RSK Statement

04.03.2004

Incident at the Davis Besse nuclear power plant (USA) rated at INES Level 3 of 6 March 2002, "Boric Acid Corrosion on the Reactor Vessel Head" and lessons learned for German plants

1 Advisory request

The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) issued an advisory request to the RSK Committee on REACTOR OPERATION regarding the incident at the Davis Besse NPP with the aim to investigate its applicability to German plants. The RSK Committee on PRESSURE-RETAINING COMPONENTS AND MATERIALS discussed material- and component-related issues, indicators for boric acid corrosion and non-destructive examinations (NDEs).

2 Background

On 6 March 2002, a corrosion-induced cavity was discovered at control rod drive mechanism (CRDM) nozzle No 3 of the reactor pressure vessel (RPV) during refuelling outage at the American Davis Besse nuclear power plant with pressurised water reactor. This corrosion cavity extended through the ferritic steel down to the cladding (size: 180 x 100 – 125 mm). At nozzle No 2, a crack was detected with a maximum width of 9.5 mm and a maximum depth of 90 – 100 mm.

During the 2002 outage, the control rod nozzles were inspected for cracking (NRC Bulletin 2001-01). The inspection of a total of 69 control rod nozzles, made of Alloy 600, revealed cracks in five nozzles; ten of these were through-wall cracks at nozzles No 1, 2 and 3. The repair measures initiated at nozzle No 3 had to be interrupted because the nozzle was displaced in the downhill direction (i.e. away from the top of the RPV head). After removal of the nozzle and the boric acid crystals deposited on the top of the RPV head, the above-mentioned corrosion cavity was discovered.

3 Course of the discussion

Discussions took place at the meetings of the RSK Committee on REACTOR OPERATION on 24.04.2002 and 22.01.2003. At meeting No 141, GRS reported to the Committee.

On 15 May 2002, the topic was dealt with by the RSK Committee on PRESSURE-RETAINING COMPONENTS AND MATERIALS at meeting No 25, where GRS and the plant manufacturer made their reports. At following meetings, the Committee was informed about the progress of the investigations on the American side. At meeting No 29 on 04.09.2002, the Committee was informed about the current status of the RPV head (construction, manufacture, quality, geometry, operation, material condition, NDEs, examination intervals, examination methods, monitoring of the RPV head area, especially with regard to leakages) of the German Obrigheim nuclear power plant (KWO) by oral reports from the licensee and the expert. At meeting No 30 on 09.10.2002, the Committee issued its statement.

At the 367th meeting on 13.11.2003, the RSK discussed the facts of the case. On this item, a written report on the previous meetings of the Committee was available.

141st meeting of the RSK Committee on REACTOR OPERATION on 24.04.2002 (consultancy document [1])

GRS reported on damages induced by boric acid corrosion on the RPV head of the American Davis Besse nuclear power plant [1]. During the 2002 outage, a corrosion cavity was detected at nozzle No 3 with corrosion wastage of the ferritic steel down to the cladding. In addition, a crack was detected at nozzle No 3 with a maximum width of 6 mm. Boric acid corrosion was assumed to be the damage mechanism.

At the Davis Besse nuclear power plant, flange leakage at the nozzles of the control rod drive mechanisms already occurred before. Regarding the detectability of leakages, GRS pointed out that at the Davis Besse nuclear power plant, an integral leakage rate of 23 l/h was considered as "normal" operational leakage in the primary circuit.

The cause of the corrosion was attributed to leakages in the area of the flanges and stress corrosion cracking in the RPV head nozzles made of Alloy 600. In the past ten years, leakages at flange connections occurred repeatedly. These had not always been removed during the outages. The "integral" leakage rate measured increased to twice the values measured in the years before.

Since the resulting boric acid deposits were not removed consequently, the deposits on the RPV head accumulated. The reactor vessel head insulation and the extensive deposits had obstructed a visual examination of the nozzle areas. In the year 2000, it was decided to remove these deposits. This, however, could not be fully performed due to hardening of the deposits for radiation protection reasons. Due to the residual deposits it was not possible to perform a complete visual examination of the nozzle area at the RPV head and so it was decided not to perform the examination, which is actually required to be performed within the frame of the monitoring programme on boric acid corrosion (NRC Generic Letter 88-05) completely (only at the accessible locations).

GRS explained the examination requirements regarding boric acid corrosion that exist at the plant. It was laid down in examination requirement "ASME XI (2001)" that a leak test and a visual examination for leakage were to performed after each refuelling. NRC Generic Letter 88-05 stipulates an identification of potential small leak locations with regard to corrosion to prevent large leaks in the pressure-retaining boundary. This provision would also include descriptions of different methods for the localisation of small leaks and for estimation and prevention of corrosion damages. Further, it referred to the maximum corrosion velocity, reached in tests, of 120 mm/a for ferritic steels.

In another NRC Bulletin (NRC 2001-01), the possibility of circumferential cracking of nozzles made of Alloy 600 due to primary water stress corrosion cracking (PWSCC) was pointed out. According to a plant-specific assessment of NRC under consideration of the RPV head operating temperature, the operating time and the material, the control rod nozzles at the Davis Besse nuclear power plant are susceptible to PWSCC. As a consequence, the plant was to be subjected to a 100 % visual examination of the nozzles from the top or a volumetric examination from the bottom by the end of 2001. In agreement between NRC and the licensee, the volumetric examination was then performed in February/March 2002 within the frame of a refuelling outage.

During examination by means of ultrasonic testing methods from the bottom it was detected that five nozzles had through-wall cracks (four axial cracks and one circumferential crack at nozzle No 3). While repairing the RPV head, nozzle No 3 loosened. After removal of the reactor vessel head insulation, severe damages were detected in the area of this control rod nozzle.

There were boric acid corrosion indicators as early as 1999 in form of brownish crusts and deposits on the RPV head and the containment air coolers which was a clear sign of iron borate formation. The licensee attributed the increase and brownish colouring of the deposits on the containment air coolers to corrosion processes on the coolers. Due to increasing deposits of similar type on the filters, the filters were changed every day instead of every month.
From this, NRC had drawn the conclusion that leakages in combination with deposits were the cause of this incident. Further, several indicators for boric acid corrosion processes at the RPV head had not been realised by the licensee. The corrosion cavity was mainly due to a leakage at nozzle No 3. These processes started at least four years before their detection. The role of deposits regarding the corrosion growth, the specific chemical processes of corrosion, the impact of the RPV head operating temperature and the velocity of crack growth on the nozzles of the Davis Besse nuclear power plant were unclear points.

Further, GRS explained the following:

- In response to the incident, NRC had ordered a more stringent performance of the corrosion management programme at the American plants. The licensees had to submit corresponding reports by the end of April.

- In Germany, comparable integral leakage rates in the containment alone do not lead to a reportable event. However, they are observed by the respective regulatory authority.

With the concentrations normally present in the primary circuit, the behaviour of the boric acid would not be aggressive. Due to the evaporation process, the concentration in the area of leakages increases and pH-values of 3 could be reached at temperature of 100 - 150 °C. Under these conditions, boric acid behaved quite aggressive towards ferritic steels. In each case, however, the precondition for corrosion processes was humidity. Ferritic steels would practically be dissolved by boric acid corrosion, stainless steels (chromium content > 13 – 15 %) were virtually immune to this corrosion. For this reason, the cladding at Davis Besse had not suffered any damage. In addition, there are also indications of a considerable corrosive effect of "dry" boric acid which eliminated water at temperatures above 185 °C, thus being converted into a viscous liquid.

- Due to the deposits, the nozzle area had not been subjected to a 100 % examination, at least in the year 2000. How the NRC arrives at four years for the incident in its assessment was not traceable by means of the available documents. Obviously, the period for the corrosion processes was derived from the maximum corrosion velocity, determined by experiments, and the thickness of the RPV head.

- The existing degree of boric acid corrosion on the nozzle was not clearly identifiable by means of a visual inspection of the RPV from the top due to the deposits.

- In some cases, the leakages also resulted in the distribution of boric acid in gaseous form and deposition on other locations (e. g. on the control rod drive mechanism).

- Compared to American plants, there are no reportable events due to damage caused by boric acid corrosion.

The Committee added that the boric acid corrosion problems in the past had been extensively discussed at the RSK by the Committee on PRESSURE-RETAINING COMPONENTS. As a result of these discussions, examinations of RPV nozzles were performed at all German plants. Except for the KWO plant, the nozzles at all German PWR plants were provided with double seals which were subjected to leakage tests after installation. At KWO, a special reactor vessel head leak monitoring system was installed, being more sensitive than the integral leak monitoring system at other plants.

25th meeting of the RSK Committee on PRESSUER RETAINING-COMONENTS AND MATERIALS on 15.05.2002 (consultancy documents [2 to 7])

In accordance with the information published on the Internet and the reports given at meeting No 141 of the RSK Committee on REACTOR OPERATION on 24.04.2002, GRS added the following:

Retrospectively, different indicators of significant corrosion/leaks on nozzles have been occurred repeatedly since 1998. The NRC assumed that further leakages were hidden by the deposits resulting from leakage at flanges. The signs of corrosion at the RPV head had not been detected. The cavity at nozzle No 3 had mainly been caused by the leakage. The wastage had at least begun four years before detection. There were still unclear points regarding the role of the deposits, the chemical processes of corrosion, the impact of the RPV head operating temperature and the crack growth in the nozzle.

The plant manufacturer Framatome ANP reported on construction-, manufacture- and material-related aspects of nickel-based alloys, especially on RPV head penetrations made of Alloy 600. The influence of the nickel content regarding susceptibility to intergranular stress corrosion cracking (IGSCC) in high-temperature water, the boric acid corrosion on the RPV head of the Davis Besse nuclear power plant, the boric acid leakage at the inspection holes of the plant, and the indications of boric acid corrosion detected there, the time history of the damage occurred, and the corrosion velocities were discussed. Globally seen, there was the following situation regarding the reactor vessel head penetrations and its applicability to Siemens/KWU plants:

Foreign plants	**Siemens/KWU plants**
Alloy 600 nozzles	compound tube (St52/1.4550 cladded)
contraction joint	threaded joint (trapezoidal thread bearing the loads)
susceptible to IGSCC	not susceptible to corrosion

In particular, the comparison is as follows:

	Davis Besse	**Obrigheim NPP (KWO)**	**Siemens/KWU PWR plants**
Nozzle Material	Alloy 600	Alloy 600	Compound tube (St52/1.4550 cladded)
Solution annealing	870-930° C	1,000-1,050° C	
$Rp_{0,2}$	340 N/mm^2	257 N/mm^2	
Mounting	Shrinking/ weld-in	Shrinking/ weld-in	Shrinking/ weld-in
Weld metal	Alloy 182	Alloy 82/182	Austenite24/12 (seal weld)
Stress-relief heat treatment	none	600° C, > 10h	none
IGSCC susceptibility	high high tensile stress from manufacture (tube) and shrinking	low low tensile stress due to stress-relief heat treatment	not given

The ferritic RPV head nozzles are welded with nickel-base weld metal (Alloy 182, unbuffered) with the austenitic nozzle flange: The root is normally austenitic (material 1.4551). At the pressure tubes, the circumferential welds RN 1 and RN 2 are unbuffered dissimilar welds with nickel-base weld metal (Alloy 82/182, normally medium-swept); the circumferential welds RN3 and RN 4 are austenitic (material 1.4551).

At Siemens/KWU PWR plants, the design of the flange seal between control rod nozzle and pressure tube was considerably more elaborate with regard to safety compared to the seal design of the US-American manufacturer Babcock und Wilcox due to an internal and external conoseal lining made of the material No

1.4541 and an instrument line (leakage monitoring). At Siemens/KWU PWR plants, the load-bearing function (trapezoidal thread) and the sealing function (seal weld) had consequently been separated (exception: KWO plant).

The report of the company IntelligeNDT and the plant manufacturer Framatome ANP on the inspection of RPV heads at Siemens/KWU PWR plants, first gave an overall survey of the inspection areas of the RPV heads and the pressure tubes. The basic principle, the manipulator of the ligaments between the RPV head nozzles, the data evaluation and the areas for the ligament examination were presented. The examination areas reached with a creeping wave phased array probe at the external surface of the RPV head were explained. They led to full examination coverage at the external surface. Regarding the examination of the ligaments between the RPV head nozzles (volume and internal surface), the phased array technique covered a large part of the volume and all ligaments at the internal surface. The detectability of discontinuities in the surfaces corresponded to a groove of 3 x 20 mm minus 6 dB and CRR 3 mm in the volume. In the area of the ligaments between the RPV head nozzles, there were no recordable indications at Siemens/KWU PWR plants. Since 1989, examinations were performed by means of the phased array technique. Since 2002, ultrasonic tests and integral visual examinations have been performed simultaneously.

Regarding the pressure tube inspection, the EMUS (electromagnetic ultrasonic) technique and the eddy-current test were mentioned, and regarding the in-core instrumentation nozzles the inspection with eddy current rotating probes. The inspection could be performed from the external surface by means of the EMUS technique, and the internal surface by means of the eddy current technique. Welds No 2, 3 and 4, the control rod nozzle welds and the in-core instrumentation nozzle welds were examined by means of the eddy current technique (internal surface examination). The detectability of discontinuities in the surfaces corresponded to a groove of 0.5 x 10 mm with eddy current and with EMUS CRR 3 mm in the volume. There were no recordable indications at Siemens/KWU PWR plants. If required, a visual examination was performed with regard to surface indications. Circumferential weld No1 of the pressure tubes can only be examined after dismantling of the pressure tube due to the latch unit installed in the interior.

The weld examination (circumferential weld) of the RPV head was performed by means of a phased array tandem system as well as 45° ET and 70° SEL, so that longitudinal and transverse discontinuities in the circumferential welds and the high-stress areas in the transition area to the head flange can be detected. Both circumferential welds were subjected to full examination. There were no indications to operational damages at Siemens/KWU PWR plants. The detectability of discontinuities in the surfaces corresponded to a groove of 3 x 20 mm minus 6 dB and CCR 3 mm in the volume.

According to the explanations given by the reports presented and the representative of the utility EnBW, the German operators of PWR plants have intensively dealt with the examination of the RPV head, among others, also with regard to the requirements of the competent *Land* authority. Regarding materials, construction and manufacture, there were no indications that the incident at the American Davis Besse nuclear power plant can be applied to German plants. In addition, it was pointed out that in the next months, an intensive exchange of experiences with US-American experts will take place.

The results of stress corrosion cracking analyses for Alloy 500 in PWR coolant, presented to the RSK Committee on PRESSURE-RETAINING COMPONENTS AND MATERIALS at the meeting, show, according to the rapporteur, a clear dependence of the crack growth data on the temperature. The area determined here – as in many other cases – in which the velocity of the crack growth by stress corrosion cracking is almost independent on the stress intensity factor, is about 10^{-9} m · s^{-1} (equivalent to about 30 mm per year) for 350° C, about 3 · 10^{-10} m · s^{-1} for 320° C, and about . 3 · 10^{-11} m · s^{-1} for 290° C, for basic material and weld metal each. Similar measurements of the crack growth velocity were also achieved for the stress-relief heat-treated, the cold worked and not cold worked condition.

In the subsequent discussion, the Committee dealt with the following aspects:

- Causes (materials, stress corrosion cracking, cracks, material Alloy 600, etc.),
- detectability (indicator quality),
- non-destructive examinations (NDEs):
  - accessibility,
  - walk-down, walkability,
  - visual examinations (Preferably after shut-down? Or also during start-up during leakage test?),
  - examination intervals,
  - examination methods,
- time behaviour (e. g. corrosion velocity and the like) regarding the question whether a plant affected by boric acid corrosion can be operated for a cycle without any safety concerns,
- procedures/testing manual. Are revisions required? (from the point of view of both committees)

29th meeting of the RSK Committee on PRESSURE-RETAINING COMPONENTS AND MATERIALS on 04.09.2002 (consultancy documents [8-14])

The operator of the KWO plant presented a safety assessment of the RPV head nozzles. The analyses and methods performed by the licensee from the first event at the French NPP Bugey 3 in the year 1991 until the outage in 2002, inclusively, were described. The main statements of the documents presented to the RSK Committee on PRESSURE-RETAINING COMPONENTS at meeting No 190 on 06.12.1991 and meeting No 193 on 06.03.1992 for the assessment of the RPV head nozzles of the KWO nuclear power plant were presented.

The measures continued by the licensee since 1992, such as calculations, installation of leakage detection systems and non-destructive examinations, were mentioned.

The licensee explained the initial situation as well as the analyses and assessments for the period from 1992 to 2002. The latter concerns construction/manufacture/quality, loads, stress and fatigue analysis, visual examinations and non-destructive examinations. The arrangement of the RPV head nozzles at the KWO nuclear power plant was presented. According to the licensee, the spare nozzles located in the peripheral area were subjected to a full examination over the length. The licensee addressed welding of the nozzles into the RPV head and the respective weld method, and compared it, regarding construction/manufacture/quality, with the Davis Besse nuclear power plant. With regard to former indications in nozzles at French plants, the operator of the KWO plant addressed the comparison of nozzle loads during operation (comparison between KWO and Bugey, Unit 3), factors promoting crack initiation at French plants and factors preventing crack initiation at the KWO plant.

In connection with the analyses for keeping up the operating licence, the operator of the KWO plant declared that finite element calculations were performed for the weld-in area of the RPV head nozzle; according to the plant operator, the maximum cumulative usage factor from the fatigue analysis was D = 0.24 for the weld nozzle/head and D = 0.02 for the ferrite near the weld. Analyses on crack growth induced by stress corrosion cracking für the material Alloy 600 in PWR coolant were performed.

The operator of the KWO plant compared the flanges of the RPV head nozzles KWO/Davis Besse and presented the leakage rates at the US-American Davis Besse plant from January 2000 until January 2002. This was compared to the flange leakage rates (seals) at the KWO plant in the year 1994. In addition to global methods, the two operational local leakage detection systems for the RPV head BLISS (Bartec Leakage Indication Sensor System: self-monitoring and located in the area of the RPV head nozzle flange for monitoring of the flange connection YA01 M001 (sensor tube)) and FLÜS (Feuchte-Überwachungssystem – humidity monitoring system), located in the area of the RPV head nozzle YA01 M010 (sensor tube), are used for leakage detection; upon inquiry of the Committee, information was given on the technical data and the capacity. According to the plant operator is BLISS a leakage detection system with yes/no indication and a response threshold of about 10 l/day, used since the beginning of the nineties; the FLÜS system had been used since 1995. According to the competent *Land* authority, the Ministry for the Environment and Transport - Baden-Württemberg (UVM B-W), tests for the determination of the response thresholds with FLÜS resulted in about 1 l/hour.

Finally, the operator of the KWO plant addressed the visual inspections in the area of the RPV head and the further NDEs for nozzles and RPV head, as well as the special tests on nozzles in the year 1992 and the eddy current tests on nozzles (1992, 1994/2000). On the basis of the examinations and tests performed in the last ten years and leakage monitoring during operation, the plant operator stated that there were no indications of incipient cracks or leakages on the nozzle tubes of the RPV head.

Due to its high sensibility in case of operational leakages, the very sensitive global and local leak detection, the accessibility and the regular visual inspections, as well as the comprehensive additional NDEs (recurrent inspections), the plant operator is of the opinion that a damage mechanism comparable to the incident at the Davis Besse plant can safely be excluded.

With regard to the leak rate of 30 l/day (from 06.01.2000 to 02.01.2002) at the American Davis Besse plant with peak values of up to 80 l/day (from 10.02.2001 to 12.02.2001), the typical basic leak rate for the KWO plant with about 10 to 15 l/day and the sensibility of the plant management in case of clear trends towards higher values which may lead to plant shut-down was addressed in the discussion. On the part of the UVM B-W, reference was made in this respect to a notification of the plant operator prior to plant shut-down due to leakages at the flange seals of the nozzles in position H12 and E05 in the year 1994. Regarding the construction-, manufacture- and material-related aspects and the seal design of the control rod nozzle at PWR plants in Germany, reference was made to meeting No 25 of the Committee on PRESSURE-RETAINING COMPONENTS AND MATERIALS on 15.05.2002.

At present, a visual inspection of the RPV head (outside) in German nuclear power plants is not mandatory.

It was reported to the Committee that in response to the incident at the American Davis Besse plant examinations were performed at several German plants. With respiratory protective equipment used by the inspector, the reliability of the results of the inspection, especially of the nozzle field, was to be regarded as impaired. It was recommended to perform a mechanised visual inspection with video recording at intervals of four years..

With the available special test probe it was possible to examine the control rod nozzles from the inner side with eddy current if the width of the gap between control rod guide tube and the nozzle is larger than 1.5 mm. This was not given for all PWR plants. Regarding the incident at the Swedish Ringhals NPP, Unit 4 (reporting of GRS at meeting No 23 of the Committee on PRESSURE-RETAINING COMPONENTS AND MATERIALS on 17.01.2001), the Committee is of the opinion that the non-destructive examination (NDE) of the medium-swept welds, which currently is not feasible in some cases, should be improved.

The representative of the expert organisation TÜV Energie- und Systemtechnik GmbH Baden-Württemberg presented a safety assessment of the RPV head nozzle penetrations of the KWO plant; from his point of view, the preceding comprehensive report of the plant operator was appropriate. The rapporteur briefly described the activities related to expert opinions on the KWO plant; in the years 1991 to 1994 detailed investigations were performed which had been confirmed by the results of non-destructive examinations (NDEs). With regard to the statement of the TÜV Südwest of 17.01.1994, the expert addressed – for comparison of the Alloy 600 head nozzles at the plants Bugey, Unit 3/Davis Besse/KWO regarding their susceptibility to stress corrosion cracking – the wall thickness of the RPV head, the spherical radius, the nozzle design, the pressure test, the material and the type of manufacture. Further, he compared installation, weld-in, weld volume and the performed stress-relief heat treatment and gave a survey of the NDE of the RPV head of the KWO plant with participation of the TÜV which had not revealed any indications of incipient cracks or leakages. The expert summarised his assessment that from his point of view there are two main factors for the resistance of the Alloy 600 nozzles against stress corrosion cracking at the KWO plant:

- Due to construction and manufacture, the operational stress maxima for the inner side of the nozzles in the weld-in area are considerably lower compared to the nozzles at comparable French and US-American plants.

- Due to the type of manufacture (usage of hot worked tubes), the material condition is more homogeneous and less susceptible.

This assessment was confirmed by the results of the comprehensive NDEs.

The representative of the UVM B-W gave the additional information that the reported facts of the case, at that time had been dealt with in co-operation with the RSK. On the part of the competent *Land* authority there were no supplements to be made to the reports of the licensee and the expert organisation.

148th meeting of the RSK Committee on REACTOR OPERATION on 21.01.2003
(consultancy documents [15-17])

In its assessment, the RSK Committee on REACTOR OPERATION agreed with the recommendations in the GRS Information Notice on the incident [17].

367th RSK meeting on 13.11.2003 (consultancy document [18])

The BMU stated that the RSK should assess the incident sequence at the Davis Besse plant. In its statement, the RSK should address the causes and assess each of them individually. In this respect, the relevant individual aspects, as e. g. the behaviour of the licensee, in comparison with Germany, the damage sequence, etc., should be addressed.

4 Assessment criteria

The general safety requirements are based on the safety criteria of the Federal Ministry of the Interior (BMI), the RSK guidelines for pressurised water reactors and the respective KTA standards.

For the assessment, the RSK considered the following aspects:

Boron deposits which may lead to corrosion attacks on safety-relevant components/systems must be prevented and existing deposits have to be detected and measures against further deposits be implemented in time.

For the assessment of the fulfilment of this requirement, the following principles have to be referred to:

- Prevention of leakages by corresponding precautions in construction, material selection, mode of operation and maintenance management,
- early detection of leakages by continuous monitoring and recurrent inspections,
- functioning safety management in such a way that in case of indicators given with regard to primary system leakages, deposits, indications of corrosion etc., efficient measures for the prevention of inadmissible consequences are immediately initiated.

The RSK examined whether these requirements were considered in the assessment according to the state of the art in science and technology and whether the analyses are plausible with regard to the facts of the case presented and explained.

5 Safety-related assessment

The RSK draws the conclusion that due to the fast progressing corrosion, the incident is of high safety significance because all of the four safety objectives are concerned. Under the incident circumstances, a failure of the wall in this area would have led to a loss of coolant accident (LOCA) with leakage at the RPV where a simultaneous ejection of the control rod concerned cannot be excluded. The special significance is also due to the fact that the operator of this plant underestimated the corrosion type and rate although the mechanism was known. In addition, there were numerous indications at the plant, as e. g. massive accumulation of corrosion products in coolers and filters which would have had to lead to a clear determination of the causes and initiation of countermeasures. On principle, the corrosion mechanism can also be applied to German plants. Regarding the cause and the maintenance deficits, a direct applicability is not given. This issue will be addressed more detailed in the following. The incident was primarily due to a massive maintenance deficiency and not only to the material mechanics.

The RSK points out that the authorities and experts working in the frame of licensing and supervision in Germany accompany plan operation more closely. In the past, the problems associated with corrosion processes have extensively been discussed at the RSK by the Committee on PRESSURE-RETAINING COMPONENTS. As a result of these discussions, the RPV head nozzles at all German plants were inspected. Except for the KWO plant, the nozzles at all German PWR plants of the manufacturer Siemens/KWU were provided with double seals and instrument lines (leakage detection) which were subjected to leakage tests after installation.

At KWO, a special reactor vessel head leak monitoring system being more sensitive than the integral leak monitoring system at other plants was installed. Further, it has to be pointed out that the construction (control rod nozzles/RPV head) and the material of the control rod nozzles of Siemens/KWU PWR plants are not comparable to the Davis Besse plant.

In comparison to the American plants, there were only very few events with boron corrosion at German plants. On this issue, a *Länder* survey was prepared on behalf of the BMU (corrosion indications at RPV head at a US-American plant, letter of the BMU to GRS of 3 April 2002 with enclosures (statements of the *Länder* on an inquiry of the BMU – RS I 3 – 14 200/1)), in which it was explicitly confirmed that at German PWR plants – for BWR plants, boron corrosion is not possible during normal operation due to the technical design – no leakages occurred at head nozzles.

Prevention of leakages

According to the present state of knowledge, the damage observed at the US-American Davis Besse nuclear power plant (stress corrosion cracking of the Alloy nozzles resulting in boron-induced surface corrosion) is not to be expected for German plants, except for the Obrigheim nuclear power plant (KWO), due to the construction – screw-in nozzles with welded joint – and due to the material-related boundary conditions. The limitation regarding the KWO plant explicitly refers to the material. After the detection of cracks in the nozzles of the pressure tubes of the control rod drives at the French plants Bugey (Units 1 and 3) and Fessenheim (Unit1) in the year 1991, the German plants were inspected without indications. At the KWO plant, the nozzles were subjected to a full examination. The RPV head penetrations installed at KWO are more resistant against stress corrosion cracking compared to comparable French and US-American plants due to conditions given by construction and manufacture type (e. g. low stress level)..

In general, through-wall cracks in components or, above all, leakages at seals cannot be excluded. In case of leakage of boric coolant (at BWRs not given in safety-significant areas with regard to integrity), boron deposits may occur. At German PWR plants, boron deposits occurred, among others, in safety valves of the primary system and in some cases also in case of small leakages. There are no cases known to the RSK where deposits led to significant corrosion. This is an indication of a well-functioning maintenance management system at German plants in case of detected leakages.

Detection of leakages

The external areas of the RPV head are annually subjected to a visual inspection within the frame of the refuelling outage. For this purpose, the external insulation is removed. The accessibility of the RPV head area at German plants is better compared to US-American plants because there is no weld-on "jacket" or "collar" as it is the case for American plants. At German plants, the insulation (insulation cover) is completely removable.

In Germany, the intervals for non-destructive examinations (NDEs) of the RPV head are, in accordance with KTA Safety Standard 3201.4, four or five years. The circumferential welds and the basic material areas of the ligaments between the RPV head nozzles are subjected, in accordance with the KTA safety standards, to ultrasonic tests and in the other areas to visual examinations (integral visual examination). The ultrasonic tests are performed at the internal and external surfaces and volumetrically. According to a declaration of intent by the operators of PWR plants, the test equipment is based on the phased-array technique which, at present, is the most advanced and progressive technique. Further, integrals visual examinations are performed by which deposits and discolorations would be detected.

Due to the monitoring system at German plants at the flanges of the pressure tubes, leakages are detectable. this has also be confirmed by experiences made with leakages in the area of the RPV head. In case of leakages, their causes immediately have to be clarified and corrective measures performed.

At the KWO plant, there are the two very sensitive leakage detection systems BLISS and FLÜSS in the area of the RPV head. The reports submitted showed that with these systems, a sensitivity for operational leakages and their potential impacts on normal operation was developed to the required degree.

Compared to the US-American Davis Besse plant, the conditions at KWO are also considerably better due to the non-destructive examinations (manufacturing and initial tests and recurrent inspections).

As a general rule, the screwed joints at the other components of the primary system are visually inspected after each loosening (direct visual examination) in accordance with the KTA safety standards. In addition an integral visual examination is performed within the frame of a plant walk-down. By means of these examinations, leakage indications and deposits as well as discolorations at not isolated surfaces of the components can be identified.

Safety management

An essential part of a functioning safety management is the implementation of an efficient safety-directed maintenance management. This begins with preventive maintenance and also includes efficient leakage detection (see above) and the implementation of measures for the prevention of inadmissible consequences. At the Davis Besse plant, there were sufficient knowledge and indicators for unexpected corrosion processes which absolutely would have given reason for taking action.

In case of leakages in other areas, especially in the area of detachable connections, the maintenance management has to ensure that no boron-induced corrosion processes occur.

Also due to the fact that the supervisory authorities and their authorised experts closely accompany plant operation and due to the respective rules and regulations it is not to be expected that the cause of such clear indicators, such as the large accumulation of corrosion products in coolers and filters, will not be investigated adequately.

6 Recommendations

Altogether, it is to be stated that the corrosion problem generally is of increasing safety significance during the operation of nuclear power plants for the further lifetime. This is shown by the incident at the American Davis Besse plant. Due to the fast progressing corrosion in the RPV wall, the incident is of high safety significance because all of the four protection objectives are concerned.

On the basis of the conditions at German nuclear power plants, the RSK recommends the following measures:

(1) During each refuelling outage, an integral visual examination (direct visual examination) is to be performed after removal of the external insulation of the RPV head; the result of this examination has to be documented.

(2) During each recurrent inspection of the ligaments between the RPV head nozzles, a visual examination of the nozzle area is to be performed (visual examination according to DIN 25435-4).

(3) Within the frame of the recurrent inspections, the areas of the other primary system components additionally have to be subjected to a visual examination (direct visual examination) after removal of the insulation

(4) For component areas with medium-swept welds made of nickel-based alloys where removal of the insulation is not scheduled (e. g. heating rod nozzle at the pressuriser, instrument nozzles, small-bore pipes), integral visual examinations have to be established.

(5) In case of anomalies during operation, such as increased accumulation of corrosion products in the room air (filters), the cause has to be clearly identified and further measures have to be determined.

(6) In case of indications of leakages and boric acid deposits in the primary system, the area concerned has to be inspected with regard to the cause and potential corrosion attacks.

(7) In case of indications of potential boron leakages in the immediate area of the RPV, especially in the area of the reactor cavity, due to leak water accumulation with boric acid or deposits of corrosion products, corresponding measures have to be initiated to clarify the cause.

(8) The scopes of the examinations required above have to be laid down in the testing manual. The measures to be taken in response to (5), (6) and (7) have to be specified in the instruction manual (Betriebshandbuch - BHB).

For the rest, the RSK agrees with the recommendations of the GRS Information Notice WLN 02/2003 an.

7 Documents, information and expertise

The following documents, information and expertise were referred to:

[1] Borsäurekorrosion am Reaktordruckbehälterdeckel der Anlage Davis Besse
Vortragsfolien zum Bericht der GRS
Tischvorlage zur 140. Sitzung des Ausschusses REAKTORBETRIEB am 24.04.2002

[2] Kopien von Folien, die von der GRS in der 141. Sitzung des RSK-Ausschusses REAKTORBETRIEB am 24.04.2002 gezeigt wurden

[3] RSK-Information DKW25/8
Korrosionsmulde im Deckel des Reaktordruckbehälters im US-amerikanischen Kernkraftwerk mit Druckwasserreaktoren Davis Besse, Block 1, entdeckt im Brennelementwechsel Februar/März 2002

[4] A. Roth, G. König:
Benetzungen von Bauteilen aus un- und niedriglegierten Stählen in DWR-Anlagen mit borsäurehaltigen Medien und deren Folgen – Betriebserfahrungen und aktueller Stand von Wissenschaft und Technik zur Korrosion von un- und niedriglegierten Stählen in wässrigen Borsäurelösungen
25. MPA-Seminar, Stuttgart, 07./08.10.1999
Vortrag Nr. 47

[5] Kopien von Folien, die von der GRS in der 25. Sitzung des RSK-Ausschusses DRUCKFÜHRENDE KOMPONENTEN UND WERKSTOFFE am 15.05.2002 gezeigt wurden

- Borsäurekorrosion am Reaktordruckbehälterdeckel der Anlage Davis Besse
- Große Korrosionsmulde im RDB-Deckel
- Befunde
- Reactor Pressure Vessel Head Degradation Location
- Photo of Degraded Area Adjacent to Nozzle 3
- Cross-Sectional Sketch of Degraded Area Adjacent to Nozzle 3
- Nozzle 2 Metal Loss
- Allgemeine Prüfanforderungen der WKP nach ASME XI (2001)
- Generic Letter 88-05: Programm gegen Borsäurekorrosion, Ziel: Vermeidung großer Lecks in der DFU
- RPV Head Configuration
- Access Openings

- Flanschleckagen und Leckraten
- Ergebnisse der visuellen Inspektionen bei Revisionen
- NRC Bulletin 2001-01: Umfangsrissbildung an Deckelstutzen
- Inspection Results
- Ergebnisse der US-Prüfung nach NRC Bulletin 2001-01
- Findings
- Indikatoren für signifikante Korrosion/Lecks an Stutzen
- Schlussfolgerungen der US NRC

[6] Deckelprüfung in KWU-Druckwasserreaktoren, Vorlage zur 25. Sitzung des RSK-Ausschusses DRUCKFÜHRENDE KOMPONENTEN UND WERKSTOFFE am 15.05.2002, Kopien von Folien, IntelligeNDT Framatome ANP

[7] Kopien von Folien von Framatome ANP:
- Nickelbasislegierungen, Alloy 600 RDB-Deckeldurchführungen
- Einfluss des Nickelgehalts auf die IGSCC-Anfälligkeit in Hochtemperaturwasser
- RDB-Deckel Borsäurekorrosion, Konstruktion Aufbau RDB Davis Besse
- RDB-Deckel Borsäurekorrosion, Fotos Davis Besse
- RDB-Deckel Borsäurekorrosion, Borsäureaustritt Inspektionsöffnungen, Fotos
- RDB-Deckel Borsäurekorrosion, Hinweise auf Borsäurekorrosion
- Probable Timeline
- Davis Besse Estimated Reactor Vessel Closure Head Corrosion Rates
- RDB-Deckeldurchführungen
- Übertragbarkeit auf S/KWU-DWR-Anlagen
- Dichtungsausführung Steuerstab-Stutzen

[8] Auszug TOP 4 des Ergebnisprotokolls der 193. Sitzung des RSK-Ausschusses DRUCKFÜHRENDE KOMPONENTEN am 06.03.1992

[9] Auszug TOP 6 des Ergebnisprotokolls der 195. Sitzung des RSK-Ausschusses DRUCKFÜHRENDE KOMPONENTEN am 04.05.1992

[10] Auszug TOP 3 des Ergebnisprotokolls der 207. Sitzung des RSK-Ausschusses DRUCKFÜHRENDE KOMPONENTEN am 11.05.1993

[11] Auszug TOP 3 des Ergebnisprotokolls der 219. Sitzung des RSK-Ausschusses DRUCKFÜHRENDE KOMPONENTEN am 18.05.1994

[12] Auszug TOP 8 des Ergebnisprotokolls der 287. RSK-Sitzung am 14.09.1994

[13] Sicherheitstechnische Bewertung der Deckelstutzen des Reaktordruckbehälters, Vorlage des Kernkraftwerks Obrigheim zur 29. Sitzung des RSK-Ausschusses DRUCKFÜHRENDE KOMPONENTEN UND WERKSTOFFE am 04.09.2002 in Bonn, 15.08.2002

[14] Tischvorlage des TÜV Süddeutschland zur 29. Sitzung des RSK-Ausschusses DRUCKFÜHRENDE KOMPONENTEN UND WERKSTOFFE am 04.09.2002 in Bonn, 03.09.2002

[15] Anlage 1 zum Ergebnisprotokoll der 30. Sitzung des RSK-Ausschusses DRUCKFÜHRENDE KOMPONENTEN UND WERKSTOFFE am 09.10.2002
STELLUNGNAHME des RSK-Ausschusses DRUCKFÜHRENDE KOMPONENTEN UND WERKSTOFFE
„Korrosionsmulde im Deckel des Reaktordruckbehälters im amerikanischen Kernkraftwerk Davis Besse Block 1“

[16] Ergebnisprotokoll der 29. Sitzung des RSK-Ausschusses DRUCKFÜHRENDE KOMPONENTEN UND WERKSTOFFE am 04.09.2002 (TOP 6)

[17] Gesellschaft für Anlagen und Reaktorsicherheit (GRS)
Weiterleitungsnachricht 2003/02:
Große Korrosionsmulde im Reaktordruckbehälter-Deckel des Kernkraftwerkes Davis Besse (USA)

[18] RSK-Information RSK365/9
Vorkommnis der INES-Kategorie 3 im amerikanischen Kernkraftwerk “Davis Besse” vom 06.03.2002, “Borsäurekorrosion am Reaktordruckbehälterdeckel”
SCHRIFTLICHER BERICHT der RSK-Ausschüsse REAKTORBETRIEB und DRUCKFÜHRENDE KOMPONENTEN UND WERKSTOFFE