Note:
This is a translation of the RSK statement entitled “Schäden an BE-Zentrierstiften und Kernbauteilen”.
In case of discrepancies between the English translation and the German original, the original shall prevail.

RSK statement
(484th meeting of the Reactor Safety Commission (RSK) on 18.05.2016)

Damages to fuel assembly alignment pins and core components

1 Background

This statement is a supplement to the RSK statement "Deformations of fuel assemblies in German pressurised water reactors (PWRs)" [1]. The statement is based on the request for advice (file number: RS I 3 – 17018/1) of the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) of 05.07.2012 [2].

The advisory request of the BMU includes the following:

Events such as fractures of fuel assembly hold-down springs and alignment pins, damages to fuel assemblies occurred and the reported damages to spacer grids and cladding tubes – also caused by handling – prompted the BMU to ask the following questions:

1 Do the requirements for the design of the reactor core and, in particular, for the design of fuel assemblies correspond to the state of the art in science and technology or can new requirements be derived from current events?

2 Do the quality assurance measures of the manufacturers ensure that systematic damage to the reactor core and, in particular, to the fuel assemblies cannot occur? If not, what additional measures are required?

3 Are additional quality assurance measures required on the part of the operators? If so, which ones?

4 How is compliance with the requirements for the reactor core and, in particular, the fuel assemblies during refuelling and over the cycle controlled?

5 Are there any indications that the control measures applied so far are not sufficient?

6 Do additional measures may have to be introduced in order to detect systematic damage effects on the integrity of the fuel assemblies at an early stage? If so, which ones?

The statement [1] deals with aspects related to the deformation of fuel assemblies. This statement also considers the damages to FA hold-down springs and FA alignment pins as well as the damages to flow restrictor assemblies that have been detected later.

2 Consultations

Starting point of the consultations of the RSK Committee on PRESSURE-RETAINING COMPONENTS AND MATERIALS (DKW) were the reportable events related to the indications on the core components and FA alignment pins. The Committee started the consultations at the 129th meeting on 28/29 May 2013 and adopted the draft statement at the 149th meeting on 12.11.2015. The statement was discussed for the first time at the 482nd meeting of the Reactor Safety Commission (RSK) on 16.03.2016 and adopted at the 484th RSK meeting on 18.05.2016.

3 Damage description

3.1 Damages to FA alignment pins

Indications (fractures and cracks) on fuel assembly (FA) alignment pins made of the material Alloy X-750 were found in the 1980s (Neckarwestheim nuclear power plant, Unit 1 in 1980, in Grafenrheinfeld 1983, in Obrigheim 1984, in Biblis, Unit A 1985, in Grohnde 1987, in Unterweser 1988, in Brokdorf 1988, in Biblis, Unit B 1989 and in Philippsburg, Unit 2 1989) and in some cases in the 1990s [3, 4]. The damage to the FA alignment pins made of Alloy X-750 corresponds to the mechanism known as intergranular stress corrosion cracking (IGSCC) under primary water conditions. At the end of the 1980s, the FA alignment pins in the upper core structure (UCS) were largely (not throughout Germany) replaced by alignment pins made of the austenitic material 1.4571K70, which significantly reduced the number of fractures. There were still a few fractures on FA alignment pins made of the austenitic material 1.4571K70. The mechanism of crack initiation underlying these fractures corresponded to two known mechanisms: that of transgranular stress corrosion cracking (TGSCC) or intergranular stress corrosion cracking (IGSCC). The further crack propagation is solely transgranular and corresponds to that of a mechanically induced fatigue fracture. All FA alignment pins affected were located in the area of the UCS.

During the visual inspection of the UCS in 2012 and 2013 in the Philippsburg 2 nuclear power plant, broken FA alignment pins were detected. Six broken alignment pins made of Alloy X-750 and a broken alignment pin of austenite 1.4571K70 were found. According to ultrasonic tests performed, 19 alignment pins showed indications, twelve of which were made of Alloy X-750 and seven of austenite 1.4571K70. Moreover, a broken FA alignment pin was detected during the visual inspection of the lower core structure (LCS) in 2013 in the Philippsburg 2 nuclear power plant. During the 2014 plant outage for refuelling, the FA alignment pins were subjected to ultrasonic tests. A total of seven pins with indications have been identified.

During further visual inspections, a deformation of a fuel assembly head was detected in one case. The affected area of the fuel assembly head had been pressed down by about 4 cm; the fuel assembly was deformed as a whole. This was due to a slightly tilted, already broken fuel assembly alignment pin during positioning of the UCS at the end of the 2012 outage, but this only became apparent when withdrawing the UCS at the beginning of the 2013 outage. As a remedial measure against recurrence, a visual examination of the position of the FA alignment pins is conducted by means of an underwater camera during lowering of the UCS shortly before immersion into the RPV.

3.2 Fractures on hold-down springs

In 2012, a large number of fractures (approximately 120) of Alloy X-750 fuel assembly hold-down springs were detected in the Brokdorf nuclear power plant (KBR). In all cases, the cause of damage was IGSCC starting from the inner radius of the springs. The damage related to high thermal performance (HTP) fuel assemblies with steel guide tubes of the first and second service cycles which, with one exception, were provided with hold-down springs of two specific spring wire batches [5]. Two broken hold-downs springs were also detected in the Grafenrheinfeld nuclear power plant (KKG) during inspections in 2012, which originated from the two batches for which indications had also been identified in the KBR plant. During the 2013 outage at the Grafenrheinfeld nuclear power plant, 24 FAs with steel guide tubes were inspected, and broken hold-down springs were detected in four cases. These broken hold-down springs originated from another batch than the broken hold-down springs identified during the 2012 outage. In the case of the broken hold-down springs of 2013, no abnormalities were detected during the visual inspections in 2012.

3.3 Fractures on springs of flow restrictor assemblies

Flow restrictor assemblies are used in the guide tubes of the fuel assemblies at all core positions which are not occupied by control elements. They ensure a constant flow of coolant through all guide tubes, irrespective of the core position. Due to the requirements for the core instrumentation, different types of flow restrictor assemblies are required [12]. The design of the flow restrictor assemblies is described in [13]. The flow restrictor assemblies are clamped between fuel assembly and the upper core structure by compression springs.

Anomalies in connection with the flow restrictor assemblies have been known since 2010. At that time, two flow restrictor assemblies in the Neckarwestheim nuclear power plant, Unit 1 (GKN-1) showed a different installation position and a stronger compression, respectively, which was detected during inspection of the fuel assemblies. In 2010, inspections in the Brokdorf nuclear power plant showed two flow restrictor assemblies in not fully extended position with signs of wear at the slotted holes.

During a control of the core loading in the Grohnde nuclear power plant on 12 May 2014, a loose part was found for the type 1 flow restrictor assembly (20 flow restrictor assembly plugs) and recovered. After a closer inspection it was found that it was a fragment of the compression spring located in the flow restrictor assembly. Another characteristic was that the flow restrictor assembly had not fully been in extended position. This usually indicates a broken compression spring in the flow restrictor assembly. An anomaly as occurred in Grohnde had only been identified, as far as known until then, in the Grafenrheinfeld nuclear power plant during the 2010 outage. At that time, some flow restrictor assemblies were removed and subjected to further examination in 2011. This examination revealed a broken spring of one of the flow restrictor assemblies. In response to the findings in Grohnde, the flow restrictor assemblies were subjected to boresonic inspection within the framework of plant outages of pressurised water reactors in the Federal Republic of Germany. It turned out that there were also some cases of damage to the flow restrictor assemblies in the nuclear power plants Brokdorf, Neckarwestheim 2, Isar 2 and Philippsburg 2.

4 Safety significance

An assessment on the safety significance of FA deformations is given in [1]. This statement deals with damages to hold-down springs, compression springs of the flow restrictor assemblies and FA alignment pins. As regards the safety significance of these components, there is no generally applicable assessment due to the different functionalities of the components.

The fuel assembly alignment pins are part of the reactor pressure vessel internals. Their task is to centre the fuel assemblies when they are inserted into the core and when positioning the UCS. During normal operation and in the case of design basis accidents, the fuel assembly alignment pins help to maintain the geometry of the core together with the core barrel in such a way as to ensure reactivity control and coolability [3]. During operation, the dead weight of the fuel assemblies and the tensioning effect of the hold-down springs between the upper and lower core structure provide an additional fixation. The movement possibilities of the fuel assemblies are thus limited in axial direction and the possibilities of radial movement are also considerably limited due to the small distances between the individual fuel assemblies and the positioning of the fuel element bottom end pieces in the LCS.

The general safety requirements for the fuel assembly alignment pins can be derived from the safety requirements for nuclear power plants [10], Section 3.2 "Requirements for the reactor core and the shutdown systems". Accordingly, the control of reactivity and coolability of the reactor core shall be ensured on levels of defence 1 to 4a. The acceptance targets and acceptance criteria for the control of reactivity, fuel cooling and confinement of radioactive materials are listed in Annex 2, Table 3 of the safety requirements [10]. Requirements for the design, materials, manufacturing, operational monitoring and in-service inspection of the reactor pressure vessel internals are included in nuclear safety standard KTA 3204 [11]. There, the requirements are classified as quality class AS-RE 2. The parts classified therein are not directly involved in reactivity control and coolability of the core. The structural integrity and functional capability of the FA alignment pins shall be verified for specified normal operation (levels A and B). In the event of a failure, safe shutdown of the facility and residual heat removal must not be impaired [3].

Previous investigations conducted by Siemens [14] show that fast control rod insertion will not be impeded up to a 3 x 3 fuel assembly arrangement with any positioning of the fuel assemblies in the core in the absence of all associated 18 FA alignment pins and unfavourable displacement of the fuel assemblies. Thus, individual fractures of the FA alignment pins in the upper core structure do not affect safe shutdown and residual heat removal from the core [3].

A potential safety significance is also to be seen in the fact that bent FA alignment pins can lead to deformations of fuel rods when the UCS is lowered and placed in position, as in the event occurred at KKP-2 (see [3]). Such deformations could damage the FA cladding tubes in such a way that radioactive substances would be released into the coolant. In the event of major damages, it might be necessary to shut down the plant. Moreover, control elements could be damaged if fuel assemblies with control elements would be affected. This, however, would in all probability already be noted during the functional testing of the control elements before start-up. Furthermore, significant problems could arise during handling or recovery of damaged fuel assemblies [3].

As stated in [3], an impact of individual fractures of FA alignment pins in the lower core structure on the capability for cooling and shutdown of the plant cannot be recognised according to the current state of knowledge. During displacement or rotation of the fuel assemblies within the scope of clearance, contact with neighbouring fuel assemblies may occur, and resulting damage cannot be ruled out. With regard to possible consequential damage caused by loose parts, it is to be noted that a broken FA alignment pin remains within the FA bottom end piece during power operation.

The safety significance of hold-down springs and flow restrictor assembly springs is described in GRS information notices [6, 7]. The hold-down springs serve to position the fuel assemblies within the core. According to [6], it can be assumed that safe positioning is still given even in the case of several spring fractures per fuel assembly, also in the case of the respective enveloping event "load rejection to auxiliary station supply". As stated in [8] and confirmed in [9], the fuel assembly is reliably held down up to a maximum number of 12 spring fractures. In the case of a postulated break of one or more hold-down springs, the fuel assembly could not leave the provided position for geometrical reasons. A lateral adjustment would be given by the fuel assembly alignment pins also in case of postulated lifting of the fuel assemblies. With regard to the hold-down function required for safety reasons, the breakage of more than one fuel assembly hold-down springs has no safety-relevant impacts from the point of view of the RSK.

According to [7], the defective spring of a flow restrictor assembly has no significance for the function of the flow restrictor assembly or the flow distribution in the core. Even with a complete loss of the spring, the flow restrictor assembly plugs would still remain in the control rod guide tubes in the fuel assembly. The flow restrictor assembly could not leave the provided position for geometrical reasons even if postulating multiple fracture of the spring. Mechanical damages to the flow restrictor assemblies or adjacent components caused by flow-induced movements of the flow restrictor assembly due to the loss of preload cannot be ruled out. From the point of view of the RSK, mechanical damages do not lead to a loss of function and thus do not pose safety concerns.

In the case of the fractures on the hold-down springs and springs of the flow restrictor assemblies, another potential safety significance is given due to loose parts, i.e. fragments of broken springs. Depending on weight and size, it cannot be ruled out that loose fragments in the primary circuit may cause damage to FA cladding tubes or the steam generator tubes, e.g. due to fretting [6, 7]. The effects of the aforementioned potential damages are covered by the plant design. According to the RSK, an impairment of the shutdown function due to loose parts of broken springs is not to be expected since these cannot reach the control rod guide structure due to the flow conditions.

5 Assessment

The damages to FA alignment pins in the UCS and core components detected as well as their possible impacts and the measures derived are assessed specifically for the different components.

5.1 Damages to FA alignment pins

In response to the damages to FA alignment pins, specific monitoring measures have been implemented in all plants. During the plant outages, the FA alignment pins are checked for damages (deformation, incipient crack or complete breakage) by visual inspections. In the case of suspected damage, these FA alignment pins are subjected to ultrasonic testing. According to the RSK, the test technology has meanwhile become state of the art. The underlying mechanism of the IGSCC under primary water conditions for Alloy X-750 and IGSCC as well as TGSCC for austenitic FA alignment pins is well known.

Thus, it is a known ageing mechanism that occurs on the FA alignment pins. In view of the low safety significance of fractures of individual FA alignment pins, it is sufficient to rule out a systematic failure of FA alignment pins due to ageing mechanisms. This is ensured by suitable in-service inspection concepts in the plants.

An event as occurred in KKP-2 with deformation of a fuel assembly head is to be avoided. Therefore, before placing the upper core structure in position after refuelling, the alignment of the FA alignment pins should be controlled such as to ensure that a deformation of the fuel assembly head by alignment pins will not occur. Such recommendation is contained in information notice WLN 2014/01 [3].

5.2 Fractures on hold-down springs

In response to the fractures on hold-down springs in the Brokdorf nuclear power plant reported in 2012 and two fractures on these springs in the Grafenrheinfeld nuclear power plant, the RSK Committee on PRESSURE-RETAINING COMPONENTS AND MATERIALS (DKW) dealt with this issue. The broken hold-down springs in the KKG originate from two batches for which indications had also been identified in the KBR plant. The manufacturer states that the fractures of the hold-down springs due to IGSCC under primary water conditions are primarily attributable to the high stresses prevailing. This can additionally be supported or accelerated by small surface defects on the spring wire, which has been demonstrated for the two wire batches affected. In connection with these findings it is to be stated that the use of fuel assemblies with steel guide tubes required the high spring tension. As described in [1], the steel guide tubes were installed as a measure to prevent the deformation of fuel assemblies with low stiffness.

After the events, the fuel assembly manufacturers have taken measures to prevent spring fractures in the future (modification of the spring material, design modification for stress reduction, monitoring of the surface condition of the spring wire during manufacture). In addition, specific tests for the control of the springs have been introduced in the plants.

5.3 Fractures on springs of flow restrictor assemblies

Within the framework of the FA inspections, the flow restrictor assemblies are regularly examined for visible changes, in particular with regard to their installation condition (about 25% during the annual refuelling). In addition to the installation condition, such as tilting between shaft and sleeve, the spring deflection is also subjected to visual examinations. This examination provides information as to whether the spring function is still ensured or if indications of a spring fracture can be derived.

A defective spring of a flow restrictor assembly has no significance for the function of the flow restrictor assembly (even flow) or the flow distribution in the core as long as the flow restrictor assembly plugs remain in the guide tubes, which is ensured by an appropriate length of the plugs. Even in case of a complete loss of the spring, the flow restrictor assembly plugs would still be immersed in the control rod guide tubes in the FA [7] since any "uplift" of the flow restrictor assembly through the flow and the opening of guide tubes caused by it is prevented by the hold-down bridge. A potential safety significance is given by the damage potential due to spring fragments, as already described in [6] for the event of broken hold-down springs. Depending on the weight and size, it cannot be ruled out that loose fragments occur in the primary circuit. According to the RSK, the effects of the aforementioned potential damages are covered by the plant design. The RSK holds the view that an impairment of the shutdown function due to loose parts of broken springs is not to be expected since these cannot reach the control rod guide structure due to the flow conditions.

6 Answers to the questions of the BMU

Within the framework of the statement "Deformations of fuel assemblies in German pressurised water reactors (PWRs)" and this statement, the RSK has taken into account and answered the BMUB's questions implicitly, so that answers to individual questions are not deemed necessary.

7 References

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