Note:
This is a translation of the statement entitled “Spannungsnachweis und Prüfbarkeit der Schweißnaht an der Verbindung zwischen Zylinder und unterer Bodenkalotte in Reaktordruckbehältern (RDB) von Kernkraftwerken mit Siedewasserreaktoren (SWR) der Baureihe 69 Kernkraftwerke Krümmel (KKK), Brunsbüttel (KKB), Philippsburg Block 1 (KKP-1) und Isar, Block 1 (KKI-1)”.
In case of discrepancies between the English translation and the German original, the original shall prevail.

RSK Statement
(446th meeting on 05 April 2012)

Stress analysis and testability of the weld at the joint between the cylinder and lower bottom head in reactor pressure vessels (RPVs) of nuclear power plants with boiling water reactors of the BWR-69 type Krümmel (KKK), Brunsbüttel (KKB), Philippsburg, Unit (KKP-1) and Isar, Unit (KKI-1)

Index

1 Advisory request

By letter (reference: RS I 3 – 17018/1 of the German Federal Ministry for the Environment, Nature Conservation and Reactor Safety (BMU) of 17 May 2011 (Quotation [1]), the RSK has been asked to provide a statement on the reactor pressure vessels (RPVs) of the BWR-69 type plants. According to BMU, in these BWR plants RPVs are installed which, regarding material characteristics and design, not fully comply with the KTA Safety Standard requirements for design and calculating as well as for in-service inspections. Due to limited accessibility, the sufficient testability of the weld at the joint between the cylinder and lower bottom head is in question. Like the whole RPV, this weld highly stressed from inside is cladded for reasons of corrosion protection, and due to time-consuming accessibility (recirculation pumps would have to be removed) can only be examined from outside by means of ultrasonic testing methods. Furthermore, there are some limitations regarding the checking of errors which might spread parallel to the cylinder wall (transverse defect detection).

A technical note on a Länder survey of GRS is attached to the letter of BMU as a consultancy document (Quotation [2]). The BMU requests for a statement on the following questions:

- To what extent the construction and design of the reactor pressure vessel of the BWR-69 type correspond to the state of the art in science and technology, and how to use the general calculation methods for the above mentioned weld according to the state of the art in science and technology?

- Is evaluation and classification of the stress parts in accordance with the KTA Safety Standard concerning this issue appropriate?

- How to furnish the leak-before-break proof for the above mentioned part of the weld for the foreseen lifetime according to the state of the art in science and technology?

- Are the examinations and their intervals for this area sufficient to be able to recognise an increasing crack under the cladding it the event of limited testability and a possible stress utilisation and fatigue usage factors?

2 Safety significance

The reactor pressure vessel (RPV) is a component of the pressure boundary, these together with the connected pipe systems of the cooling circuit ensure the cooling of the core. Furthermore, the reactor pressure vessel aims to preserve the core geometry in order to ensure the coolability and safe shutdown by the control rods. In addition, as part of the pressure boundary, the reactor pressure vessel is an essential barrier for the confinement of the radioactive materials in the cooling circuit

3 Assessment criteria

The safety requirements on the joint between the cylinder and bottom head in RPVs of the BWR-69 type plants (seam weld of the bottom head) are specified in the nuclear rules and regulations. The assessment is based on the state published in the professional literature and on the knowledge of experts consulted. The General Requirements for this special case are:

- stress limitation and fatigue protection according to the nuclear rules and regulations,
- assessment of integrity according to the flow chart in the KTA standard 3201.4 and
- testability of the seam weld of the bottom head.

4 Course of discussions

The RSK Committee on Pressure-Retaining Components and Materials has been informed on the advisory request at the 110th meeting on 25 and 26 May 2011. At the 112nd meeting on 14 September 2011, the committee started the discussion and receives reports from Prof. Dr. Zehn (Technical University Berlin), from Vattenfall and from the Helmholtz-Zentrum Dresden-Rossendorf (HZDR), as well as from TÜV SÜD Energietechnik (quotations [3], [4] and [6]).

In its report, Prof. Dr. Zehn stated that all regulations for pressure vessels define that container welding seams in bending and stress endangered zones are to be prevented. The explanation of the reason for the derogation from this requirement at the time of the design of the RPV of the BWR-69 type has been: "*the arrangement of a convex bottom where the attachment welds lie outside the bending zone was not possible, because otherwise the penetration for the circulation pumps had to be included at the knuckle area.*" In the report, it was noted that, also according to the current KTA safety standards, the RPV bottom design is not optimal. With regard to BWR types, the RPV bottom has great safety significance because the control rods are inserted from the bottom – thus contrary to the force of gravity.

Firstly, the commentator of the HZDR explained that the report "Stress and fatigue analysis for the RPV bottom of the Krümmel nuclear power plant (KKK)", Rev. A, May 2010 (quotation [5]) has been drawn-up on behalf of Vattenfall for the Periodic Safety Review of KKK. In this report, the focus is not on the bottom weld; the bottom weld is covered by higher stressed RPV bottom positions. The report of the 112nd meeting presents the results of the report of May 2010 and includes an additional consideration of details of the bottom head seam weld. According to the presentation in the report, the stress of the bottom head seam weld is uncritical. The KTA approach to categorise the stress is appropriate. By considering all relevant loads, there is no plastic deformation in the area of the bottom seam. Thus, no relevant fatigue is expected. The strain measurements during the commissioning and the stresses determined confirm the reliability of the calculations. The stress level is known since the commissioning.

In the report of TÜV SÜD Energietechnik, it is stated that the initial design calculations as well as recent stress and fatigue analyses has been reviewed by expert, and new stress analyses have been investigated by means of FEM analyses. According to the commentators, the RPVs of the BWR-69 type, compared to conventional RPVs, have an unusual design where the bottom in a channel head form without knuckle is directly connected to the reinforced, cylindrical supporting ring. In the frame of the manufacturing test, the seam weld of the bottom head has been tested, also inside, without any restrictions. No incorrect readouts have been registered. Also during in-service inspections in the KKP 1 plant, no unusual findings were determined. The limitation in test in case of transverse defect detection does not constitute a significant limitation within the meaning of KTA 3201.4. Regarding the categorisation and evaluation of stress, there are no differences between the ASME BPV Code (Section III and VIII) and the KTA 3201.2 and DIN EN 13445. The stress condition in the transition area bottom/supporting ring (weld seam) is characterised by dominant meridian stresses with high bending stress components. Bending stresses in the transition area bottom head/supporting ring are secondary. The stress levels determined with different FE models and evaluated according to KTA°3201.2 and ASME BPVC, Subsection NB are considerably lower than the permissible stresses according to these regulations. Limit analyses according to KTA 3201.2 constantly recorded permissible internal pressures for the design. The failure critical area is not in the transition area bottom/supporting ring, rather there are still significant load bearing reserves.

The committee agreed in the assessment that the design for the specific purpose is optimised regarding the manufacturing technology and the geometry. Nevertheless, it is not optimal with regard to the weld seam, as the weld seam lies in the area of locally increased stresses and in-service inspections can only be performed from outside.

During the 113rd meeting on 5 October 2011, the committee started discussions on the statement, which was adopted during the 114th meeting on 16 November 2011. The RSK debated and adopted the statement during its 446th meeting on 5 April 2012.

5 Results of the discussions

The RSK noted that the BWR-72 type, too, has a similar design at the joint between the cylinder and the bottom head of the RPV.

After consulting, the RSK answers questions of the BMU as follows:

- To what extent the construction and design of the reactor pressure vessel of the BWR-69 type correspond to the state of the art in science and technology, and how to use the general calculation methods for the above mentioned weld according to the state of the art in science and technology?

At the time of design, construction and manufacturing, with regard to several boundary conditions, the RPV of BWR-69 type plants had an optimised design in accordance with the state of the art at that time. Although, the membrane stress level of the weld seam shows only a capacity utilisation of 50%, according to the current knowledge, the design is not optimal with regard to stress peaks and non-destructive tests at the weld seam area.

However, in the Committee's view, the design and the safety analyses on the RPV meet the requirements according to the state of the art in science and technology due to the recent calculation methods and the recent non-destructive tests.

- Is evaluation and classification of the stress parts in accordance with the KTA Safety Standard concerning this issue appropriate?

According to the RSK's view, this is absolutely the case, if the current version of the KTA 3201.2 and the ASME Code are fulfilled.
The RSK bases its judgement on the results of calculations which have been reinforced by limit analyses ([7]). According to the RSK, this could have been expected for this geometry; furthermore, the RSK refers to the corresponding calculation results for other geometrical factors like e.g. nozzles or other more complicated boundary conditions also confirming the reliability of the evaluation and categorisation of the stress components according to the KTA Safety Standards.

- How to furnish the leak-before-break proof for the above mentioned part of the weld for the foreseen lifetime according to the state of the art in science and technology?

The leak-before-break mentioned in the question does not exist for the reactor pressure vessel. Break preclusion and integrity are quality characteristics of the RPV. For limit analyses, a leak in the spherical bottom of BWR pressure vessels has been investigated[1)].

- Are the examinations and their intervals for this area sufficient to be able to recognise an increasing crack under the cladding it the event of limited testability and a possible stress utilisation and fatigue usage factors?

A postulated crack in the weld metal is positioned at the internal surface. For a crack alongside the weld seam the testability is ensured; with regard to the stress, these are the leading crack orientations. There are limitations in testability with regard to cracks transversely to the weld seam; these are known. Cracks of the same size as the root extension of the lower bottom head weld can be detected in the direction of the lower bottom head.

[1)] For the design of the emergency cooling systems, a leak of 80 cm^2 (geometric cross section: circular) was postulated of the reactor core below the top edge of the reactor core.

According to RSK, the examinations and their intervals for the timely identification of a crack are sufficient despite the geometrical limitations, as the required defect detection limits are kept.

Fatigue analyses have shown that these are negligible.

6 Recommendations

The RSK recommends reviewing the applicability of the results presented to the BWR-72 type plants, as the design is comparable.

References

[1] Schreiben des BMU vom 17.05.2011 an die RSK (Aktenzeichen: RS I 3 – 17018/1, betr.: Spannungsnachweis und Prüfbarkeit der Schweißnaht an der Verbindung zwischen Zylinder und unterer Bodenkalotte bei Reaktordruckbehältern der SWR Baureihe 69 (KKK, KKB, KKP I und KKI)

[2] Untersuchungen zum Spannungsnachweis für die Bodenschweißnaht bei Reaktordruckbehältern der SWR Baureihe 69, Technische Notiz der GRS vom 25.02.2011

[3] Schweißnaht an der Verbindung zwischen Zylinder und unterer Bodenkalotte bei Reaktordruckbehältern der SWR-Baureihe 69, Kopien der im Bericht von Herrn Prof. Zehn gezeigten Bilder

[4] Spannungs- und Ermüdungsanalyse für den RDB-Boden des KKW Krümmel, Schwerpunkt Schweißnaht Bodenkalotte, Kopien der im Bericht von Vattenfall und HZDR (Helmholtz Zentrum Dresden Rossendorf) gezeigten Bilder

[5] Spannungs- und Ermüdungsanalyse für den RDB-Boden des Kernkraftwerks Krümmel, Forschungszentrum Dresden-Rossendorf e. V., Institut für Sicherheitsforschung, Ergebnisbericht zum Auftrag: EAC-4501044346

[6] Spannungen im Übergangsbereich zwischen Stützring und Kugelkalotte, Reaktordruckbehälter des SWR 69, Kopien der im Bericht des TÜV SÜD Energietechnik gezeigten Bilder

[7] L. Mkrtchyan, H. Schau, W. Wolf, W. Holzer, R. Wernicke, R. Trieglaff Stress analyses for reactor pressure vessels by the example of a product line `69 Boiling Water Reactor, Kerntechnik, 76 (2011), 4, 225-230