Guy ROUSSEL, AVN (Belgium)
Management of the Nickel-Base Alloy Cracking in Butt Welds at the Belgian Nuclear Power plants

G. Roussel, AVN, Brussels, Belgium

ABSTRACT

Following the discovery of Control Rod Drive Mechanism flaws and leaks, the occurrence of cracking in Reactor Pressure Vessel nozzle dissimilar metal butt welds at some foreign plants (Ringhals Units 3 and 4 and V.C. Summer) initiated in Belgium several actions addressing the issue of nickel-base alloy cracking in component nozzle butt welds. These actions had the objective of managing the stress corrosion cracking in Alloy 182/82 thick-section weld metals. The paper provides an overview of the integrated approach adopted in Belgium to define a material degradation management program. An update of the non-destructive inspection results is also provided.

INTRODUCTION

Alloys 182 and 82 are NiCrFe alloys that are extensively used to weld dissimilar metals such as low-alloy steel to austenitic stainless steel. The Alloys 182/82 are the counterparts of the Alloy 600 for the weld metals. Typical applications in PWRs are J-groove welds of Alloy 600 vessel head penetrations, pressurizer penetrations, heater sleeves and instrument nozzles. In addition, Alloy 182/82 pipe butt welds are used in the reactor pressure vessel (RPV) and steam generator inlet and outlet nozzles, pressurizer surge line nozzle and safety and relief valves nozzles. Alloy 182 welding electrode contains approximately 15% chromium and is used for manual welding with the shielded metal arc process. Alloy 82 filler metal contains about 20% chromium and is used for automatic welding with the gas tungsten arc process. When compared to Alloy 600, Alloys 182 and 82 showed for a while a better service performance in PWRs. However the discovery at Bugey-3 (1991) of a through-wall crack in a control rod drive mechanism nozzle (Alloy 600) with a crack penetration in the weld metal (Alloy 182) was the first field experience evidencing the sensibility of Alloy 182 to stress corrosion cracking in primary water environment. Later primary water stress corrosion cracking (PWSCC) has been detected in Alloy 82/182 butt welds Ringhals Unit 3 (1999) between reactor vessel hot leg nozzle and primary coolant pipes at three plants:), V.C. Summer (2000), and Ringhals Unit 4 (2000). Following the occurrence of cracking in RPV nozzle welds at foreign plants, an integrated approach has been adopted in Belgium to define a material degradation management program for the 182/82 butt welds in the Reactor Coolant System.

OVERVIEW OF THE ALLOY 182/82 BUTT WELDS AT THE BELGIAN PLANTS

Seven PWRs are operated by the Belgian utility Electrabel. The following table provides an overview of the Belgian nuclear units.

Unit	Capacity (Mwe, netto)	Year of first operation	NSSS designer
Doel Unit 1	392	1974	Westinghouse
Doel Unit 2	440	1975	Westinghouse
Doel Unit 3	1006	1982	Framatome
Doel Unit 4	985	1985	Westinghouse
Tihange Unit 1	962	1975	Framatome
Tihange Unit 2	1008	1983	Framatome
Tihange Unit 3	1015	1985	Westinghouse

Table 1: Belgian Nuclear Units

The reactor coolant piping and fittings in Westinghouse designed Reactor Coolant Systems (RCS) are made of austenitic stainless steel. Smaller diameter piping, such as the pressurizer surge line, spray line, safety and relief lines, and connecting lines to other systems are also austenitic stainless steel. All of the joints and connections are welded. The major components of the RCS are low alloy steel. These include the reactor vessel, pressurizer, and steam generators[1]. Stainless steel safe-ends are applied to the nozzles of the low-alloy steel components to make easier the field welding of the austenitic stainless steel pipe to the component. The low-alloy steel nozzles are joined to the austenitic stainless steel safe-ends with a dissimilar metal weld, also referred to as bimetallic welds. The weld filler metal is usually a NiCrFe alloy (Alloy 82/182) or stainless steel. A schematic of typical dissimilar metal weld in a nozzle-to safe end is shown on Figure 1.

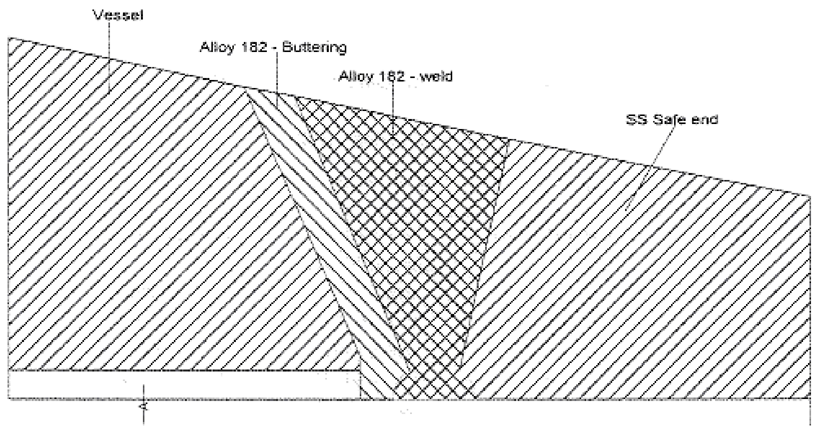

Figure 1: Typical safe-end to nozzle Alloy A182 butt weld

[1] The reactor coolant pump is austenitic stainless steel.

A summary of the Alloy 82/182 pipe butt welds in the RCS of the Belgian PWRs is given in Table 2 below where symbol **X** is used.to indicate that the nozzle-to-safe end weld is made of Alloy 82/182 material. At the exception of the nozzle-to-safe end butt welds at the steam generator inlet and outlet nozzles at Tihange Unit 1, which are Alloy 82 welds, all the butt welds are Alloy 182 welds.

Alloy 82/182 Pipe Butt Welds		**Doel Unit 1**	**Doel Unit 2**	**Doel Unit 3**	**Doel Unit 4**	**Tihang e Unit 1**	**Tihang e Unit 2**	**Tihange Unit 3**
Reactor Vessel (	Inlet and outlet nozzles	-	-		**X**	-	**X**	**X**
Steam generat ors	Inlet and outlet nozzles	-	-	**X**(*)	-	**X**	-	-
Pressuri zer	Surge line nozzle	-	-	**X**	**X**	-	**X**	**X**
	Spray line nozzle	-	-	**X**	**X**	-	**X**	**X**
	Safety and relief lines nozzles	-	-	**X**	**X**	-	**X**	**X**

(*) + stainless steel cladding

Table 2: Alloy 82/182 pipe butt welds in the Reactor Coolant System of the Belgian PWRs

The RPV nozzle-to-safe end welds have been stress relieved after welding but one repair has been performed after stress relief in a cold leg nozzle at Doel Unit 4. The pressurizer nozzle-to-safe end welds have not been stress relieved after welding and a significant repair has been performed in the pressurizer surge nozzle-to-safe end weld at Tihange Unit 2.

INSERRVICE INSPECTION OF THE DISSIMILAR BUTT WELDS

Edition 92 without addenda of Section XI of the ASME Boiler and Pressure Vessel Code is applicable for the current inspection interval at the Belgian plants. Edition 92 makes Appendices I (Ultrasonic examinations) and VIII (Performance demonstration for ultrasonic examination systems) to Section XI mandatory.
Volumetric and surface examinations are required. The volume examined with volumetric method is limited to the first (inner) third of the weld over an axial length equal to the width of the weld plus a quarter of an inch on each side.
In addition to that volumetric examination, a surface examination of the external surface is required, with an extent equal to the width of the weld plus half of an inch on each side.
These examinations are required to be performed on all the welds following a ten-year inspection interval.

Inspection of the dissimilar welds of the reactor pressure vessel nozzle –to-safe-end welds

The ultrasonic (UT) inspection of the dissimilar welds at the reactor pressure vessel nozzles is performed from the ID of the vessel. Qualification of the procedure was based on the requirtements of Appendix VIII to Section XI of the ASME Boiler and Pressure Vessel code, Edition 92 without addenda but the European (ENIQ) methodology was also used as a guideline. The qualification program took place in 1999.
Due to the practical difficulties of performing liquid penetrant testing (PT) on the external surface of the weld, as required by Section XI of the Code, a proposal was made by the Utility to replace the PT by the UT inspection of the external surface from the ID. However, the UT procedure does not ensure with a high confidence the detection of defects on external surface, notably the transversal (axial) ones. This limitation is still under discussion between the Utility/Tractebel and AVN, and the PT requirement is maintained so far.

ID detection of circumferential indications in the first (inner) third of the weld thickness is achievable from 5 mm depth and characterization from 8 mm depth knowing that the dead zone can extend from 4 to 6 mm.
ID detection of transverse (axial) indications in the first third of the weld is achievable from 5 mm depth and characterization from 5 mm depth.
ID detection of circumferential external indications is theoretically achievable from 1.3 mm depth and characterization from 7 mm depth.

Inspection of the dissimilar welds of the pressurizer

All Alloy 182 pressurizer nozzle-to-safe end welds at the Doel and Tihange plants are UT inspected. The examination is performed from the OD. The procedure applies to the automated ultrasonic examination of circumferential bimetallic nozzle-to-safe end welds with wall thickness from 10 to 60 mm and diameter from 3” to 14”.

In the 14” weld, OD detection of axial cracks in the first third of the weld is achievable from 2 mm depth and characterization from 4 mm depth according to the latest version of the procedure. A revision of the procedure is ongoing to take into account, in the characterization of the indications, for information coming from both T and L probes. The modification would allow a threshold of 3 mm depth for the characterization.

BIMETALLIC BUTT WELD ASSESSMENT BY THE UTILITY

Following the detection of PWSCC in Alloy 82/182 butt welds at Ringhals Unit 3 V.C. Summer, and Ringhals Unit 4, an assessment program has been launched by Electrabel and Tractebel (the Architect-Engineer) for managing the Alloy 182/82 material degradation. Those include:

(1) residual and operating stress
(2) crack initiation model
(3) stress corrosion crack growth model
(4) crack growth analysis
(5) inspection interval

(6) critical flaw size
(7) leak rate calculation
(8) repair/mitigation processes

Residual and operating stress

The stresses in the welds have been evaluated for most of the nozzle-to safe ends welds. The evaluation of the operating stresses is obtained by finite element calculations. The residual stresses due to welding are also taken into account in the specific stress reports. For stress relieved welds, the adopted value of the welding residual stresses is 30 MPa in the axial direction and 60 MPa in the circumferential direction. For as-welded (i.e., not stress relieved) welds, the welding residual stresses are calculated using formulæ found in the literature.
The calculated normal operating hoop stresses at RPV outlet or inlet nozzle-to-safe end welds do not exceed 220 MPa. The calculated normal operating hoop stresses at the pressurizer nozzle-to-safe end welds are close or above 350 MPa, which is the commonly agreed value of the threshold for PWSCC initiation.
Axial stresses are found to be much lower than the hoop stresses.

Crack initiation model

Tractebel has developed a model for predicting the probability of crack initiation in Alloy 82/182 butt welds. The prediction model relies on a methodology developed by EDF to estimate the crack initiation time of Alloy 600. The EDF methodology makes use of indices that are indicative of the three main parameters governing the stress corrosion cracking, i.e., material, stress and temperature.
The results of the application of the probabilistic model to the Alloy 182 butt welds at the Belgian units, as used for the assessment of the dissimilar butt welds, are the “probability of crack initiation after 20 years” and the “probability of crack initiation after 40 years”. However Tractebel stresses that the model should be used as a tool for ranking the welds according to their crack initiation probability rather as a reliable tool for predicting the lifetime of the component.
As a final result of the application of the crack initiation model, the Alloy 82/182 butt welds are ranked into four categories as shown in Table 3 hereafter. Welds belonging to group nr 1 are the most sensitive to PWSCC.

Group	**Alloy 82/182 butt welds**
1	Pressurizer surge nozzle-to- safe end weld
2	Pressurizer discharge line, spray line and safety valve nozzle-to- safe end welds
3	RPV outlet nozzle-to-safe end nozzle welds (+ 1 RPV inlet nozzle-to-safe end nozzle repaired weld)
4	RPV inlet nozzle-to-safe end nozzle welds

Table 3:ranking of the Alloy 82/182 butt welds

Stress corrosion crack growth model

Tractebel used three formulæ available in the literature for PWSCC crack growth in Alloy 182, i.e.,

(1) The EPRI formula that was used by Westinghouse in the analysis performed to assess the flaws detected in the V.C. Summer reactor vessel nozzle-to-pipe welds as revised by the NRC in his safety evaluation report
(2) The EDF/CEA crack model developed from crack growth rate tests carried out in EDF, CEA and ETH (Zurich) laboratories.
(3) The Ringhals 3-4 formula developed by the Swedish utility for the structural assessment of the flaws detected in the Ringhals 3 and 4 RPV nozzle-to-pipe welds.

The following table provides the various proposed crack growth rates as used b Tractebel .

EPRI crack growth rate formula as revised by the NRC	$da/dt = 2.1 \times 10^{-11} (K_I-9)^{1.16}$ m/s
EDF crack growth rate formula (best estimate)	$da/dt = 3.87 \times 10^{-11} (KI-9)^{0.55}$ m/s
EDF crack growth rate formula (upper bound)	$da/dt = 4.0 \times 10^{-10} (KI-9)^{0.1}$ m/s
Ringhals crack growth rate formula	$K_I < 25.1$ MPa$\sqrt{m}$ $da/dt = 5.79\ 10^{-20} K_I^{9.3}$ mm/s $K_I > 25.1$ MPa$\sqrt{m}$ $da/dt = 6.00\ 10^{-7}$ mm/s

Table 4: Proposed formulae for crack growth rates at 323°C

The following figure provides the comparison between the proposed crack growth rates. It should be noted that the formulae shown are those at 343°C. They are obtained from the proposed formulae at 323°C by multiplying those by a factor of 2.545 as obtained by the Arrhenius equation with an activation energy of 130 kJ/mole.

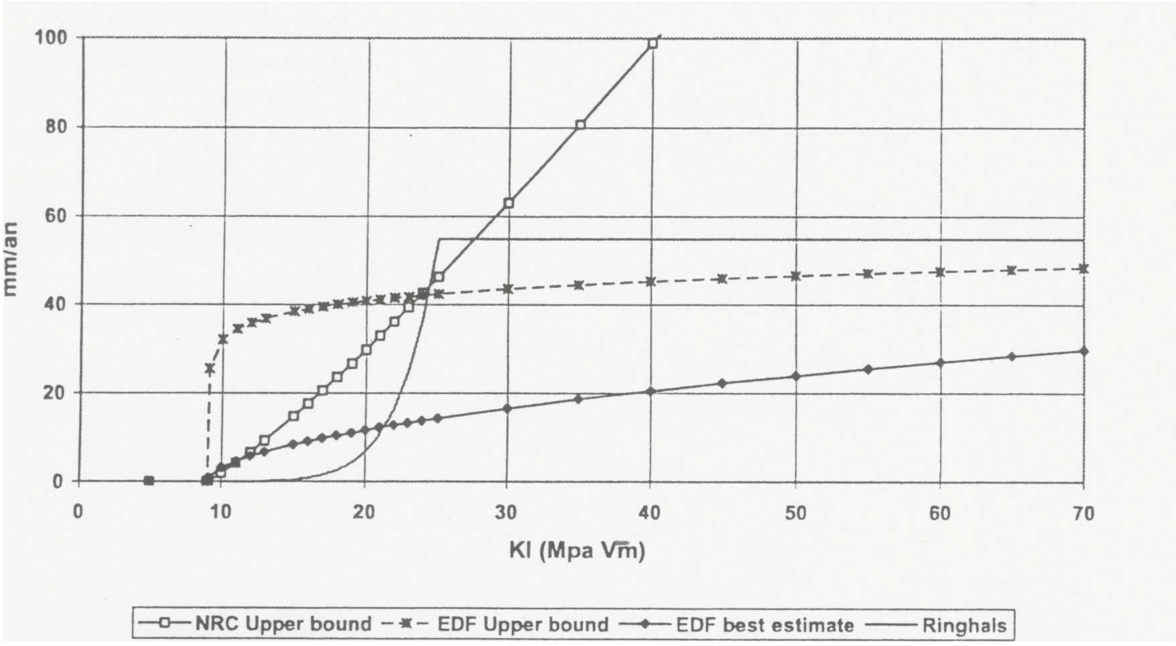

Figure 2: Proposed corrosion crack growth of Alloy 182 at 345°C

<u>Crack growth analysis</u>

Tractebel has performed crack growth analysis of postulated axial and circumferential flaws in the various Alloy 182 butt welds at the Belgian units. Tractebel calculated the flaw growth following the procedure of Appendix C to Section XI of the ASME Boiler and Pressure Vessel Code. For most of the welds, only the flaw growth due to stress corrosion cracking has been considered. Fatigue crack growth has not been performed for all Alloy 182 butt welds as it has been shown to be negligible based on the fatigue crack growth analysis performed for the inlet and outlet nozzles of the reactor pressure vessel at Tihange Unit 2 and Doel Unit 3.]

The stresses used to determine the stress intensity factors are the operating stresses and the surimposed welding residual stresses as prescribed in Appendix C to Section XI of the ASME Boiler and Pressure Code. The stresses induced by the loads (deadweight, pressure, thermal) in normal operating conditions at nominal power have been determined in the specific stress reports of the various Alloy 182 butt welds using non-cracked models of the welds. The stress distributions along the thickness of the welds as obtained in the stress reports are used to calculate stress intensity factors K_I for the flaws. The stress intensity factors K_I are calculated according to the formulæ provided in Appendix A to Section XI of the ASME Boiler and Pressure Code for the surface flaws.

The allowable flaw depth, as determined according to the requirements of the Section XI of the ASME Boiler and Pressure Code, is 75 percent of the wall thickness. Hence, the allowable operation time as determined by the crack growth analysis is the time when the postulated initial flaw reaches 75 percent of the wall thickness.

The initial objective of the analysis was to determine the maximum (initial) size of the flaw which, when growing in service by stress corrosion cracking and cycle fatigue, will have at the end of the inspection interval, i.e., after 10 years, a size equal to the allowable size as per the requirements of IWB-3600 in Section XI of the ASME Boiler and Pressure Vessel Code. However, this objective was later found to be not realistic for most of the welds and the allowable initial flaw size for 2 and 5 years of operation have been calculated. The results depend of course on the selected crack growth model but, for the pressurizer nozzle-to-safe end weld, the calculated allowable initial flaw size, even for a 2 year operation, is well below the detection threshold of the inspection technique.

Inspection interval

Tractebel proposed an extended inspection program of the Alloy 182/82 welds with the objective of increasing the confidence that the stress corrosion cracks are detected before they reach the maximum size allowed by Section XI of the ASME Boiler and Pressure Vessel Code.
The proposed extended inspection program is based on the ranking of the Alloy 182/82 butt welds into 4 groups.
The program includes volumetric examination using qualified ultrasonic testing procedure and visual examination of the OD of the weld (with removal of the insulation). The visual inspection aims at detecting in cold shutdown conditions accumulation of boric acid deposits from borated reactor coolant leakage. The visual inspection is performed once approximately at mid interval between two successive ultrasonic examinations. The following table summarizes the proposed extended inspection program.

Group	Weld location	Max. interval between UT examination	Max. interval between either UT or VT examination
1	Pressurizer surge line nozzle	3 years	2 years
2	Pressurizer safety and relief valve nozzles Pressurizer spray line nozzle	5 years 5 years	3 years 3 years
3	PRV outlet nozzles (+ Doel Unit 4 repaired inlet nozzle weld)	5 years	3 years
4	RPV inlet nozzles	10 years	5 years

Table 5: Summary of the proposed extended inspection program

Critical flaw size

TE performed the stability analysis of a through-wall axial crack bounded by resistant low alloy steel or stainless steel material. The analysis is performed for the butt weld at the reactor pressure vessel inlet nozzles of Doel Unit 4 and at the pressurizer surge line nozzle of Tihange Unit 2. Those two welds have been considered due to their high stress level. The reactor pressure vessel inlet nozzle of Doel Unit 4 has been selected because a repair has been performed at one nozzle after final heat treatment and the pressurizer surge line nozzle of Tihange Unit 2 has also been repaired.

It should be mentioned that the objective of such analyses is not to justify plant operation with a through-wall flaw, which is not permitted by the Section XI of the ASME Pressure and Vessel Code, but to assess from a defense-in-depth point of view, the behavior of an axial crack in the case where it would become through-wall while being bounded by the surrounding corrosion resistant material. Roughly speaking, the objective is to show that the critical flaw size for rupture is several times the width of the weld.

The results of the analysis show that the margin on the stress intensity factor for the RPV inlet nozzle at Doel Unit 4 is well above 1.0 as well for initiation of brittle fracture in the ferritic steel material of the nozzle as for initiation of ductile tearing in the stainless steel material of the piping.

The analysis for the pressurizer surge line nozzle at Tihange Unit 2 is rather an estimation of the margin derived from the analysis performed for the butt weld at the RPV inlet nozzles of Doel Unit 4. Corrections are brought to the results of this analysis to account for the data specific to the critical flaw analysis of the pressurizer surge line nozzle, i.e., nozzle geometry, flaw dimensions and hoop stresses. The margin on the stress intensity factor is above 1.0 for initiation of brittle fracture in the ferritic steel material of the pressurizer nozzle. The margin on the stress intensity factor is nearly equal to 1.0 for initiation of ductile tearing in the stainless steel material of the surge line. TE has also calculated the margin based on a stable ductile propagation _a of 2 mm. For this case, the value of the margin exceeds 1.0.

Leak rate calculation

Expected leak rate in normal operating conditions from a through-wall axial crack bounded by resistant low alloy steel or stainless steel material has been calculated by Tractebel. The objective of this calculation is to verify whether the leakage from such a crack would be detected by the existing continuous leak detection system.

The calculation is performed for the same butt welds as those for which a crack stability analysis has been performed, i.e., the weld at the reactor pressure vessel inlet nozzles of Doel Unit 4 and at the pressurizer surge line nozzle of Tihange Unit 2. The computer code used for the leak rate calculation is the PICEP code that is currently used by Tractebel for Leak-Before-Break analyses.

For the assumed nominal values of the crack morphology parameters, the calculated leak rate at the reactor pressure vessel inlet nozzle exceeds 3 kg/hr and the calculated leak rate at the pressurizer surge line nozzle is below 20 kg/hr.

Repair/mitigation processes

Two repair/mitigation processes have been qualified for specific application at the Belgian plants.

Specific application of the Mechanical Stress Improvement Process (MSIP) developed par AEA Technology has been qualified for its application to the conical geometry the pressurizer surge line nozzle at Tihange Unit 2. The MSIP is a method developed to eliminate susceptibility of weldments to stress corrosion cracking by alleviating weld-induced tensile stresses in the vicinity of circumferential welds. The MSIP consists of squeezing a pipe plastically near a weld using a specifically designed set of rings that grip a short length of pipe. The squeezing is continued until the tensile residual stresses along the inner region of the weld are replaced by low tension or compressive stresses.
Qualification of PWSCC repair technique by grinding has also been performed for specific application at the RPV outlet nozzle also at Tihange Unit 2.

ASSESSMENT BY AVN OF THE PWSCC MANAGEMENT PROGRAM

PWSCC as an ageing mechanism

A prescribed lifetime is attached to each mechanical component. Life extension may also be required at the end of the prescribed lifetime. In general terms, ageing may be defined as any discrepancy with what has been considered or assumed at the time of initial design and manufacturing and being susceptible to question the operability and/or ongoing structural integrity of a mechanical component for the prescribed lifetime or for a potential extended lifetime.
There is nowadays a consensus that Alloy 182/82 weld metals in primary water environment will crack and AVN believes that most of the alloy 182 welds at the Belgian plants have been in service long enough that cracking is increasing likely. Hence, managing stress corrosion cracking of Alloy 182/82 weld metals as an ageing mechanism is found necessary.

Assessment of the PWSCC management program

To AVN belief, three aspects need to be considered when managing material degradation: (i) to predict, (ii) to monitor, and (iii) to repair/replace.
With regard to these considerations, AVN recognizes that the PWSCC management program as proposed by the Belgian utility and Tractebel meets the objectives assigned by AVN to such a program. More specifically, AVN recognizes the adequacy of the degradation management philosophy based on the qualification of enhanced non-destructive examination procedures and extended inservice inspections rather than on extensive justification analyses. However AVN has some concerns mainly about the justification of the inspection intervals.

The regulatory approach to ensure that the integrity of the reactor coolant pressure boundary is maintained is through requiring periodic inservice inspection and primary coolant leakage monitoring and through defining specific (allowable flaw size and leak rate) limits. Section XI of the ASME Boiler and Pressure Vessel Code requires volumetric inspection of the pressure retaining dissimilar welds in vessel nozzles with diameter of 4 inch or larger every 10 years. Past experience as well as knowledge of the initiation and propagation characteristics of the primary water stress corrosion cracking of the Alloy 182/82 butt welds puts into question the ability of this inspection interval to allow the timely detection of the cracks.

As mentioned above, the Belgian Utility and Tractebel proposed an extended inspection program of the Alloy 182/82 welds with the objective of increasing the confidence that the stress corrosion cracks are detected before they reach the maximum size allowed by Section XI of the ASME Boiler and Pressure Vessel Code. The proposed extended inspection program is based on the ranking of the Alloy 182/82 butt welds into 4 groups depending on the so-called risk of cracking with some consideration of the crack growth calculation.

The crack initiation of Nickel base alloys is known to be a stochastic process. The experience shows that, even in laboratory conditions where the parameters (chemistry of the environment, temperature and stresses) are carefully controlled, initiation times for various individual identical test specimens are found to be statistically distributed over a wide range. Moreover, in service, additional uncertainties arise from the uncertainties associated to the controlling parameters, i.e., stress, temperature, and sensitivity to stress corrosion cracking.
When comparing the stress corrosion characteristics of Alloy 600 and Alloy 182, Alloy 182 is characterized by longer initiation times but shortest propagation times. Then, when attempting to define an inspection program for Alloy 182 welds, it may be thought adequate to define inspection intervals on basis of the predicted times to initiation. Using such an approach, the objective of the inspection is to verify the prediction model. This procedure requires determining for each specific weld the minimum crack initiation time, i.e., the time of the first crack initiation. The procedure has also the advantage of not fully considering the stochastic nature of the corrosion process as no account is explicitly taken of the distribution of the statistical distribution of the initiation times under given conditions of temperature, stress and sensitivity to stress corrosion cracking. Hence, to AVN belief, the objective is adequate but the method used by Tractebel to achieve it raises some concerns.
To AVN understanding, the probabilistic model developed by Tractebel from the EDF deterministic model is not an adequate statistical model for calculating the probability of initiation of a first crack in an Alloy 182 weld at time t. Defining a statistical model for crack initiation would require to select a distribution function of the initiation times (e.g., the Weibull distribution) and to determine the parameters of the distribution function from the available data.
To AVN understanding, there is so far no validated statistical model for predicting the probability of a first crack initiation in an Alloy 182 weld at time t. The median crack initiation times calculated by deterministic phenomenological models on the basis of best estimate value of the controlling parameters (temperature, stress, sensitivity to corrosion cracking…) and possibly corrected to account for the uncertainties associated to these parameters may be useful for a ranking the Alloy 182 welds. However, due to the stochastic nature of the corrosion process, there is no insurance that cracking will occur in service in conformity with the ranking.
Despite those remarks on the probabilistic model developed by Tractebel, AVN found acceptable that the selection of the Alloy 182 butt welds to be examined for the first time with a qualified ultrasonic technique be based on the proposed ranking procedure. However AVN has some concerns about the justification of the proposed in service inspection program for the forthcoming years. This program is still under discussion between AVN and Electrabel/Tractebel.

To AVN opinion, for those welds on which no suspicious flaw has been detected so far, the inservice inspection program must be based on a propagation model, i.e., the inspection interval shall be shorter than the predicted time period required by the largest non detectable flaw to reach the maximum allowable size per Section XI of the ASME Boiler and Pressure Vessel Code. Even if a strong correlation could be demonstrated between the sensitivity to initiation and the sensitivity to propagation, i.e., even if the Tractebel crack initiation model could also be used to rank the welds according to the risk of propagation, AVN does not see any reason why the ranking of the welds should not be considered as an acceptable tool to determine the inspection intervals.

Nevertheless AVN recognizes that the crack growth equations used by Tractebel in the crack growth analyses lead, for some Alloy 182 butt welds, to inspection intervals too short for commercial power plant operation. For those welds, AVN expressed his opinion that he was ready to consider a proposition for using mean crack growth rates in calculations related to inspection intervals while the use of maximum or upper bound growth rates will be kept when preparing the justification for continued operation when PWSCC indications have been detected.

More specifically, AVN is ready to consider inspection intervals based on mean crack growth equations for axial cracks. For the circumferential cracks, the justification of the inspection intervals shall be based on the maximum or upper bound crack growth rates. While not satisfactory from a regulatory point of view, using mean crack growth rate would allow to quantify roughly the confidence to be placed in the so-defined inspection intervals and is therefore believed by AVN to be better than a method based on qualitative rules. The main reason for distinguishing the axial cracks from the circumferential cracks results from the fact that the safety assessment of the circumferential cracks is less strong especially because of the difficulty of eliminating the potential occurrence of very long cracks.

The uncertainties associated with the initiation and propagation of the primary stress corrosion cracks make even more demanding the expected performance of the leak detection systems. Visual detection of leaks through the visual observation of boric acid deposits during plant shutdown has also been proved to be the best available method to detect very small leaks.

Tractebel has proposed to perform periodic visual inspection of the welds (with removal of the insulation) at mid interval between two successive ultrasonic examinations. This proposal is considered by AVN as an adequate measure to ensure detection of through-wall cracks leading to very small leaks, i.e., leaks below the sensitivity level of the existing leak detection systems. However, AVN also thinks that this measure should be supplemented by some actions to be taken during the forthcoming refueling shutdown when an existing leak monitoring system indicates an increase of the non-identified leak but no location can be assigned thereto.

UPDATE OF THE NON-DESTRUCTIVE EXAMINATION RESULTS

<u>Axial indication in the pressurizer surge nozzle-to-safe end weld at Tihange Unit 2</u>

As inspection findings at Ringhals 3-4 and V.C. Summer have led to questions regarding the likelihood of similar flaws in other plants, the Belgian Utility decided to anticipate the inservice inspection of some dissimilar metal welds at the Tihange Unit 2 plant. Four

pressurizer nozzle-to-safe end welds, which the inservice inspection program required to UT test in 2009, were inspected during the October 2002 refueling outage. One of those nozzles was the surge nozzle-to-safe end weld.
Indications were detected in five areas of the weld. Four of those indications are oriented in the circumferential direction and, assuming that they are planar flaws, their size was found acceptable according to the ASME Section XI criteria.
The fifth detected indication is oriented in the axial direction, i.e., in the transverse direction of the weld. Its evaluation was found to be difficult due to the high noise level obtained on the UT responses. As no diffraction signal was observed from the reported indication, application of the procedure does not allow to size its depth. Then the depth of that indication was put on 8 mm, which is the limit under which sizing was proved to be not possible during the qualification stage of the procedure. The length was measured to be 26 mm by direct application of the qualified procedure.
AVN believed that the crack growth analysis as provided by the Utility did not provide a strong technical basis for justifying continued operation for six months in accordance with the Code requirements. AVN also believed that no immediate safety concern existed which would require an immediate shutdown.
The key issue was found to be the real nature of the indication. Although there was a high probability that the detected surface planar indication was a crack attributed to stress corrosion cracking, that remained an assumption. In order to avoid an immediate and possibly unnecessary repair campaign, AVN believed that the plant might be operated for some time period at the end of which a UT inspection of the flawed weld should be performed to confirm (or refute) the assumption of PWSCC. Indeed, should the indication be a stress corrosion crack, then it would grow and the crack growth should be evidenced by the UT examination. There was no technical basis for numerically determining the “correct date” of the inspection, i.e., the date at which the crack growth should be detected by UT examination if the indication is due to PWSCC. However, as it seemed to be a consensus that the occurrence and behavior of PWSCC in Alloy 182 is characterized by a long incubation time followed by a relative fast growth, it was thought that plant operation for a few months would allow the potential PWSCC indication to grow by a detectable increment. AVN accepted plant operation for a 6-month period.
The re-inspection of the weld at the end of May 2003 led to the following results: (i) no diffraction signal from indication #5 and (ii) ultrasonic picture of the indication quite similar to the one obtained in October 2002

Hence, comparison of the May 2003 results with the October 2002 results did not allow therefore to confirm the PWSCC nature of the indication and re-inspection of the weld was planned during the October 2003 refueling outage. The re-inspection of the weld during the October 2003 refueling outage led to the same results as those obtained in May 2003.
During the March 2005 refueling outage, the weld was re-inspected again and the results did not show any difference with the October 2002/May 2003 results.

<u>Axial indications in the RPV outlet nozzle-to-safe end weld at Tihange Unit 2</u>
The inservice inspection activities during the May 2003 outage at Tihange Unit 2 also included the inspection of all the reactor pressure vessel nozzles. The ID UT examination of

the RPV nozzle-to-safe end welds did not show any significant indication. But, for the first time, an ID Eddy Current examination was also performed on all the welds. The EC examination of outlet nozzle # H2 showed a 10 mm indication oriented in the axial direction, i.e., in the transverse direction of the weld. According to the NDE experts, the indication was no false call but well a crack type flaw. Then, the zone with the indication was examined successively by two specialized UT probes dedicated to the characterization of close-to-surface cracks. Those examinations did not show any indication. As both UT probes cannot detect cracks within a 1mm thick layer on the ID, it was concluded that the indication was a 10X1 mm crack type flaw. Visual examination of the zone did not show any indication looking like a crack.
During the March 2005 refueling outage, the weld was re-inspected again and the results did not show any difference with the May 2003 results.

CONCLUSIONS

The operational experience feedback as well as the opinion of most of the experts lead to believe that Alloy 182/82 weld metals in primary water environment will crack and AVN believes that most of the alloy 182 welds at the Belgian plants have been in service long enough that cracking is increasing likely. Hence, managing stress corrosion cracking of Alloy 182/82 weld metals as an ageing mechanism is found necessary. Electrabel, the Belgian utility and Tractebel, the Architect-Engineer, have developed a PWSCC degradation management program for the Alloy 82/182 butt welds mainly based on the qualification of enhanced non-destructive examination procedures and performance of extended inservice inspections. AVN mainly agrees with the basic principles of the management program but is still discussing the implementation of the inservice inspection program and more specifically the justification of the inspection intervals.