Transactions, SMiRT 16, Washington DC, August 2001 *Paper # 1725*

General Concept for the Integrity of Pressurized Components

Eberhard Roos[1)], Karl-Heinz Herter[1)], Frank Otremba[1)] and Klaus-Jürgen Metzner [2)]

1) Staatliche Materialpruefungsanstalt (MPA), University of Stuttgart, Pfaffenwaldring 32, 70569 Stuttgart, Germany
2) E.ON, Kernkraft GmbH, Tresckowstraße 5, 30457 Hannover, Germany

ABSTRACT

World wide efforts were made in the last 30 years to develop concepts to proof the integrity of pressurized components and piping systems of nuclear power plants. This includes the verification of methods to describe the load bearing capacity as well as the fracture mechanics behaviour. The main topics were to demonstrate the failure behaviour of ferritic and austenitic pipes and piping components (e.g. straight pipe, pipe bend, T-joint) with and without cracks under different loading and boundary conditions. This has been investigated in numerous experimental and analytical/numerical research projects. The results of these projects were used to adjust and to verify different methodologies and leak-before-break procedures to calculate the failure loads, the respective critical crack sizes as well as the leak area and the leak rates.

In the present paper a general concept to proof the integrity of pressurized components and systems is presented applicable for operational as well as for postulated loading conditions. The concept is based on the actual material characteristics, the actual as-built configurations and the design of the components and systems including the knowledge of possible failure mechanism during operation. An important part of the assessment is the leak before break behaviour and the break preclusion concept. Based on essential research results the developed procedures and methodologies for the assessment of the critical crack sizes as well as the critical loading conditions are reported and discussed. The general concept based on the Basis Safety Concept to ensure the integrity of components are stated and described. In detail the following aspects have to be treated: (a) evaluation of the as-built status of quality (design, construction, material, fabrication; results of recurrent non destructive examinations up to now, operational experience, match the requirements of the basis safety); (b) determination of the relevant loading conditions by means of in-service monitoring (monitoring of the mode of operation, the water chemistry, the mechanical and thermal stresses, the dynamic loading); (c) evaluation of the as-built status of quality with respect to the relevant loading conditions (stress analysis - limitation of the stresses; fatigue analysis - determine the usage factor; fracture mechanics analysis - determination of crack growth and critical crack and loading conditions); (d) evaluation and extent of the in-service monitoring to guarantee the succeeding operation (recurrent non destructive examination - minimum detectable flaw sizes, examination area, examination intervals; leak detection system - leak area and flow rate); (e) a closed general concept with graduated measures (independent redundancies) by a summarising evaluation of the integrity. With these procedures and methodologies the proof of the integrity of piping components and systems, especially the leak before break and break preclusion concept used in Germany are demonstrated.

INTRODUCTION

The Basis Safety Concept (BSC) in Germany has been estabished into nuclear practice since 1979, Kussmaul [1, 2]. Moreover the long term experience in the field of conventional and chemical pressure vessel and piping technology made an essential contribution. With the BSC it is essential to assess and quantify the integrity of components in a mechanistic/deterministic way. Through stringent measures for all safety related components and systems, in the choice of optimised materials and processing, design, stress analysis, manufacture, operation, testing and inspection, it is possible to create the necessary prerequisites for redundancies which make catastrophic failure incredible (exclusion of catastrophic failure or break preclusion concept).

In the last 25 years world wide, Wilkowski [3], as well as within the German reactor safety research programs tremendous efforts were made to develop and to verify methods to describe the load bearing capacity as well as the fracture behaviour of primary circuit piping of nuclear power plants, Kussmaul et al. [4], Bartholomé et al. [5] and Schulz [6]. Parallel to the research activities in the late 1970's in Germany the BSC, also designated as break preclusion concept, was developed and adopted in principle by the German Reactor Safety Commission (RSK guidelines 1982) [7], Fig. 1. The background of the technical understanding and basis was published in original papers by Kussmaul et al. [1, 2, 8]; by Bartholomé et al. [9]and by Schulz [6]. In Germany thus the break preclusion concept became a legal requirement. For practical reasons an upper limit of the leakage area of 0.1A (A corresponds to the cross section area of the pipe) was chosen even if break preclusion was demonstrated. In general the break preclusion concept is applied to the large diameter primary piping, Fig. 2, and to the branch connections down to a nominal diameter of 200 mm, Fig. 3 to 5. The concept was in principle also applied to pipes down to a nominal diameter of 50 mm, Fig. 6 and 7. ($M_{b,3Sm,act}$ and $M_{b,3Sm,KTA}$ - bending moment calculated on a elastic basis for a stress level according to the actual 3Sm value of the material respectively to the material data given in the KTA code; $M_{b,Oper.+Upset}$ - bending moment developed by the pipe system analysis for operating plus upset conditions).

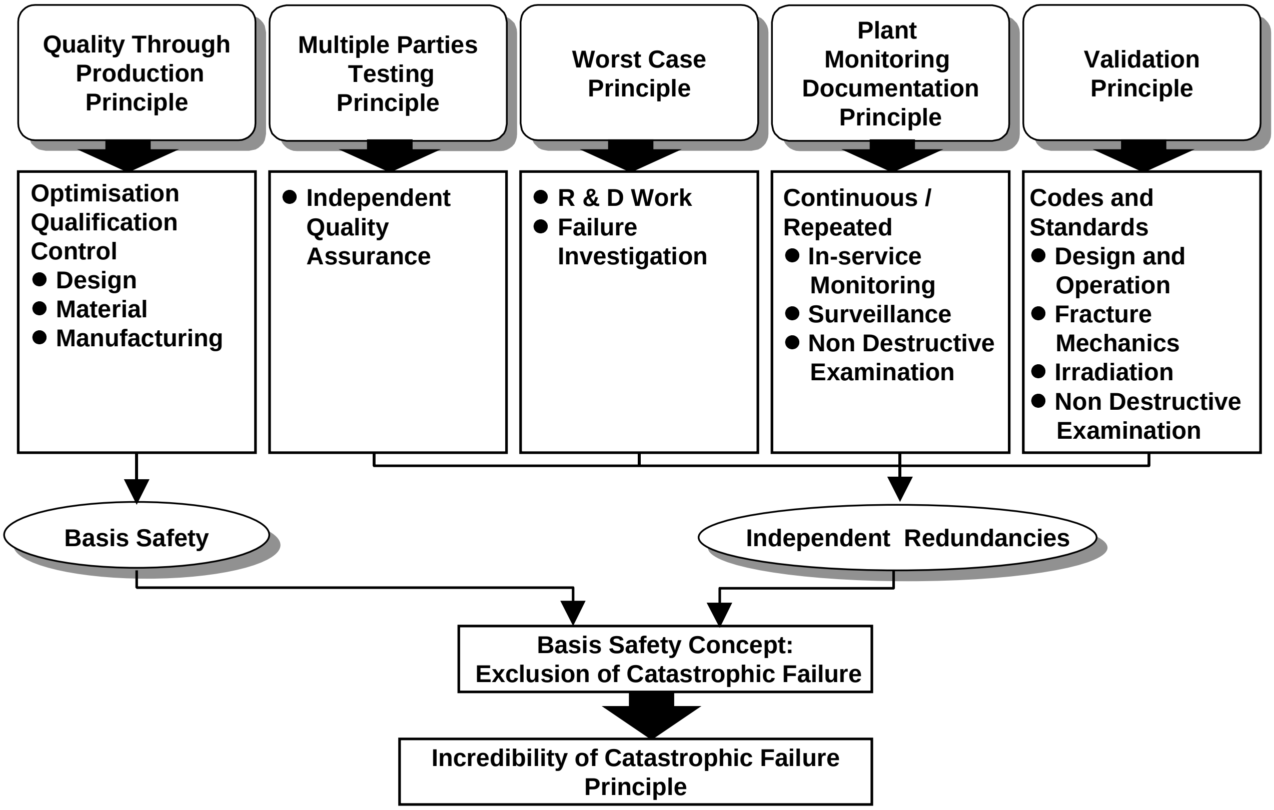

Figure 1: German Basis Safety Concept (BSC) schematically

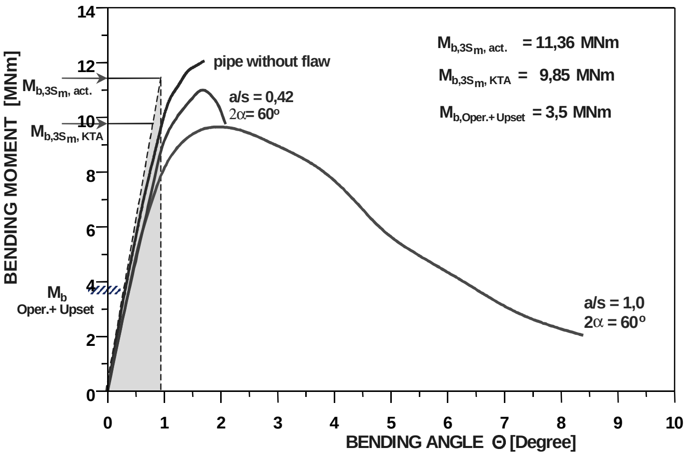

Figure 2: Load bearing behaviour of ferritic pipes with nominal diameter DN800 (outer diameter 800 mm, wall thickness 47 mm) and internal pressure 15 MPa at room temperature

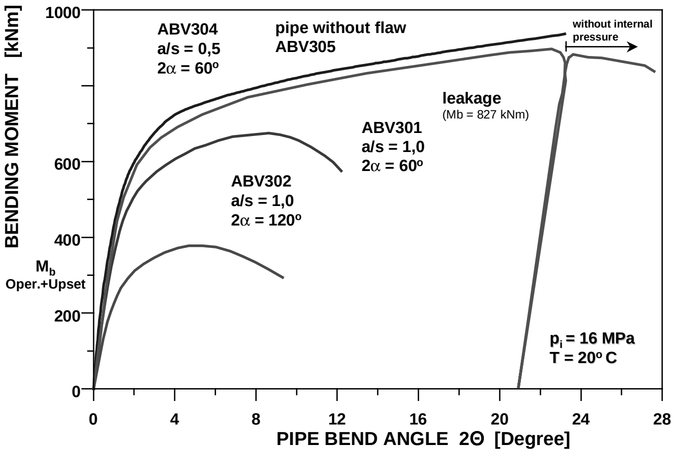

Figure 3: Load bearing behaviour of austenitic pipes with nominal diameter DN300 (outer diameter 331 mm, wall thickness 32 mm) and internal pressure 16 MPa at room temperature

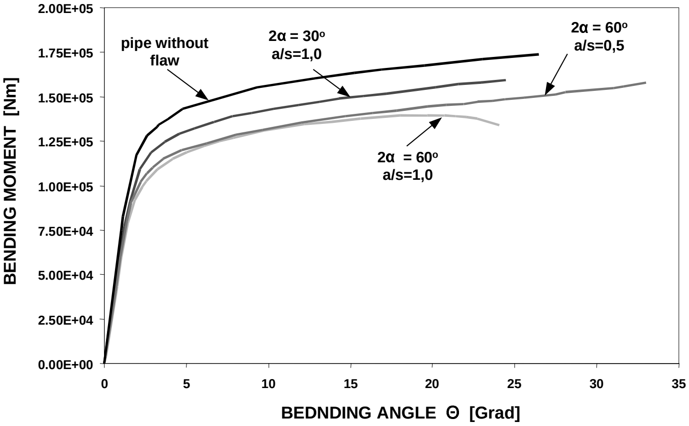

Figure 4: Load bearing behaviour of austenitic pipes with nominal diameter DN200 (outer diameter 219 mm, wall thickness 14.2 mm) and internal pressure 7 MPa at room temperature

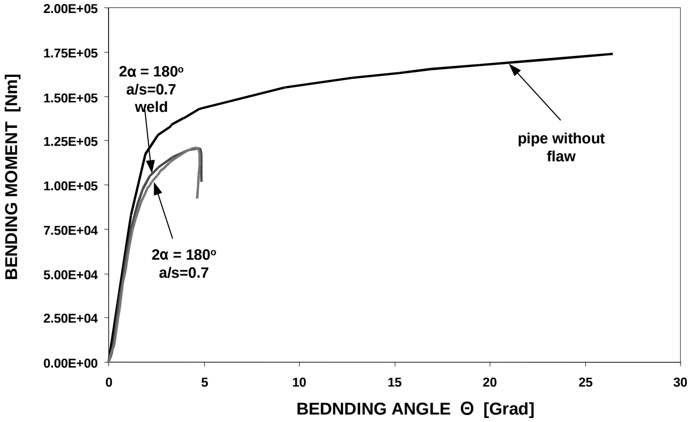

Figure 5: Load bearing behaviour of austenitic pipes with nominal diameter DN200 (outer diameter 219 mm wall thickness 14.2 mm) and internal pressure 7 MPa at room temperature

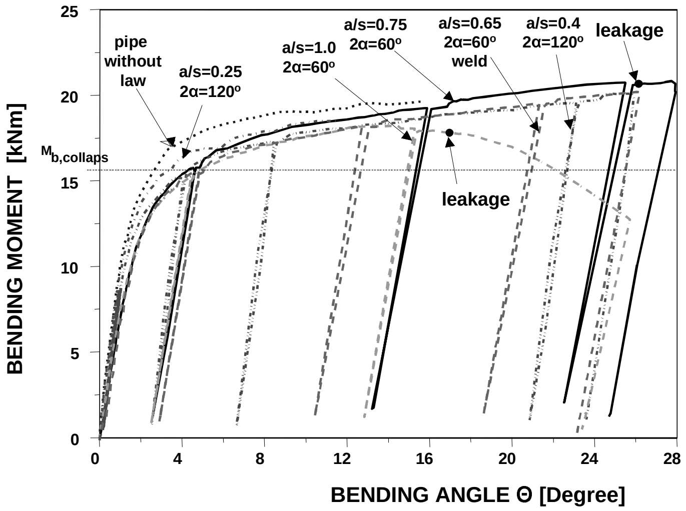

Figure 6: Load bearing behaviour of austenitic pipes with nominal diameter DN80 (outer diameter 88.9 mm, wall thickness 8.8 mm) and internal pressure 16 MPa at room temperature

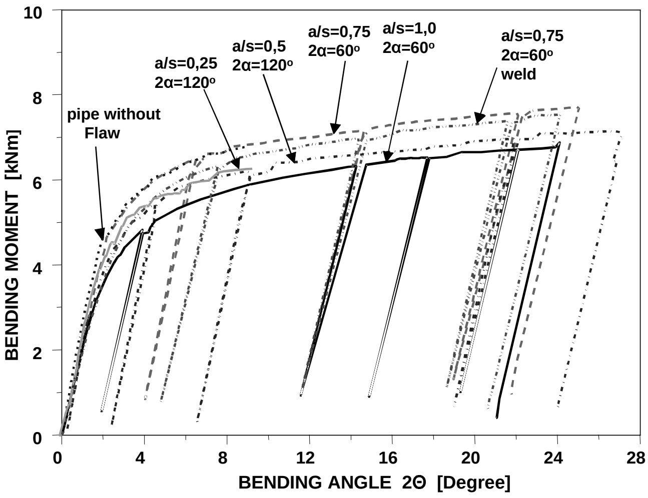

Figure 7: Load bearing behaviour of austenitic pipes with nominal diameter DN50 (outer diameter 60.3 mm wall thickness 8.8 mm) and internal pressure 16 MPa at room temperature

In the GRS report [10] a compilation of the individual national procedures, requirements and practices related to the integrity of light water reactor (LWR) piping with respect to the different so-called leak-before-break (LBB) concepts and philosophies is included, Table 1. Such comprehensive approaches have been developed in the United States of America (US) as the LBB concept, and in Germany, where it is known as the BSC. These concepts have been adopted also in many other countries. Although, large breaks are precluded by a successful application of the LBB concept or BSC the consequences of leakage to other components or equipment in the vicinity of the investigated components and piping system have to be assessed sufficiently by the design.

The aim of the following discourse is to state and describe in detail a general concept based on the Basis Safety Concept to ensure the integrity of components. Although the procedure may differ in a plant and component specific way, the concept can be used generally.

Table 1: LBB application (comparison of main aspects) in different countries according to [10]

Aspects of Regulatory Position	Applying in the Countries:														
	AC	Be	CS	Ger	Fin	Fr	Jap	SAf	SAr	Sd	Sp	Sw	UK	US	RF
Acceptance of LBB concept:															
- generally accepted			y	y									y	y	
- case-by-case basis	y	y				y	y		y		y	y			y
- under discussion					y			y		y					
Applied LBB procedure:															
- NRC procedure	y	(y)	(y)		(y)				(y)		y	y		y	(y)
- German procedure				y					(y)		y				(y)
- own national procedure		y	y	y	y		y		y	y					y
Reason for LBB application:															
- avoidance of installation of pipe whip restraints	y	y	y	y	y		y		y	y	y	y		y	y
- compensation of low design deficiencies (type L)			y						y		y	y			y
- compensation of high design deficiencies (type H)			y												y
Plants with LBB application:															
- total number of PWR units	16	7	14	14	2	58	23	2	5	3	7	3	1	76	29
- PWR units with LBB application	4	7	4	14	0	0	10	0	2	0	6	1	1	71	4
- total number of BWR units	6			6	2		28		2	9	2	2		37	17
- BWR units with LBB application	0			6	0		1		2	0	0	1		0	2

Key:	AC	Asian Countries (China, India, Pakistan, S-Korea, Taiwan), Japan separate	SAf	South Africa
			SAr	South America (Argentina, Brazil, Mexico)
y = yes	Be	Belgium	Sd	Sweden
p = partly	CS	Czechoslovakia	Sp	Spain
m = missing information	Ger	Germany	Sw	Switzerland
(y) = based on	Fin	Finland	UK	United Kingdom
	Fr	France	US	USA
	Jap	Japan	RF	Russian Fed. plus Ukraine, Lithuania & Armenia

BASIS OF VALUATION

In Germny the principles for the safety-related requirements taken as a basis for the design of nuclear power plants (NPP), especially with respect to the state-of-the-art in science and technology, are detailed in the "Safety Criteria for Nuclear Power Plants" of the BMI [11]. The criterion 1.1 "Principles of Safety Precautions" of the BMI safety criteria requires, besides others, a comprehensive quality assurance for fabrication, erection and operation. The criterion 2.1 "Quality Assurance" requires, besides others, the application, preparation, and observation of design rules, material specifications, construction rules, testing and inspection as well as operating instructions and the documentation of quality assurance. The criterion 4.1 "Reactor Coolant Pressure Boundary" principally requires, besides others, the exclusion of dangerous leakage, rapidly extending cracks and brittle fractures with respect to the state-of-the-art. Moreover the German Reactor Safety Commission (RSK) prepared guidelines [7] as a compilation of the safety-related requirements that, in the Commission's opinion, have to be compiled with the design, construction and operation of a NPP with pressurised water reactor (PWR). In relation with these safety-related requirements postulated leaks and breaks for the main coolant pipes are led down as well as for the main steam and feed water piping, Fig. 8 and 9.

PREMISE TO ENSURE THE INTEGRITY OF COMPONENTS

During the development of the BSC safety-related requirements were established which make catastrophic failure incredible by assessing and quantifying the integrity of components in a mechanistic/deterministic way. The requirements will provide the components with a "Basis Safety" (BS) that will preclude any disastrous failure of the component as a result of manufacturing defects (the "quality through production" principle), Kussmaul [2]. A comparable statement for components already in operation implies that the assumptions taken during design, especially for the loading conditions (mechanical, thermal, corrosive), are monitored and compared to the loading conditions included in the design specifications. For the practical application of the BSC (break preclusion concept) under operational conditions, the existence of the independent redundancies is demanded, but their application has to be balanced in a way case by case. The third redundancy ("continuous in-service monitoring and documentation" principle) in the BSC consists of continuous in-service verification that design conditions are not exceeded during plant operation (continuous plant monitoring, repeated testing) which is of important significance (Fig. 1). This makes evident that "Basis Safety" (the "quality through production" principle) exclusively can not ensure the integrity of components for all the life time and therefore the independent redundancies are demanded in a balanced way.

Primary System (RSK Guideline, Chapter 21.1, version 03/1984)		
Component	Leak and Break to be postulated	Effects
Reactor Coolan Lines	➨ 0,1 A, 15 ms linear	➨ Pressure waves (RPV internals)
	➨ 0,1 A, steady-state blowdown	➨ Jet forces (piping, components, building) ➨ Reaction forces (piping, components, building)
	➨ ≤ 2 A	➨ LOCA analysis ➨ Containment ➨ Pressure Differences (building) ➨ Qualification of I&C
Circumf. Nozzle Weld	➨ p·A·S, S=2	➨ Stability fo the components (e.g. RPV, SG, RCP, PRZ)
RPV Leak	➨ 20 cm^2 Leak	➨ RPV supporting ➨ RPV internals ➨ LOCA analysis
Austenitic connection lines with DN>200 mmm (surgeline, ECCS up to the 1st isolation)	➨ 0,1 A	➨ Jet forces (piping, components, building) ➨ Reaction forces (piping, components, building)

RPV=Reactor Pressure Vessel; SG=Steam Generator; RCP=Reactor Coolant Pump; PRZ=Pressurizer

Figure 8: Postulated leaks and breaks for the primary pressure boundary system (PWR) [7]

Main Steam Line (MSL) and Main Feedwater Line (MFL) (RSK Guideline, Chapter 21.2, version 12/1982)		
Component	Leak and Break to be postulated	Effects
MSL: Between SG and MS valve assembly	➨ Leakage *), steady-state blowdown	➨ Jet and reaction forces (pipings)
MFL: Between the valve assemly outside contaiment and SG	➨ p·A·S, S=2	➨ Stability of the SG
MSL: Behind MS valve assembly MFL: Before the valve asssembly outside containiment	➨ 2 A	➨ Jet forces (building) **) ➨ Reaction forces (pipings, components, building) **) ➨ Pressure differences (building) **) ➨ Pressure waves (pipings, components, building; guillotine break, 15 ms, linear)
MSL: Not isol. cirumferent. break	➨ 2 A	➨ Reactivity behaviour

*) Leakage area due to a subcritical crack determined using fracture mechanics or limited to 0.1 A

**) According to Basis Safety (RSK-Guidelines Chapter 4.2)

SG=Steam Generator

Figure 9: Postulated leaks and breaks for the primary pressure boundary system (PWR) [7]

Within the general analysis of the mechanical behaviour of the components it has to be demonstrated, that stresses (mechanical and thermal loading) as well as the usage factor (fatigue) will not exceed the limits given by the KTA safety standards [12]. Furthermore already during design the supporting of piping system has to be optimised using fracture mechanics analysis taking into consideration the minimum detectable flaw sizes, the examination intervals, the specified loading conditions, the material characteristics and the in-service monitoring. Taking care of these aspects it is possible to demonstrate leak-before-break (LBB) behaviour for the succeeding operation. By this it can be avoided that critical crack sizes become too small due to high loads resulting from non optimised supporting of components or of the piping system and that leak flow rates are too small for detection (a critical crack size will be reached before the leak flow rates can be detected).

For components and piping systems already in operation or not fulfilling the requirements of the basis safety (BS) in a complete extent the integrity of components can be demonstrated using the independent redundancies of the BSC ("multiple party testing" principle, "worst case" principle, "continuous in-service monitoring and documentation" principle, "validation" principle) in a balanced way associated with the operational experience of the NPP's and using the results of ongoing research programs world wide. In this way a "Quasi Basis Safety" can be demonstrated.

As a premise for a systematically approach to ensure the integrity of components it is indispensable to show that the as-built status of quality (design, construction, loading) is according to the requirements given in the guidelines and standards, to show that sufficient knowledge of possible failure mechanism (e.g. no inadmissible dynamic loading, no corrosion[1]) is available and to show that the as-built status of quality can be guaranteed for the succeeding operation.

In detail the following aspects have to be treated: (a) evaluation of the as-built status of quality (design, construction, material, fabrication; results of recurrent non destructive examinations up to now, operational experience, match the requirements of the basis safety); (b) determination of the relevant loading conditions by means of in-service monitoring (monitoring of the mode of operation, the water chemistry, the mechanical and thermal stresses, the dynamic loading); (c) evaluation of the as-built status of quality with respect to the relevant loading conditions (stress analysis - limitation of the stresses; fatigue analysis - determine the usage factor; fracture mechanics analysis - determination of crack growth and critical crack and loading conditions); (d) evaluation and extent of the in-service monitoring to guarantee the succeeding operation (recurrent non destructive examination - minimum detectable flaw sizes, examination area, examination intervals; leak detection system - leak area and flow rate); (e) proof of the closed general concept with graduated measures (independent redundancies) by a summarising evaluation of the integrity.

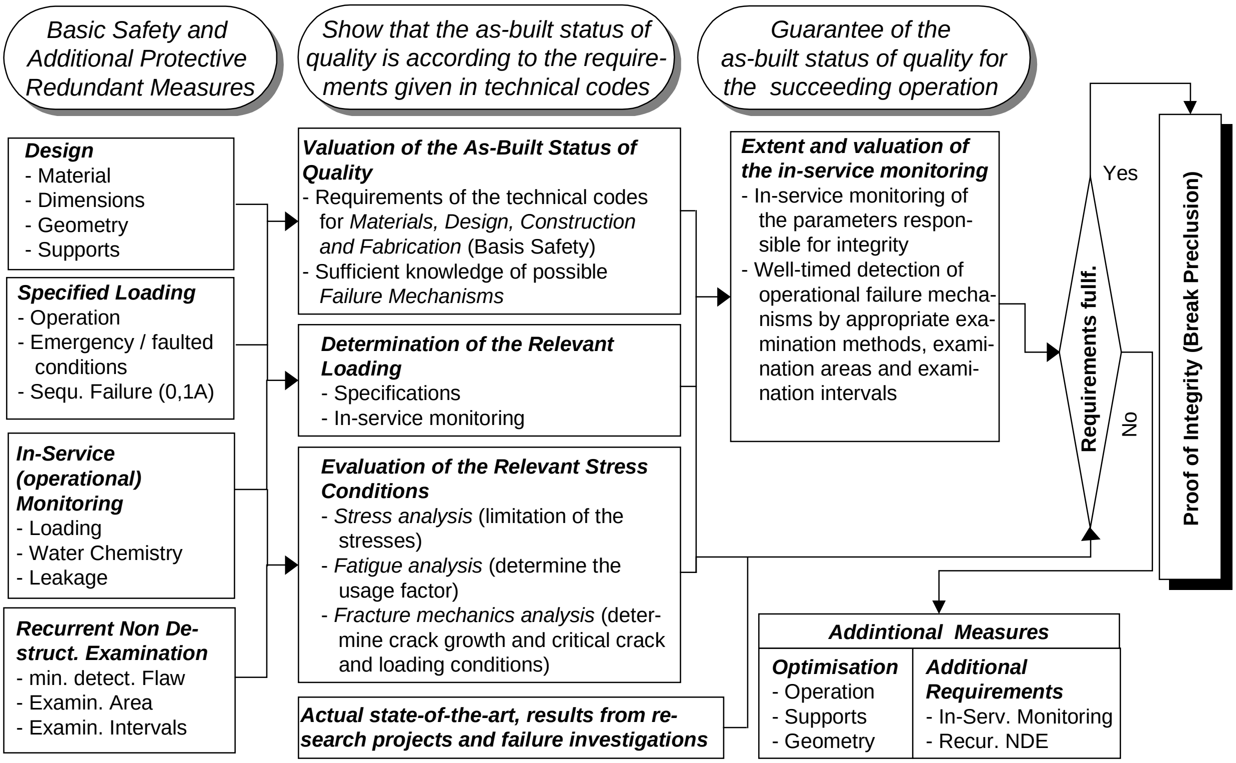

Figure 10: Procedure (schematically) to proof the integrity of components during design

---

[1] It has to be demonstrated, that there is no safety relevant corrosion cracking / crack growth.

METHOD OF PROOF TO ENSURE THE INTEGRITY OF COMPONENTS

The method of proof to ensure the integrity of components differentiates between (1) the proof for components under construction (new design and new fabrication), Fig. 10, and (2) the proof for components already under operation (differentiates between cases where the real loading conditions are well known by in-service monitoring and cases where no in-service monitoring is available) [13], Fig. 11.

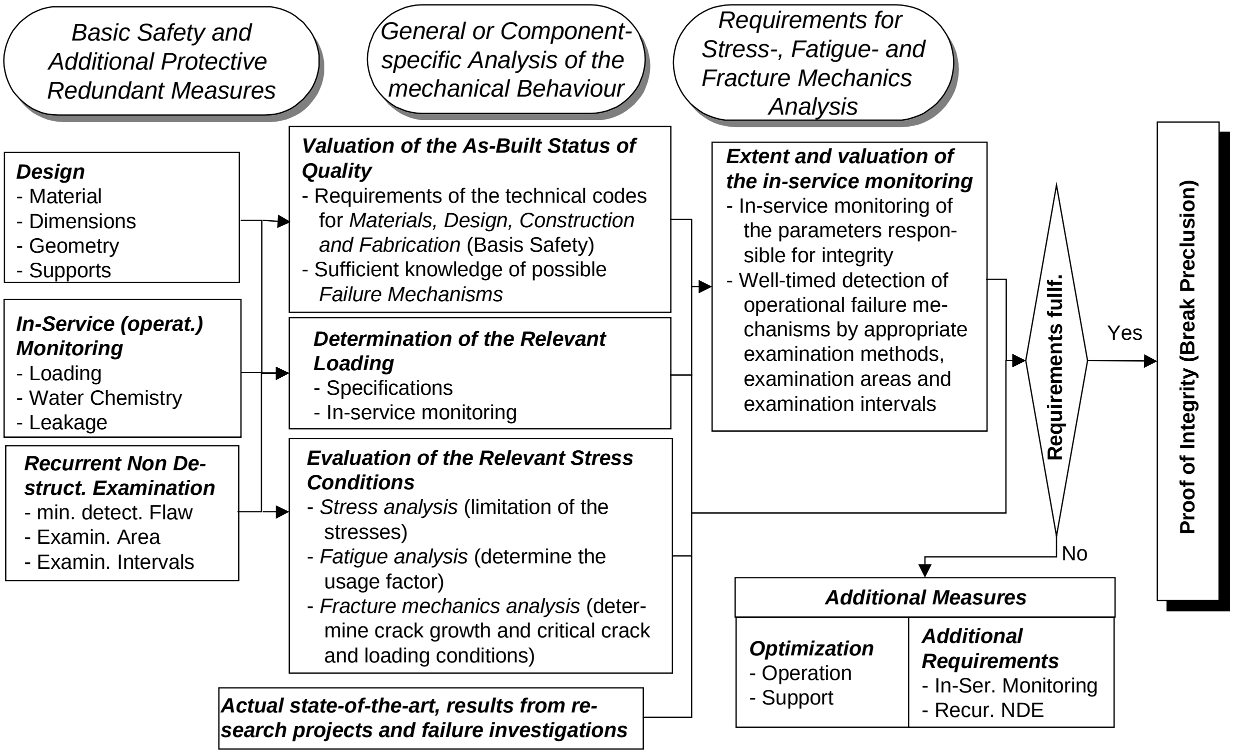

Figure 11: Procedure (schematically) to proof the integrity of components for components or systems in operation

(1) Method of proof for components under construction (new design and new fabrication)

Evaluation of the as-built status of quality

Concerning the as-built status of quality documents must be checked with respect to design, material and fabrication (it is a prerequisite that the requirements of the RSK-guidelines, of the Basis Safety and of the KTA-standards are fulfilled) and possible failure mechanism must be well known. Based on the operational experience and the state-of-the-art the failure mechanism must be identified and and their causes monitored.

Relevant loading conditions

The knowledge of the relevant loading for components under construction is of decisive importance. This forms the relevant input for stress analysis, fatigue analysis and fracture mechanics analysis. The relevant loadings (normal and upset conditions, reaction forces resulting from a 0.1A leak) are included in the load specifications of the design.

Determination of stresses and limitation

Fracture mechanics analysis must be performed for a crack size and shape safely detectable by non-destructive examination (NDE) methods, Wellein [14]. Stimulated by discussion with experts and the licensing authorities as well as the results from research programs in the following the different steps for the fracture mechanics procedures to be used for the proof of integrity (break preclusion) are explained and shown in Fig. 12.

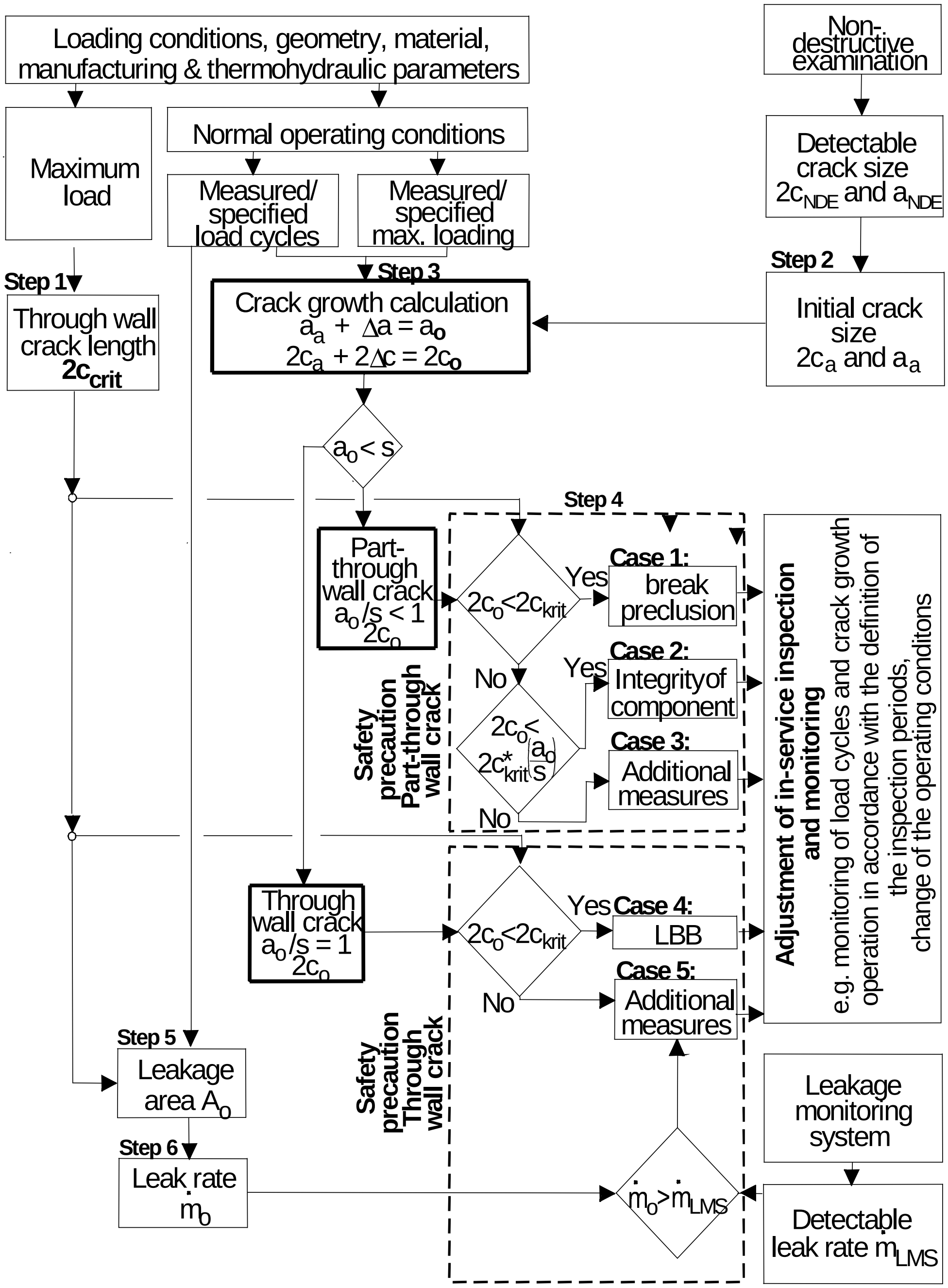

Figure 12: Fracture mechanics procedure (schematically) to proof the leak-before-break behaviour of components

Step1: Calculation of the critical crack length $2c_{crit}$

The critical crack length of a through wall crack $2c_{crit}$ has to be calculated for the maximum loads specified for plant lifetime (plant and system specific maximum load combination for normal operating and emergency/faulted conditions). This can be achieved by limit load calculations or fracture mechanics approaches verified by component testing, Fig. 13 to 16.

Step 2: Definition of the initial crack size (crack depth a_a and crack length $2c_a$)

Component specific definition of the initial crack size well detectable by non-destructive examination (NDE) methods (the safety factor S_{NDE} has to be determined in a component and examination specific way) is

crack depth $a_a = a_{NDE} \bullet S_{NDE}$

crack length $2c_a = 2c_{NDE} \bullet S_{NDE}$

Step 3:Crack growth calculations (Δa and $2\Delta c$)

Crack growth calculation (Δa, $2\Delta c$) for the initial crack shape (depth a_a and length $2c_a$) with loads specified for normal operating conditions or for loads determined by in-service monitoring considering the appropriate load cycles. The final crack shape for the period to be considered will be

crack depth $a_o = a_a + \Delta a$
crack length $2c_o = 2c_a + 2\Delta c$

Crack growth shall be calculated for a period safely covering the intervals of the recurrent inspections. The concept for recurrent inspections and in-service monitoring has to be adjusted to the results of the crack growth calculation.

Step 4: Leak before break (LBB) behaviour

a) Part through crack ($a_o/s < 1$)

The final crack length $2c_o$ must be less than the critical through wall crack length $2c_{crit}$, that means $2c_o < 2c_{crit}$. For the case $2c_o \geq 2c_{crit}$ it has to be demonstrated that $2c_o$ is less than the critical crack length $2c_{krit}$* of a part through crack with crack depth a_o, that means $2c_o < 2c_{crit}*(a_o/s)$ or it has to be demonstrated that the critical moment for the initial crack shape (a_a and $2c_a$) is higher than the moment corresponding to the critical through wall crack length $2c_{crit}$, that means $M_{crit}(a_a, 2c_a)/M_{crit}$ (a/s=1) > 1.

b) Through wall crack ($a_o/s = 1$)

The final crack length $2c_o$ must be less than the critical through wall crack length $2c_{crit}$, that means $2c_o < 2c_{crit}$.

Step 5: Calculation of leak area A_o

The leak area A_o has to be calculated for the critical through wall crack length $2c_{crit}$ (Step 1) and the crack opening (COD) for loads under normal operating conditions.

Step 6: Calculation of leak rate $\dot{m}_o$

It has to be demonstrated that for loads under normal operating conditions the leak rate becomes $\dot{m}_o/S > \dot{m}_{\text{LÜS}}$ (detectable leak rate by leak rate monitoring system) with a safety factor S. The safety factor S has to be determined in a component and plant specific way. The concept for recurrent inspections has to be adjusted to the results of the leak rate calculations. The leak rate shall be calculated based on a model verified by experimental data.

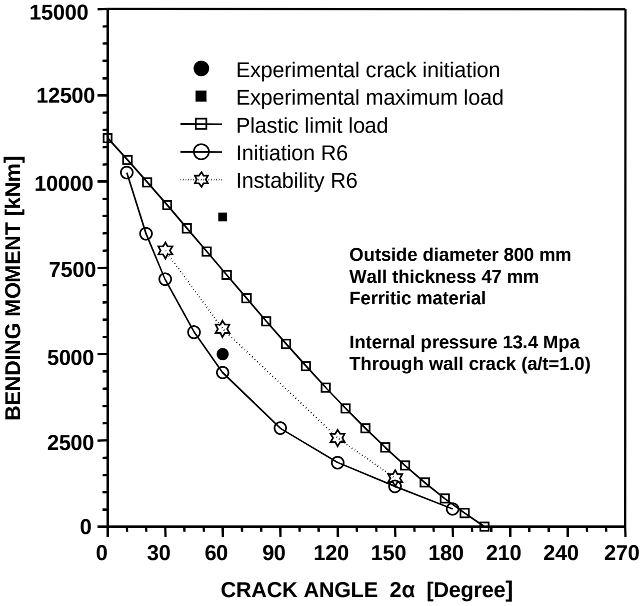

Figure 13: Critical crack sizes R6-method and limit load calculations ($\sigma_{fl}=[R_{p0,2}+R_m]/2$) for pipes with nominal diameter DN800

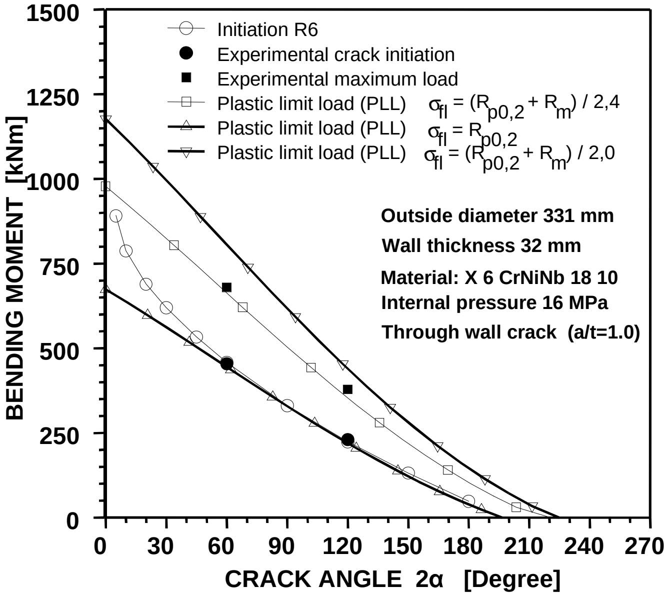

Figure 14: Critical crack sizes R6-method and limit load calculations for pipes with nominal diameter DN300

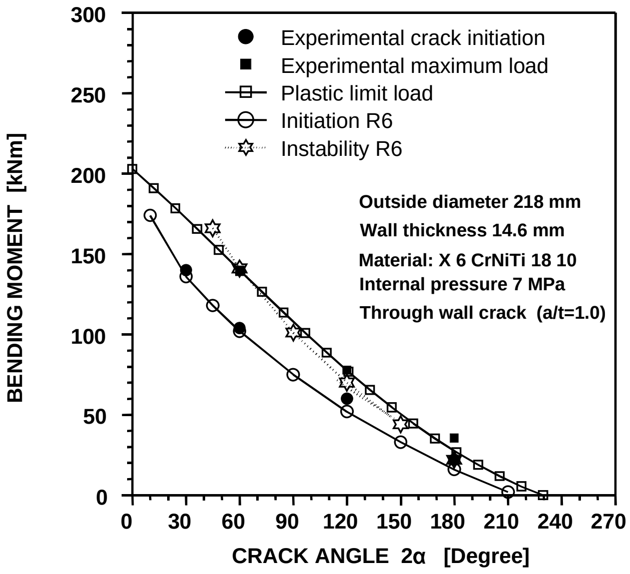

Figure 9: Critical crack sizes R6-method and limit load calculations (σ_{fl}=[$R_{p0,2}$ +R_m]/2.4) for pipes with nominal diameter DN200

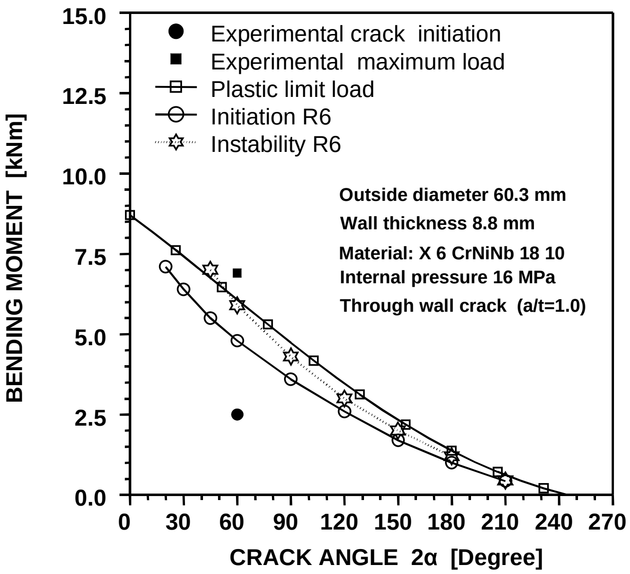

Figure 10: Critical crack sizes R6-method and limit load calculations (σ_{fl}=[$R_{p0,2}$ +R_m]/2.4) for pipes with nominal diameter DN50

Recurrent inspections and in-service monitoring

By recurrent inspections and in-service monitoring it has to guaranteed that assumptions of design, especially the loading conditions (mechanical, thermal, corrosive) do not change during operation. The requirements of KTA safety standard 3201.4 must be kept. In particular the in-service monitoring must detect the relevant local and global loading. The status of quality after fabrication ("Basis Safety") must be guaranteed for the succeeding operation. Therefore in-service monitoring is of decisive importance

Evaluation of the integrity

The evaluation of the integrity is based on the results of the procedure shown and thereby the following aspects are of importance: (a) monitoring of the variables responsible by sufficient detection of the causes of possible operational failure mechanisms (protective provisions, avoidance or control of the causes); (b) well-timed detection of operational failure mechanisms by appropriate examination methods, examination areas and examination intervals; (c) use of the state-of-the-art and the operational experience.

(2) Method of proof for components under operation

Evaluation of the as-built status of quality

If the requirements of the “Basis Safety” are fulfilled, the procedure is following the method of proof for components under construction. If the requirements are not fulfilled documents must be checked with respect to design, material and fabrication (geometry, weldment, supporting, snubbers, function of active components) and the possible failure mechanisms (material, design, processing boundary conditions, mode of operation, results of recurrent non destructive examinations, operational experience).

As a result of the evaluation of the as-built status of quality areas for additional measures concerning the loading conditions, the in-service monitoring and the recurrent non-destructive examinations can be determined.

Relevant loading conditions

It differentiates between two cases: (a) In the previous operation the relevant loading is known by in-service monitoring, the upset conditions are lay down in the specifications of the design; (b) Relevant loading conditions are only available in the specifications of the design.

Determination of stresses and limitation

The procedure is following the one described in chapter "method of proof for components under construction" (step 1 up to step 6).

Recurrent inspections and in-service monitoring

Going beyond the procedure described in chapter "method of proof for components under construction", additional measures for recurrent inspections and in-service monitoring are necessary, especially for the case where in the previous operation no in-service monitoring was installed.

Evaluation of the integrity

Going beyond the procedure described in chapter "method of proof for components under construction" for the succeeding operation additional measures are indispensable. It must be guaranteed by recurrent non-destructive examinations and in-service monitoring that during operation no failure mechanism will occur.

CONCLUSIONS

Based on the German Basis Safety Concept a general concept to ensure the integrity of pressurised components and systems is developed. The concept can be applied to components and systems under construction (new design) as well as to components and systems already in operation for their remaining lifetime. The calculation methods and fracture mechanics approaches are verified by numerous experimental data. The main points are on the one hand to demonstrate the actual as-built status of quality and on the other hand in-service monitoring and recurrent non-destructive examinations to guarantee the ongoing operation of the plants.

NOMENCLATURE

a = crack depth
$2c$ = circumferential crack length
$\dot{m}_o$ = leak rate
p_i, p = pipe internal pressure
s = wall thickness
A = pipe cross section area
DN = nominal pipe diameter (outside)
M_b = pipe bending moment
R_m = tensile strength
$R_{p0,2}$ = yield strength
S = safety factor
T = temperature
α = circumferential crack angle
Δa, Δc = crack growth
σ_{fl} = flow stress
θ = pipe bending angle

REFERENCES

1. K. Kussmaul and D. Blind; "Basis Safety – A Challenge to Nuclear Technology," IAEA Spec. Meeting, Madrid, March 5.-8. 1979; Ed. in *Trends in Reactor Pressure Vessel and Circuit Development* by R.W. Nichols 1979, Applied Science Publishers LTD, Barking Essex, England
2. K. Kussmaul; "German Basis Safety Concept Rules Out Possibility of Catastrophic Failure," *Nuclear Engineering International* 12 (1984), 41-46
3. G.M. Wilkowski, R. J. Olson and P. M. Scott; "State-of-the-Art Report on Piping Fracture Mechanics" *NUREG/CR-6540, BMI-2196*, January 1998
4. K. Kussmaul, D. Blind, E. Roos and D. Sturm; “The leak before break behaviour of pipes,” *VGB Kraftwerkstechnik 70*, No. 7, July 1990, 465-477
5. G. Bartholomé, E. Bazant, R. Wellein, W. Stadtmüller and D. Sturm; “German experimental programs and results,” *Spec. Meeting on LBB*, Lyon, France October 1995
6. H. Schulz; “Current position and actual licensing, decisions on LBB in the Federal Republic of Germany,” *CSNI Report No. 82*, *NUREG/CP-0050*, Monterey, September 1983

7. *Guidelines of the German Reactor Safety Commission (RSK-Guidelines) for Pressurised Water Reactors*; 3rd Edition, October 14, 1981; Revised Section 21.1 of 03/1984 and Section 21.2 of 12/1982; associated general specification "Basis Safety of Pressurised Components; Editor: Gesellschaft für Reaktorsicherheit (GRS)
8. K. Kussmaul, W. Stoppler, D. Sturm, P. Julisch; "Exclusion of fracture in piping of pressure boundary, Part 1: Experimental investigations and their interpretation,*" Int. Symposium on reliability of reactor pressure components*, IAEA-SM-269/7, Stuttgart, March 1983
9. G. Bartholomé, W. Kastner, E. Keim, R. Wellein; "Exclusion of fracture in piping of pressure boundary, Part 2: Application to the primary coolant piping"; *Int. Symposium on reliability of reactor pressure components*, IAEA-SM-269/7, Stuttgart, March 1983
10. Contract with the European Commission, DG XI, „Survey of European Leak-Before-Break procedures and requirements related to the structural integrity of nuclear powerplant components, comparative analyses for harmonisation purposes", *final report: National European Leak-Before-Break procedures and practices – summary of reults and potential for greater harmonisation*, Revision 2, April 2000, GRS Köln
11. *Safety Criteria for Nuclear Power Plants* by the Minister of the Interior (BMI); notification of October 21, 1977
12. *Safety Standards of the Nuclear Safety Standards Commission (KTA)*; KTA 3201.2 Components of the Reactor Coolant Pressure Boundary of Light Water Reactors, Part 2: Design and Analysis, 06/1996
13. Roos, E., K.-H. Herter, F. Otremba; "A General Conceot to Ensure the Integrity of Components", Assessment Methodologies for Preventing Failures-I: Deterministic and Probabilistic Aspects and Weld Residual Stress, *ASME PVP-Vol. 410*-1 (2000)
14. R. Wellein and G. Preusser; "State of Engineering of the Leak-Before-Break Procedure in Germany"; *7th German-Japanese Joint Seminar*, September 29-30, 1997, MPA Stuttgart