Adaptation and Optimisation of Non-destructive Testing Methods for Safety Relevant Systems and Components

Statement by the Reactor Safety Commission (Germany)
11th April 2002

Request for Discussion

In the request for discussion of 3rd January 2001 by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) to the Reactor Safety Commission (RSK) regarding the test interval for the Brokdorf nuclear power plant (KBR) (document [1] for discussion) the RSK was requested to resume discussions with regard to the adaptation and optimisation of non-destructive testing (NDT) methods for safety important systems and components with the aim of preparing a statement.

Facts

At the beginning of the 90's extensive cracks had been detected in pipes at boiling-water reactor facilities (KWU series 69 and 72) /2/. Since then , further cracks which are caused by corrosion have only been found occasionally in such stabilised austenitic steels pipes. Recently in German nuclear power plants, an increase in incidents, where cracks were either discovered more or less "accidentally" in austenitic pipes or where results were found through re-evaluation or new evaluation, has occurred.

In October 2000 the RSK committee Pressure – retaining Components and Materials was informed about crack findings at a feedwater nozzle (dissimilar weld) of the emergency cooling and residual heat removal system in the Biblis nuclear power plant, unit A (KWB-A). It is stated in the message WL 2001/01 by GRS to be forwarded regarding the detection of a crack at this dissimilar weld, that areas in the middle of the wall could remain untested as the preferred area of testing referred to in the KTA standard are near to the surface. In the standard NDT methods are required with a high detection potential for near surface defects.

The cases of damage that became known in foreign nuclear power plants (US-American Vergil C. Summer nuclear power plant, unit 1 and Swedish Ringhals nuclear power plant, unit 4) occurred more recently. In the case of Summer /3, 4/ the damage found through visual inspection (boron precipitation) could be clarified using ultrasonic and eddy current techniques from the inside diameter (ID). At the ID a 68 mm-long axial defect at the peripheral position of 7° - counterclockwise, starting from the 12-o`-clock position – was found with the help of this technique. Visual inspection from the outer diameter (OD) at this position showed a weephole at the

weld with a diameter of 4.7 mm which was not detected with the help of the dye penetrant test carried out from OD.

The detectability of defects is one aspect, which has also been investigated by extensive international programs. The results of these international programs such as PISC (PISC = Program for the Inspection of Steel Components), HSST (HSST = Heavy Section Steel Technology) or NESC (NESC = Network for Evaluating Structural Components /5/) or the investigation program of EPRI (EPRI = Electric Power Research Institute) show sufficient reliability regarding defect detectability for thick-walled components, provided the conditions demanded in the corresponding rules are fulfilled /6, 7/. Furthermore it could be shown that the detection of safety-related defects, represented by the Probability of Detection, is higher for mechanised inspection than for manual inspection. From this it can be concluded that by reducing human factors it is possible to improve safety. It is another result of these programs that the evaluation of the measured data (for the examination, the international programs mostly used the ASME code), i. e. characteristic data such as the dimension of a defect or defect region, respectively, still shows gaps, unless modern NDT techniques are applied /8/. In the KTA Safety Standards such modern inspection systems that have the potential of determining the dimension of defects are only demanded if a defect has been detected for the first time or if there are changes in the result compared with the previous inservice inspection. Only in exceptional cases are analysing techniques applied with which it is possible to estimate the dimension of defects in the physical limits.

From the evaluation of the investigation program regarding NDT of austenitic welds and welds between ferritic and austenitic steels /9/ the authors came to the conclusion that ultrasound testing is carried out with progressive test techniques such as e. g. ALOK (amplitude locus curves) or SAFT (SAFT = Synthetic Aperture Focussing Technique). In the case of welds that are difficult to inspect regarding geometry and material, several complementary NDT techniques should be used. According to the defect type and the defect position into the material, X -ray and eddy current techniques are applicable with advantage.

More recent investigations on grinded welds (avoiding the influence of geometry) show better results /10/. Experience gained in the examination of austenitic welds also show that it is absolutely necessary to optimise the ínspection technique using a reference block or material.

Furthermore the exposition by the TÜV Nord regarding the experience in the performance, analysis and evaluation of results received during inservice inspection (ISI) have to be mentioned /11/. At the 17th meeting of the RSK committee Pressure – retaining Components and Materials which took place on the 4th April 2001 the TÜV Nord suggested modifying the KTA Safety Standard with respect to the manufacturing inspection (KTA Safety Standards 3201.3 and 3211.3) as well as to the *ISI* (KTA Safety Standards 3201.4 and 3211.4), in particular regarding the avoidance of misinterpretation during the examination. This suggestion was received positively by the RSK committee on *Pressure – retaining Components and Mater*ials due to the events in the Biblis nuclear power plant, unit A (KWB-A) at the end of 2000 and the event at the primary shutdown fitting in the Stade nuclear power plant (KKS) in spring 2001 /12, 13/. It was also shown from the example in KWB-A, that the mechanised inspection is fully capable of detecting relevant defects.

It is described in /14/ under which conditions an image presentation of the results can be achieved and which procedure should be applied in the analysis of the measured data and the evaluation. A directive issued by the VGB (organisation of plant operators) with regard to analysis and evaluation of ultrasonic data is available. Furthermore the results of the TRL – Probe working group (TRL Transmitter-Receiver- Longitudinal wave probe) /15/ appointed by the RSK committee on *pressure – retaining components and materials*, are available which must also be taken into account.

Discussion

Results of research funded projects relating to the aforementioned topics were presented to the RSK committee on *Pressure – retaining Components and Materials* at the meetings listed below:

2nd meeting on 6th October 1999	Qualification and evaluation of concepts relating to monitoring of pipes and containers in nuclear power plants; investigation project SR 2218 of BMU (TÜV Rheinland) *State of work of the team SEL-Testing Technique; introduction of the DGZfP directive US 3, May 1999*
3rd meeting on 1st December 1999	State of knowledge regarding inter-granular stress corrosion cracking (IGSCC) on austenitic pipes; final report on the investigations at the pipes of the boiling water reactors Isar-1, Philippsburg-1, Gundremmingen units B and C
4th meeting on 12th January 2000	Austenite program accompanying operation due to cracking in pipes > NW 80 of stabilised austenitic steels X 10 CrNiTi 18 9 (W.-No. 1.4541) and X 10 CrNiNb 18 9 (W.-No. 1.4550) in German light-water reactors, investigation project SR 2235 of BMU (MPA Stuttgart)
8th meeting on 7th June 2000	Failure at a pipe of the pressure boundary made of the austenitic material 1.4541 at KKS
10th meeting on 5th/6th September 2000	Continuation of the European Network for Inspection Qualification activities of the power plant owners (licensee)
12th meeting on 31st October 2000	Cracks in a weld of a pipe (TH system) connected to the reactor coolant pipe of KWB-A
13th meeting on 8th November 2000	Results of ISI at the replaced austenitic pipes of the pressurised water reactors during the annual inspection 2000
17th meeting on 4th April 2001	Non-destructive testing in production

	quality controls and recurring inspections, required changes in the KTA Safety Standards (TÜV Nord)
	Crack like defects at the outlet nozzle of the residual heat suction fitting TH 002 S001 (first isolation) and at the adjoining pipe in KKS

The RSK committee on *pressure – retaining components and materials* discussed the drafted statement "Adaptation and Optimisation of Non-destructive Testing Methods for Safety-Important Systems and Components" in their 21st, 22nd and 23rd meeting on 14th September 2001, 24th October 2001 and 17th January 2002. The RSK finally discussed this statement during its 349th meeting on 7th March 2002.

Assessment Standards

The applied measuring technology and its handling and the documentation of results must be suitable for detecting safety relevant defects (inhomogeneities) in components in a reliable manner. Non-destructive testing is to be assigned to the preventive measures in order to maintain quality requirements. The RSK is of the opinion that in order to provide and/or improve the required confirmation potential such as described above, up to date progress in the state-of-the-art of science and technology in NDT techniques as well as test execution and data evaluation – have to be taken into consideration.

Procedure

When assessing the facts the current state-of-the-art of science and technology was assumed. In particular the possibilities of advanced NDT equipment technology were considered. With the help of such new equipment technology a nearly complete data acquisition is possible, so that reconstruction algorithms can be used for objective analysis and evaluation. In addition to the conventional amplitude evaluation of the ultrasound data, this would enable, another amplitude-independent evaluation. Methods which have proven themselves in practical application include the SAFT reconstruction technique, echotomography, the TOFD technique (TOFD = Time of Flight Diffraction Technique) or techniques using diffraction of sound waves. However the application of such reconstruction techniques demands well qualified testing personnel. Proof of typical testing skills is in most cases no longer sufficient. The application of phased array technique with the possibility of electronic sound field steering can often also provide additional information for data analysis and evaluation. The modern radiography techniques such as laminography or the evaluation of digitalised X-ray films have to be mentioned in association with failure evaluation as well as optimised eddy current techniques.

Taking into account the circumstances, in addition to the experience gained by the members of the committee on *Pressure – retaining Components and Materials* and the RSK, the results from research projects as well as from occasional practical experience were the basis for the present statement, with regard to the possibility of detection and characterisation of failures /7/. Recent cognitions are described in /5/

and they show that the detectability of defects can be considered as good. In this case, for example, eight of ten test teams detected 14 failures (note: One team detected 10, the other 12 out of 14 failures). Further, it also showed that reliable results can be achieved by well educated examiners, in combination with optimised and qualified NDT techniques. Another step towards objective testing can be the application of the ENIQ methodology (European Network for Inspection Qualification). An essential issue here is that the technical justification presented on the basis of experiments and theoretical evaluation complies with the requirements /16, 17/.
Other new rules and guidelines /14, 15/ facilitate the approach to examination and evaluation of defects.

Safety Engineering Evaluation

In the discussions about the occurrences in the plants KWB-A and KKS the RSK came to the conclusion that the cracks detected in the pipes were of safety-related significance. Cracks which occur during operation must be detected by NDT techniques, so that it is guaranteed that the barriers for the isolation of the radioactive substances are entire.

Regarding the event in the plant KWB-A it is stated in /16/ that the importance of this occurrence is mainly due to the fact that a failure which occurred during production, reported during ISI in 1992 was wrongly interpreted. The RSK agrees with this appraisal.

With respect to the KKS plant, according to the RSK the cause has not been clarified yet; it is very probable, however, that the fitting in the first isolation were polluted by chloride and that this pollution triggered the stress-corrosion cracking detected. The crack propagation was in the long axial direction. Due to the fact that these cracks at the ISI=WKP?? were not detected during ISI, decision parameters have been listed in /11, 19/ which, if they apply, require ndt measures. In the opinion of the RSK these requirements should be included in the standards.

Conclusions and Recommendations

With the increasing operating time of nuclear facilities the requirements on ndt techniques increase accordingly. On the one hand, the plant-specific activity level increases and, with this the radiation exposure of the examiner unless this is counteracted by mechanised NDT techniques or shielding. Furthermore damage have become known (cracks in pipes) on which one has to react through suitable NDT measures. The partly negative influence of human factors should not be forgotten which as the results of the international investigation and research programs have shown, can be reduced by mechanisation of the examination.

The following recommendations result from the discussions of the RSK:

- It is necessary that the examiners are trained well.

  In addition to qualification and certification according to DIN EN 473 the examiners should be particularly familiar with the characteristic manifestations of defects generated during operation. The examiner should have sufficient

knowledge about the component to be inspected regarding material, geometry and the structural state. Evidence of examiner training on the equipment systems to be used has to be provided.

- Good working conditions for the examiner are required.

  e.g. time pressure, working with respirators, high temperatures in the immediate vicinity, noise and radiation exposure can have negative influence on the quality of the inspection.

  During the annual inspection of the nuclear power plant time frames and the inspection sequence of the components at the pressure boundary are to be planned in accordance with the personnel available (precondition good training, see above!). Planning should take place in such a way that putting the examiner are under too great a strain is avoided.

- The reliability required according to the state-of-the-art of science and technology has to be ensured by corresponding equipment technology.

  In the case of ultrasound testing e. g. phased array probes, equipment with the capability to capture and process HF data, evaluating computer programs with the capability to analyse (SAFT, TOFD or crack tip techniques)

  In the case of X-ray inspection e. g.: X-ray film digitalisation in connection with image processing algorithms and mechanised X-ray inspection.

  In the case of eddy current testing e. g.: further development of special probes; low-frequency, far field and impulse eddy current technique for welds and for claddings; special computing algorithms to suppress interference signals.

  In the case of visual testing e. g.: underwater inspection equipment with zoom technologies and with industrial endoscopes for the inspection of narrow gaps, e. g. at the core shroud and at the feedwater distribution ring of reactor pressure vessel nozzles in BWR (boiling water reactor) nuclear power plants.

  The suitability of the developed NDT techniques has to be proven taking into account the procedure formulated according to ENIQ.

- Mechanised inspections to reduce human factors are to be preferred.

  Mechanised inspection with recording facilities and representation of the measured data are to be applied in areas with strong radiation exposure and when disturbance or form indications exist such as

  - in the case of coarse-grained materials (e. g. austenitic welds)
  - in the case of complicated geometries (e. g. nozzle to pipe weld)
  - in the case of shape changes (e. g. weld root notch)

  or if this is required by the inspection task (e. g. detection of cracks with branches, wall thickness measurements at corrosion and erosion cavities, ferritic components).

- In the case of welds with complicated geometry that are difficult to detect, the testing technique has to be optimised and calibrated with the help of reference blocks.

  Reference blocks with artificial or natural failures have to correspond to the object to be tested with respect to the relevant parameters (material, form, wall thickness, possibly existing cladding or buffering, possibly coarse grained welding areas), so that the reliability/validity of NDT technique applied can be evaluated.

- In the case of doubtful or ambiguous ultrasonic results from data examination and evaluation, further analysis for the characterisation of the defects have to be carried out and in general in the case of defects detected an components at the pressure boundary (position of and defect size)

- For a safety evaluation of detected defects analysis techniques have to be applied. For example, the application of calculation algorithms for defect illustration and the evaluation of diffraction signals at defect tips

- In the case of a restricted defect assignment or ambiguity combined techniques have to be applied, e.g.:

  - ultrasound and radiography testing of pipe welds
  - testing of the reactor pressure vessel cladding and, possibly, of austenitic welds with ultrasound and eddy current.

- Quality assurance management has to ensure that all evaluations are carried out and documented to the necessary extent and conclusions have to be drawn from the results.

  To avoid false evaluations it is important that any peculiarities or special features which influence the test result are always recorded and evaluated. Supervisiors from the NDT vendors , the licensee and third party experts have to make sure that the tests are performed completely according to the directives and have been evaluated correctly in a comprehensible way.

The RSK considers a short-term revision of the KTA Safety Standards 3201 and 3211 necessary taking into account these recommendations.

Note: This recommendation does not deal with the questions concerning the scope or regularity of inspection.

Documents, Information and Expertise

The following documents, information and expertise listed below were used – *see German version*