-14)  
Emission of nuclear fission and activation products with plant waste water (excluding tritium): $3.7 \cdot 10^{10}$ Bq

Proportion of licensed annual emission limits for radioactive materials in 2016 for:

Emission of noble gases with plant exhaust air: 0.097 %  
Emission of iodine-131 with plant exhaust air: 0.0 %  
(incl. H-3 and C-14)  
Emission of nuclear fission and activation products with plant waste water (excluding tritium): 0.00 %  
Collective dose: 0.054 Sv
During the reporting year 2016 the nuclear power plant Grohnde was taken off the grid for a 75-day revision with refuelling. It achieved an availability factor of 75.1 %.

The gross production amounted to 8,903,638.8 MWh. The scheduled 16-day downtime for the revision had to be extended by 59 days due to a failure at the rotor assembly of the residual-heat removal pump TH40 D001, thus requiring an extensive inspection programme. The plant was additionally taken from the grid for 16 days in July/August due to the repair of a small leak at the pressure head measurement system of one of the reactor coolant pumps.

Planned shutdowns
2 April to 16 June: 33rd fuel element exchange and plant revision:

- After a 19-days stretch-out operation the nuclear power plant Grohnde was shut down as scheduled for its annual revision and the 33rd fuel element exchange on 2 April. Restart was on June 15.
- Significant works during the overall maintenance inspection were:
  - Fuel element exchange.
  - Inspection of fuel elements and spacers.
  - Eddy current and visual testing of control rods.
  - Visual testing of 15 flow restrictor assemblies.
  - Ultrasonic testing on all four main coolant pipes YA10 to 40.
  - Diesel engine replacement and axial bearing revision.
  - Internal examination of the nuclear intercooler, the flooding tanks TH30 B001/2 and of the accumulator TH36/37 B001.
  - Internal examination and pressure test of the residual heat exchanger TA00 B001 and of the high-pressure pre-heater TA11/12 B001.
  - Inspection of pumps TF31 D001 and TH35 D001.
  - Inspection of the valve S002 on the low-pressure TH11 injection system.
  - Pressure testing of the high-pressure pre-heaters.

In the course of the tests during restart of the plant for its 34th cycle, at 156 bars and a primary coolant temperature of approx. 296 °C, a leaking fitting was detected on 18 April at the TA volume control system which required another controlled shutdown to cold condition of the entire plant. A damage of the residual heat removal system TH40D001 was verified (material removal on the impeller and the stator of the pump). As a consequence (in addition to the repair of the residual heat removal pump), an extensive flushing and inspection programme on the primary coolant system (including the reactor core and all components of its adjacent systems) was initiated. Due to the extension to 59 days the core loading was adapted for the 34th cycle. The new core comprises only 16 fresh fuel elements.

Unplanned shutdowns and reactor/turbine trip
30 July to 15 August: Extraordinary shutdown for repair of a small hot leak. The plant was extraordinarily shut down on 30 July 2016, due to a small leak at the pressure head measurement of the main coolant pump YD40. After the repair of a defect weld seam and the inspection of further 23 weld seams the plant was started-up again on 15 August 2016.

Power reductions above 10% and longer than for 24 h
In January, June, July, August and December the unit was operated in load following mode as required by the load dispatcher. Between 28 June and 13 July the maximum generator output had to be limited to 1,220 MW (net) due to increased temperatures at the mechanical seal of the main feed pump RL22 D001. 26 August to 15 September: On 26 August a fatal accident occurred in the tunnel between the (fossil-fired) auxiliary boiler and the turbine, when a worker was scalded by leaking steam after a pipe break due to a water hammer. The plant further operated with a constant power of 1,100 MW net.

Delivery of fuel elements
In 2016 a total of 34 AREVA U-/U-Gd-fuel elements were delivered to the unit.

Waste management status
During the period from August until October 2016 in total three CASTOR®-V/19 casks were loaded. Thus currently 30 CASTOR®-V/19 casks are stored in the interim storage building.

General points
In October 2016 an audit of the quality management system (ISO 9001), the environmental management system (ISO 14001), the health and safety managements system (OHSAS 18001) as well as a first certification of the energy management system (ISO 50001) were successfully carried out.
Operating data

Review period 2016

**Plant operator:** Gemeinschaftskernkraftwerk Grohnde GmbH & Co. OHG  
**Shareholder/Owner:** PreussenElektra GmbH (83,3 %), Stadtwerke Bielefeld (16,7 %)  
**Plant name:** Kernkraftwerk Grohnde (KWG)  
**Address:** Gemeinschaftskernkraftwerk Grohnde GmbH & Co. OHG, P.O. bx 12 30, 31857 Emmerthal  
**Phone:** 05155 67-1  
**Web:** www.preussenelektra.de

First synchronisation: 09-05-1984  
Date of commercial operation: 02-01-1985  
Design electrical rating (gross): 1,430 MW  
Design electrical rating (net): 1,360 MW  
Reactor type: PWR  
Supplier: Siemens/KWU

The following operating results were achieved:

**Operating period, reactor:** 6,609 h  
**Gross electrical energy generated in 2016:** 8,903,639 MWh  
**Net electrical energy generated in 2016:** 8,415,909 MWh  
**Gross electrical energy generated since first synchronisation until 12-31-2016:** 356,942,689 MWh  
**Net electrical energy generated since first synchronisation until 12-31-2016:** 337,497,013 MWh  
**Availability factor in 2016:** 75.10 %  
**Availability factor since date of commercial operation:** 91.90 %  
**Capacity factor 2016:** 73.20 %  
**Capacity factor since date of commercial operation:** 91.6 %  
**Downtime (schedule and forced) in 2016:** 24.90 %  
**Number of reactor scrams 2016:** 0

**Licensed annual emission limits in 2016:**

- **Emission of noble gases with plant exhaust air:** $9.0 \cdot 10^{14}$ Bq  
- **Emission of iodine-131 with plant exhaust air:** $7.5 \cdot 10^{9}$ Bq  
- **Emission of nuclear fission and activation products with plant waste water (excluding tritium):** $5.55 \cdot 10^{10}$ Bq  

**Proportion of licensed annual emission limits for radioactive materials in 2016 for:**

- **Emission of noble gases with plant exhaust air:** 0.017 %  
- **Emission of iodine-131 with plant exhaust air:** 0.000 %  
- **Emission of nuclear fission and activation products with plant waste water (excluding tritium):** 0.0006 %  

**Collective dose:** 0.519 Sv
In the review year 2016, unit B of the Gundremmingen nuclear power plant was operated at full load without any major restrictions except for a 35-day outage for refuelling with an overall maintenance inspection. From 1 December 2015 to 7 April 2016, unit B was in stretch-out operation. In spring, during the refuelling outage, a total of 119 fuel elements were unloaded and replaced with 84 fresh and 35 (12 MOX) partially irradiated fuel elements. With the support of up to 1,200 additional external specialist workers the employees of the plant accomplished roughly 4,700 work orders. During the refuelling outage all safety-related relevant works were monitored by the relevant nuclear authority, the Bavarian State Ministry of the Environment and Consumer Protection (StMUV), and consulted authorized experts. The inspection of the technical systems with regard to safety and reliability confirmed the excellent condition of the plant.

From 16 November, unit B was in stretch-out operation because of the refuelling in spring 2017. A gross total of 10,015,303 MWh of electricity was produced.

Planned shutdowns
7 April to 12 May: 31st refuelling outage and 20th overall maintenance inspection.

The following major activities were carried out:
- Refuelling and inspection of fuel elements.
- Non-destructive tests on stud bolts and holes of reactor pressure vessel.
- Inspection of main isolation valves of the feed water, main steam and residual heat removal systems.
- Emptying of redundancies 1 and 3 for preventive measures on valves, motors, pumps and tanks.
- Emptying of reactor water cleanup system for inspection of valves and tanks as well as pressure tests.
- Inspection of main transformers, circuit breakers and 400 kV power grid.
- Pressure test and inner inspection of feed water tank.
- Motor exchange on service water pump.
- Extensive non-destructive testing on pipes and tanks.

Unplanned shutdowns and reactor/turbine trip
13 May to 16 May: Reactor Scram (periodic test), sealing replacement on a safety and relief valve.

Power reductions above 10 % and longer than for 24 h
None.

Delivery of fuel elements
None.

Waste management status
At the end of 2016, the local interim storage facility accommodated 48 loaded CASTOR© casks with each 52 spent fuel elements out of units B and C. No casks from unit B were placed in or taken out of storage during the period under review.

General points
Management systems
From 24 to 28 October, a VGB-SBS event (safety culture assessment system) took place in Gundremmingen. The final evaluation report listed the various efforts for safety culture and evaluated them as mainly positive developments in all considered areas.

Twinning program
From 26 to 30 September, Gundremmingen was visited by a delegation from Novovoronezh, Russia. An exchange of experiences took place with colleagues from human resource management, economic and financial affairs, fire departments and operating experience/incident investigations.
Operating data

Review period 2016

**Plant operator:** Kernkraftwerk Gundremmingen GmbH  
**Shareholder/Owner:** RWE Power AG (75 %), PreussenElektra GmbH (25 %)  
**Plant name:** Kernkraftwerk Gundremmingen B (KRB B)  
**Address:** Kernkraftwerk Gundremmingen GmbH, Dr.-August-Weckesser-Straße 1, 89355 Gundremmingen  
Phone: 08224 78-1, Telefax: 08224 78-2900  
E-mail: kontakt@kkw-gundremmingen.de  
Web: www.kkw-gundremmingen.de

First synchronisation: 03-16-1984  
Date of commercial operation: 07-19-1984  
Design electrical rating (gross): 1,344 MW  
Design electrical rating (net): 1,284 MW  
Reactor type: BWR  
Supplier: Siemens/KWU, Hochtief

The following operating results were achieved:

- **Operating period, reactor:** 7,889 h  
- **Gross electrical energy generated in 2016:** 10,015,303 MWh  
- **Net electrical energy generated in 2016:** 9,517,678 MWh  
- **Gross electrical energy generated since first synchronisation until 12-31-2016:** 321,652,944 MWh  
- **Net electrical energy generated since first synchronisation until 12-31-2016:** 305,318,785 MWh  
- **Availability factor in 2016:** 89.80 %  
- **Availability factor since date of commercial operation:** 90.30 %  
- **Capacity factor 2016:** 89.30 %  
- **Capacity factor since date of commercial operation:** 88.70 %  
- **Downtime (schedule and forced) in 2016:** 10.20 %  
- **Number of reactor scrams 2016:** 0

**Licensed annual emission limits in 2016** (values added up for Units B and C, site emission):

- Emission of noble gases with plant exhaust air: $1.85 \times 10^{15}$ Bq  
- Emission of iodine-131 with plant exhaust air: $2.2 \times 10^8$ Bq  
- Emission of nuclear fission and activation products with plant waste water (excluding tritium): $1.10 \times 10^{11}$ Bq  

**Proportion of licensed annual emission limits for radioactive materials in 2016** for (values added up for Units B and C):

- Emission of noble gases with plant exhaust air: 0.24 %  
- Emission of iodine-131 with plant exhaust air: 0.18 %  
- Emission of nuclear fission and activation products with plant waste water (excluding tritium): 0.45 %  
- **Collective dose:** 0.99 Sv

**Collective radiation dose of own and outside personnel in Sv**

[Graph showing availability and capacity factors from 2009 to 2016]
In the review year 2016, unit C of the Gundremmingen nuclear power plant was operated at full load without any major restrictions except for two outages for refuelling. From 8 March to 5 July unit C was in stretch-out operation. During the following shutdown a total of 107 fuel elements were unloaded and replaced with 52 fresh and 55 (12 MOX) partially spent fuel elements. With the support of over 1,000 additional external specialist workers the employees of the plant accomplished roughly 3,400 work orders. From 25 September to 11 December unit C was again in stretch-out operation. During the subsequent shutdown a total of 76 fuel elements were unloaded and replaced with 72 fresh and 4 partially irradiated fuel elements. With the support of up to 400 additional external specialist workers the employees of the plant accomplished roughly 750 work orders. During both refuelling outages all safety-related relevant work was monitored by the relevant nuclear authority, the Bavarian State Ministry of the Environment and Consumer Protection (StMUV), and consulted authorized experts. The inspection of the technical systems with regard to safety and reliability confirmed the excellent condition of the plant.

In 2016, a gross total of 9,396,741 MWh of electricity was produced.

Planned shutdowns
5 July to 5 August: 30th refuelling outage.
The following major activities were carried out:
- Refuelling and sipping of all fuel elements inside the core; result: One defective fuel element.
- Extensive testing and inner inspections of pumps and valves.
- Partial emptying of redundancy system 3.
- Emptying of cooling tower basins for replacement of cooling tower internals.
- Sealing replacement of reactor water cleanup cooler.
- Exchange of pilot valves and check valves on main steam isolation valves.
11 December, 2016 to 5 January, 2017:
Special shutdown for refuelling.
The following major activities were carried out:
- Refuelling and sipping of all fuel elements inside the core; result: One defective fuel element.
- Mechanical seal replacement on a feed water pump and a service water pump.
- Works in the condensation chamber.
- Clearing of main cooling water system.
- Repair works on service water and auxiliary steam system.
- Exchange of ground fault monitoring relay and works on voltage regulators.

Unplanned shutdowns and reactor/turbine trip
None.

Power reductions above 10 % and longer than for 24 h
None.

Delivery of fuel elements
In 2016, for Gundremmingen unit C 80 fresh fuel elements were delivered.

Waste management status
At the end of 2016, the local interim storage facility accommodated 48 loaded CASTOR® casks with each 52 spent fuel elements out of units B and C. No casks from unit C were placed or taken out of storage during the period under review.

General points
Management systems
From 24 to 28 October, a VGB-SBS event (safety culture assessment system) took place in Gundremmingen. The final evaluation report listed the various efforts for safety culture and evaluated them as mainly positive development in all considered areas.

Twinning program
From September 26 to 30, Gundremmingen was visited by a delegation from Novovoronezh, Russia. An exchange of experiences took place with between colleagues from human resource management, economic and financial affairs, fire departments and operating experience/incident investigation about their issues.
Operating data

Review period 2016

**Plant operator:** Kernkraftwerk Gundremmingen GmbH  
**Shareholder/Owner:** RWE Power AG (75 %), PreussenElektra GmbH (25 %)  
**Plant name:** Kernkraftwerk Gundremmingen C (KRB C)  
**Address:** Kernkraftwerk Gundremmingen GmbH, Dr.-August-Weckesser-Straße 1, 89355 Gundremmingen  
Phone: 08224 78-1, Telefax: 08224 78-2900  
E-mail: kontakt@kkw-gundremmingen.de  
Web: [www.kkw-gundremmingen.de](http://www.kkw-gundremmingen.de)

First synchronisation: 11-02-1984  
Date of commercial operation: 01-18-1985  
Design electrical rating (gross): 1,344 MW  
Design electrical rating (net): 1,288 MW  
Reactor type: BWR  
Supplier: Siemens/KWU, Hochtief

The following operating results were achieved:

**Operating period, reactor:** 7,553 h  
**Gross electrical energy generated in 2016:** 9,396,741 MWh  
**Net electrical energy generated in 2016:** 8,918,293 MWh  
**Gross electrical energy generated since first synchronisation until 12-31-2016:** 310,650,073 MWh  
**Net electrical energy generated since first synchronisation until 12-31-2016:** 295,845,815 MWh  
**Availibility factor in 2016:** 86.00 %  
**Availibility factor since date of commercial operation:** 89.20 %  
**Capacity factor 2016:** 85.50 %  
**Capacity factor since date of commercial operation:** 87.50 %  
**Downtime (schedule and forced) in 2016:** 14.00 %  
**Number of reactor scrams 2016:** 0

**Licensed annual emission limits in 2016**  
(values added up for Units B and C, site emission):  
Emission of noble gases with plant exhaust air: 1.85 · 10¹⁵ Bq  
Emission of iodine-131 with plant exhaust air: 2.20 · 10¹⁵ Bq  
Emission of nuclear fission and activation products with plant waste water (excluding tritium): 1.10 · 10¹¹ Bq  

**Proportion of licensed annual emission limits for radioactive materials in 2016** (values added up for Units B and C):  
Emission of noble gases with plant exhaust air: 0.24 %  
Emission of iodine-131 with plant exhaust air: 0.18 %  
Emission of nuclear fission and activation products with plant waste water (excluding tritium): 0.45 %  
**Collective dose:** 0.84 Sv
Isar 2

Operating sequence in 2016

The Isar 2 nuclear power plant remained constantly on the grid during the reporting year with the exception of one refuelling with regular annual outage.

With achieving a boron concentration of 40 ppm on 8 May 2016 only a restricted standard operation was possible. The plant was operated in “stretch-out operation (phase 1)” during the period from 22 May 2016 until 5 July 2016 as well as subsequently until 15 July 2016 in “stretch-out operation (phase 3)” mode.

After the outage, the plant remained in full-load operation from 1 August 2016 until 3 August 2016 for fuel element conditioning. On 3 August 2016 the system services “primary and secondary control” system services operation mode was granted. With achieving a boron concentration of 40 ppm again on 25 October 2016 the scope of operation modes was again restricted.

Since 10 November 2016 the unit was in stretch-out operation of phase 1 and logged out from secondary control. In coordination with the electricity trading floor the plant output was reduces by approximately 350 MW during the low-demand Christmas holidays from 24 to 27 December 2016. On request of the grid operator the centre the unit output was raised by approximately 160 MW on 26 December 16. Since 29 December 2016 the Isar 2 nuclear power plant remained in stretch-out operation of phase 3. Due to many primary and secondary load followings as well as to the stretch-out operation (in total 107 days) the total electricity production of 11.99 TWh represented a very good operating result during the year 2016. Thus the plant is on top of the German plants’ leaderboard.

Planned shutdowns

The refuelling took place from 16 to 31 July 2016 with duration of 15.2 days. Eight fuel elements were exchanged during the outage. The revision was completed 8 h ahead of the planned date. The revision dose amounted to 42.2 mSv and was well below the planned value of 66 mSv. This is the lowest revision dose since the commissioning of the plant.

The responsible supervisory authority and its consulting experts monitored all safety-relevant works. The audit on the systems with regard to safety and reliability confirmed the very good condition of the plant.

Unplanned shutdowns and reactor/turbine trip

None

Power reductions above 10 % and longer than for 24 h

None.

WANO Review/Technical Support Mission

The Follow-up for the WANO Peer Review 2014 was carried out from 19 until 14 October 2016.

Delivery of fuel elements

During the reporting year 32 fresh Westinghouse uranium fuel elements were delivered. In the dry storage area are currently 48 unirradiated uranium fuel elements stored as well as 36 new uranium fuel elements in the wet storage for reloading in a short shutdown in January 2017.

Waste management status

Currently 35 CASTOR® V casks as well as one TN®24E cask are stored in the on-site intermediate storage. The first transport and storage cask TN24E from AREVA was delivered to KKI-2 on 13 April 2016. The approval to carry out a prototype “cold handling” was provided by the Bavarian regulator StMUV on 12 April 2016. The procedure was carried out inside the reactor building of KKI-2 between 13 and 27 April 2016. The approval for storing the TN24E inside the interim storage building BELLA, was issued on 28 July 2016. The first TN®24E casks was stored on 26 September 2016. The federal authorisation for the „constructional optimisation of the storage building“ (erection of a separate outer concrete wall to protect the building against missiles) was issued on the 20 June 2016. The construction licence was granted by the district administration of the KKI host town Landshut on 9 November 2016. The official start of construction followed on 14 November 2016.

General points

From 7 to 11 March 2016 recertification audits according to DIN EN ISO 9001/14001/BS OHSAS 18001 as well as a revalidation according to EMAS III (quality, environmental protection industrial safety and health protection management system by the “DNV GL BA Zertifizierung und Umweltgutachter GmbH” were successfully carried out at the KKI. Validation of the environmental management system and environmental statement according to EMAS III including energy management was carried out on 25 October 2016.
Operating data

Review period 2016

Plant operator: PreussenElektra GmbH
Shareholder/Owner: PreussenElektra GmbH (75 %), Stadtwerke München GmbH (25 %)
Plant name: Kernkraftwerk Isar 2 (KKI 2)
Address: PreussenElektra GmbH, Kernkraftwerk Isar, Postfach 11 26, 84049 Essenbach
Phone: 08702 38-2465, Telefax: 08702 38-2466

Web: www.eon.com/isar

First synchronisation: 01-22-1988
Date of commercial operation: 04-09-1988
Design electrical rating (gross): 1,485 MW
Design electrical rating (net): 1,410 MW
Reactor type: PWR
Supplier: Siemens/KWU

The following operating results were achieved:

Operating period, reactor: 8,420 h
Gross electrical energy generated in 2016: 11,990,925 MWh
Net electrical energy generated in 2016: 11,338,879 MWh
Gross electrical energy generated since first synchronisation until 12-31-2016: 330,074,810 MWh
Net electrical energy generated since first synchronisation until 12-31-2016: 312,065,345 MWh
Availability factor in 2016: 95.86 %
Availability factor since date of commercial operation: 93.26 %
Capacity factor 2016: 95.68 %
Capacity factor since date of commercial operation: 92.31 %
Downtime (schedule and forced) in 2016: 4.14 %
Number of reactor scrams 2016: 0

Licensed annual emission limits in 2016:
Emission of noble gases with plant exhaust air: $1.1 \times 10^{15}$ Bq
Emission of iodine-131 with plant exhaust air: $1.1 \times 10^{10}$ Bq
Emission of nuclear fission and activation products with plant waste water (excluding tritium): $5.5 \times 10^{9}$ Bq

Proportion of licensed annual emission limits for radioactive materials in 2016 for:
Emission of noble gases with plant exhaust air: 0.058 %
Emission of iodine-131 with plant exhaust air: < limit of detection
Emission of nuclear fission and activation products with plant waste water (excluding tritium): 0.0005 %
Collective dose: 0.057 Sv

Collective radiation dose of own and outside personnel in Sv
Neckarwestheim II

Operating sequence in 2016

In 2016 a gross total of 11,394,820 MWh was produced by the Neckarwestheim II (GKN II) nuclear power plant. The electrical net generation reached 10,687,230 MWh of which 10,295,540 MWh were fed into the public three-phase high-voltage grid and 1,099,280 MWh into the single-phase system of Deutsche Bahn AG via the static converter unit. The plant was for 8,317.7 h on the grid. Thus an availability of 94.69% was achieved.

Since the commissioning of the unit in 1989, the threephase generator has produced 309,585,684 MWh gross and 289,436,509 MWh net.

Planned shutdowns
2 to 22 September 2016: 32nd overall maintenance inspection with refuelling.

Main inspection works were:
- Refuelling and overall maintenance inspection.
- Maintenance of the oil cooler of one out of four main coolant pumps.
- General overhaul of the primary relieve valves.
- Inner pressure testing of the feed-water tank.
- General maintenance of one out of three feed-water tanks.
- Exchange of three transformers of one out of four redundancies of the power supply.

Unplanned shutdowns and reactor/turbine trip
None.

Power reductions above 10 % and longer than for 24 h
25 July to 2 September: Stretch-out operation.
24 to 27 December: Load sequence.

Safety reviews
Stress tests, initiated from the German Reactor Safety Commission and the EU after Fukushima have confirmed the high safety standards of German nuclear power plants. All plants – including the decommissioned ones – possess significant safety reserves beyond all anticipated scenario. All possess by design especially sufficient, sometimes high margins against external hazards such as flooding or earthquakes. Even more important, the stress tests have confirmed that the design requirements (e.g. flooding heights, design earthquakes) had been set up correctly.

On top, further robustness improving measures (i.e. beyond the scope of regulatory requirements) were developed in the framework of a national action plan. E.g. in Baden-Württemberg (where KKP is located), the recommendations from the national action plan had been listed in a so-called „Action Plan“. All recommended works are now completed on a voluntary basis with the exception of single aspects of the plant-specific robustness analyses. Furthermore, KKP-2 is mirrored with regards to incident management in the context of the so-called “further amended safety examinations Baden-Württemberg” on the new safety requirements of nuclear power plants (SiANf).

Integrated management system (IMS)
EnKK [NPP P, GKN, KWO]
The integrated management system (IMS) of the EnBW Kernkraft GmbH EnKK with its sub-system for nuclear safety (SMS), quality management (QMS/QSU) as well as the environmental and energy management (UMS, EnMS) was continuously improved during the year 2016. Content and coverage of each process were continuously adapted to the internal requirements and thus to authorisation related requirements. For this reason a respective adjustment concept for processes and indicators was developed.

In addition to the confirmation of conformity of the established IMS, and an improvement of the energetic efficiency in 2016, a the EnKK energy management system (ENMS) certificate according to DIN EN ISO 50001 was renewed.

The completeness and effectiveness of the measures as well as the status of the quality management system (QUS) were approved according to respective internal audits as well as with an on-site inspections by the an expert organisation (KeTAG) at all three sites of the EnKK. The modular design of the process-oriented IMS according to nuclear standard KTA1402 enabled also in the following year a continuous and efficient adaptation to the site-specific requirements of the post-operational/dismantling phase.

Waste management status
During the reporting year no further storage procedures were carried out. Thus by the end of 2016, 53 loaded CASTOR© V/19 casks were stored at the on-site intermediate storage Neckarwestheim. The cold handling for CASTOR© 440/84 mK was successfully carried out in November 2016.
Operating data

Review period 2016

Plant operator: EnBW Kernkraft GmbH (EnKK)
Shareholder/Owner: EnBW Erneuerbare und Konventionelle
Erzeugung AG (98,45 %), ZEAG Energie AG, Deutsche Bahn AG,
Kernkraftwerk Obrigheim GmbH
Plant name: Kernkraftwerk Neckarwestheim II (GKN II)
Address: EnBW Kernkraft GmbH, Kernkraftwerk Neckarwestheim,
Im Steinbruch, 74382 Neckarwestheim
Phone: 07133 13-0, Telefax: 07133 17645
E-mail: poststelle-gkn@kk.enbw.com
Web: www.enbw.com/gkn

First synchronisation: 01-03-1989
Date of commercial operation: 04-15-1989
Design electrical rating (gross): 1,400 MW
Design electrical rating (net): 1,310 MW
Reactor type: PWR
Supplier: Siemens/KWU

The following operating results were achieved:

Operating period, reactor: 8,324 h
Gross electrical energy generated in 2016: 11,394,820 MWh
Net electrical energy generated in 2016: 10,687,230 MWh
Gross electrical energy generated since first synchronisation until 12-31-2016: 309,585,684 MWh
Net electrical energy generated since first synchronisation until 12-31-2016: 289,436,509 MWh
Availability factor in 2016: 94.69 %
Availability factor since date of commercial operation: 93.67 %
Capacity factor 2016: 94.26 %
Capacity factor since date of commercial operation: 93.30 %
Downtime (schedule and forced) in 2016: 5.31 %
Number of reactor scrams 2016: 0

Licensed annual emission limits in 2016:
Emission of noble gases with plant exhaust air: 1.0 \cdot 10^{15} Bq
Emission of iodine-131 with plant exhaust air: 1.1 \cdot 10^{10} Bq
Emission of nuclear fission and activation products with plant waste water (excluding tritium): 6.0 \cdot 10^{15} Bq

Proportion of licensed annual emission limits for radioactive materials in 2016 for:
Emission of noble gases with plant exhaust air: 0.0 %
Emission of iodine-131 with plant exhaust air: 0.0 %
Emission of nuclear fission and activation products with plant waste water (excluding tritium): 0.0 %
Collective dose: 0.0782 Sv
Philippsburg 2
Operating sequence in 2016

In 2016 the Philippsburg 2 nuclear power plant (KPP 2) generated a gross amount of 10,318,992 MWh. The electrical net generation amounted to 9,697,028 MWh. The plant was on the grid for 7,230.75 h. Thus an availability factor of 82.32% was calculated. Since the plant’s commissioning 347,313,689 MWh gross and 329,372,390 MWh net were generated.

Planned shutdowns
8 April to 1 June: 31st overall maintenance inspection with refuelling.
Main inspection works were:
- Refuelling and inspection.
- Inspection of all four main coolant pumps.
- Pressure testing of two out of four steam generators and the reactor pressure vessel.
- Motor exchange of two out of six coolant water pumps.
- Inspection of one out of six main coolant trains.
- Regular inspection of single emergency power generator.

20 to 31 December: Premature shutdown of the unit for the 32nd refuelling due to licence requirements’ mismatch on ventilation tray holding devices inside the emergency diesel building ULB.

Unplanned shutdowns and reactor/turbine trip
None.

Power reductions above 10 % and longer than for 24 h
5 March to 8 April: Stretch-out operation.
1 to 20 December: Stretch-out operation.

Safety reviews
Stress tests, initiated from the German Reactor Safety Commission and the EU after Fukushima have confirmed the high safety standards of German nuclear power plants. All plants – including the decommissioned ones – possess significant safety reserves beyond all anticipated scenario. All possess by design especially sufficient, sometimes high margins against external hazards such as flooding or earthquakes. Even more important, the stress tests have confirmed that the design requirements (e.g. flooding heights, design earthquakes) had been set up correctly. On top, further robustness improving measures (i.e. beyond the scope of regulatory requirements) were developed in the framework of a national action plan. E.g. in Baden-Württemberg (where KKP is located), the recommendations from the national action plan had been listed in a so-called „Action Plan“. All recommended works are now completed on a voluntary basis with the exception of single aspects of the plant-specific robustness analyses. Furthermore, KKP-2 is mirrored with regards to incident management in the context of the so-called “further amended safety examinations Baden-Württemberg” on the new safety requirements of nuclear power plants (SiANI).

Integrated management system (IMS) EnKK (NPP P, GKN, KWO)
The integrated management system (IMS) of the EnBW Kernkraft GmbH EnKK with its subsystem for nuclear safety (SMS), quality management (QMS/QSU) as well as the environmental and energy management (UMS, EnMS) was continuously improved during the year 2016. Content and coverage of each process were continuously adapted to the internal requirements and thus to authorisation related requirements. For this reason a respective adjustment concept for processes and indicators was developed. In addition to the confirmation of conformity of the established IMS, and an improvement of the energetic efficiency in 2016, a the EnKK energy management system (ENMS) certificate according to DIN EN ISO 50001 was renewed.

Waste management status
In the year 2016 in total 18 transport and storage casks of the CASTOR© V/52 type were stored at the on-site intermediate storage, containing all remaining spent fuel from the decommissioned KKP-1.
By the end of 2016, 29 loaded CASTOR© V/19 (from KKP-2) and 29 loaded CASTOR© V/52 casks (from KKP-1) were stored at in the on-site interim storage building.
Operating data

Review period 2016

**Plant operator:** EnBW Kernkraft GmbH (EnKK)

**Shareholder/Owner:** EnBW Erneuerbare und Konventionelle Erzeugung AG (98,45 %), ZEAG Energie AG, Deutsche Bahn AG, Kernkraftwerk Obrigheim GmbH

**Plant name:** Kernkraftwerk Philippsburg 2 (KKP 2)

**Address:** EnBW Kernkraft GmbH, Kernkraftwerk Philippsburg, P.O. box 11 40, 76652 Philippsburg

Phone: 07256 95-0, Telefax: 07256 95-2029

E-mail: Poststelle-kkp@kk.enbw.com

Web: www.enbw.com/kkp

- First synchronisation: 12-17-1984
- Date of commercial operation: 04-18-1985
- Design electrical rating (gross): 1,468 MW
- Design electrical rating (net): 1,402 MW
- Reactor type: PWR
- Supplier: Siemens/KWU

The following operating results were achieved:

- Operating period, reactor: 7,240 h
- Gross electrical energy generated in 2016: 10,318,992 MWh
- Net electrical energy generated in 2016: 9,697,028 MWh
- Gross electrical energy generated since first synchronisation until 12-31-2016: 347,313,689 MWh
- Net electrical energy generated since first synchronisation until 12-31-2016: 329,372,390 MWh
- Availability factor in 2016: 82.32 %
- Availability factor since date of commercial operation: 89.51 %
- Capacity factor 2016: 82.19 %
- Capacity factor since date of commercial operation: 89.25 %
- Downtime (schedule and forced) in 2016: 17.68 %
- Number of reactor scrams 2016: 0

**Licensed annual emission limits in 2016:**

- Emission of noble gases with plant exhaust air: $1.1 \times 10^{15}$ Bq
- Emission of iodine-131 with plant exhaust air: $1.1 \times 10^{10}$ Bq
- Emission of nuclear fission and activation products with plant waste water (excluding tritium): $5.5 \times 10^{9}$ Bq

**Proportion of licensed annual emission limits for radioactive materials in 2016 for:**

- Emission of noble gases with plant exhaust air: 0.04 %
- Emission of iodine-131 with plant exhaust air: < limit of detection
- Emission of nuclear fission and activation products with plant waste water (excluding tritium): 0.05 %
- Collective dose: 0.179 Sv
## Operating results of nuclear power plants in Germany 2015 and 2016

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<th>Energy availability factor** in %</th>
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<tr>
<td>Isar KKI 2</td>
<td>1,485</td>
<td>1,410</td>
<td>11,107,228</td>
<td>11,990,925</td>
<td>89.01</td>
<td>88.74</td>
</tr>
<tr>
<td>Neckarwestheim GKN II</td>
<td>1,400</td>
<td>1,310</td>
<td>11,212,950</td>
<td>11,391,770</td>
<td>93.13</td>
<td>92.96</td>
</tr>
<tr>
<td>Philippsburg KKP 2</td>
<td>1,468</td>
<td>1,402</td>
<td>11,303,875</td>
<td>10,318,992</td>
<td>90.55</td>
<td>90.39</td>
</tr>
<tr>
<td>Total***</td>
<td>11,357</td>
<td>10,799</td>
<td>91,786,310</td>
<td>84,634,367</td>
<td>91.76</td>
<td>91.77</td>
</tr>
</tbody>
</table>

* Availability factor (time availability factor) $k_t = t_v / t_n$: The time availability factor $k_t$ is the quotient of available time of a plant ($t_v$) and the reference period ($t_n$). The time availability factor is a degree for the deployability of a power plant.

** Energy availability factor $k_W = W_v / W_n$: The energy availability factor $k_W$ is the quotient of available energy of a plant ($W_v$) and the nominal energy ($W_n$). The nominal energy $W_n$ is the product of nominal capacity and reference period. This variable is used as a reference variable (100 % value) for availability considerations. The available energy $W_v$ is the energy which can be generated in the reference period due to the technical and operational condition of the plant. Energy availability factors in excess of 100 % are thus impossible, as opposed to energy utilisation.

*** Inclusive of round up/down, rated power in 2016.

**** The Grafenrheinfeld NPP was permanently shut-down in 2015 due to the revision of the German Atomic Energy Act in 2011.

All data in this report as of 31 March 2017.
In Deutschland sind 8 Kernkraftwerke in Betrieb. Die Gesamtleistung beträgt 11,357 MWe (brutto).

- Brokdorf: 1.480 MW (1986)
- Grohnde: 1.430 MW (1985)
- Gundremmingen B: 1.344 MW (1984)
- Gundremmingen C: 1.344 MW (1985)
- Neckarwestheim II: 1.400 MW (1989)
- Philippsburg 2: 1.468 MW (1985)

Stand: Januar 2017

Im Jahr 2017 sind 6 Kernkraftwerke in Deutschland in Betrieb.

Die Kernkraftwerke sind:
- Brokdorf
- Emsland
- Grohnde
- Gundremmingen B
- Gundremmingen C
- Isar 2
- Neckarwestheim II
- Philippsburg 2

Die Gesamtleistung beträgt 11,357 MWe (brutto).

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