Operating experience of a Swiss BWR (KKL)

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Field Experience Leibstadt NPP

Contents

Introduction

Leibstadt Nuclear Power Plant (KKL)

- BWR/6, 1275 MWe

  EPU of 114% accomplished in 2003

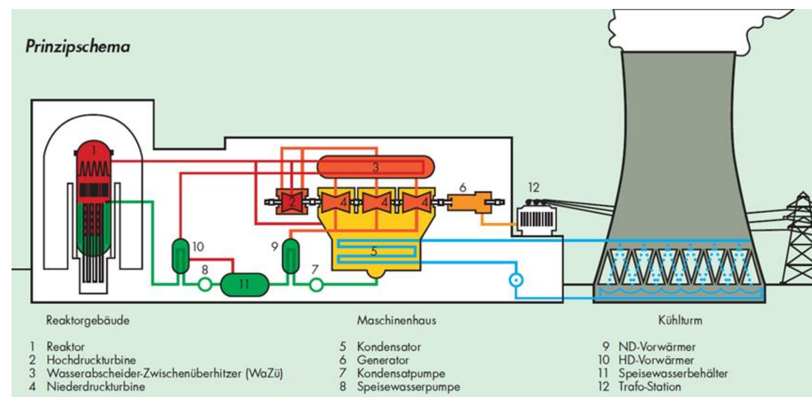
  + LP turbine refurbishment in 2010

  + new turbine generator in 2012

  + new moisture separator reheater in 2017

  + new condenser in 2020

  ….
- Mark III containment
- Commercial operations: 1984
- Newest and largest NPP in Switzerland
- Located at the River Rhine on the border between Switzerland & Germany



EAC in Reactor Water

KKL EAC in Reactor Water
Findings

Three different kinds of indications so far:

- Recirculation loop piping
- Core shroud (horizontal weld)
- Dissimilar Metal Weld (DMW) of feed water nozzle to safe end

Recirculation Loop Piping

- Made out of 316 NG

  low carbon content < 0.02 % (from 0.007 to 0.018%)

- Most of all indications found at shop welds made by Hitachi

  acceptable according ASME Code Sect. XI

- Augmented inspections by UT

- All indications did not show growth since 2001

  in accordance with the observations made for Japanese recirc. piping*

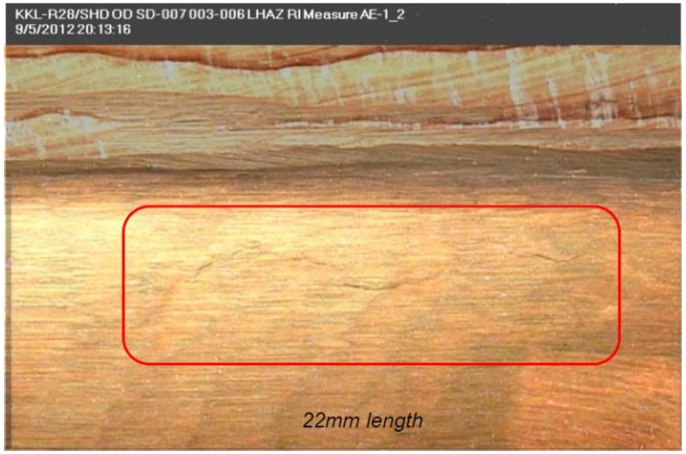
* = e.g. *K.Kumagai et.al. Proceedings of ASME-PVP 2004: 2004 ASME/JSME Pressure Vessels and Piping Conference San Diego, California, July 25 – 29, 2004*

Core Shroud

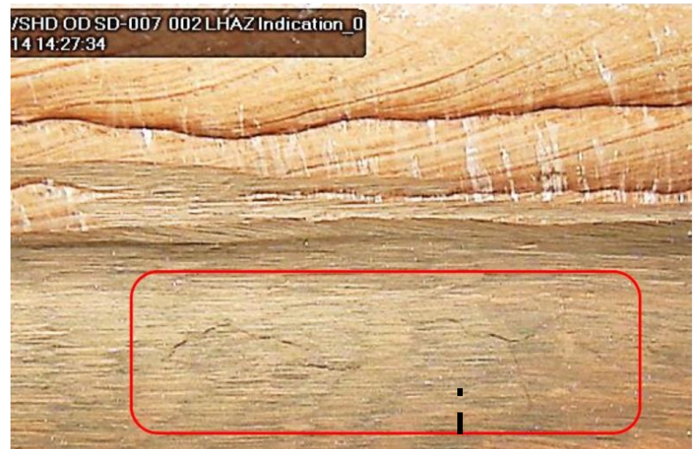
- Made out of 304L / 308L
- OD of Weld SD-007: two small indications found by VT in 2012
  maximum length of 22 mm
- Reinspection after 2 und 5 years revealed no apparent change of both indications

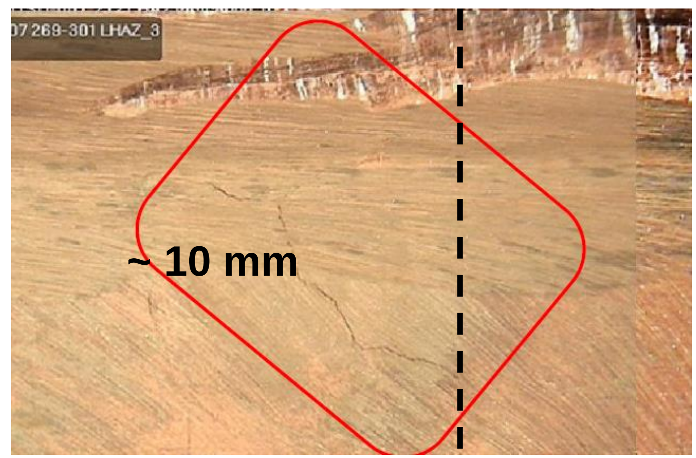
Indications in Core Shroud

2012

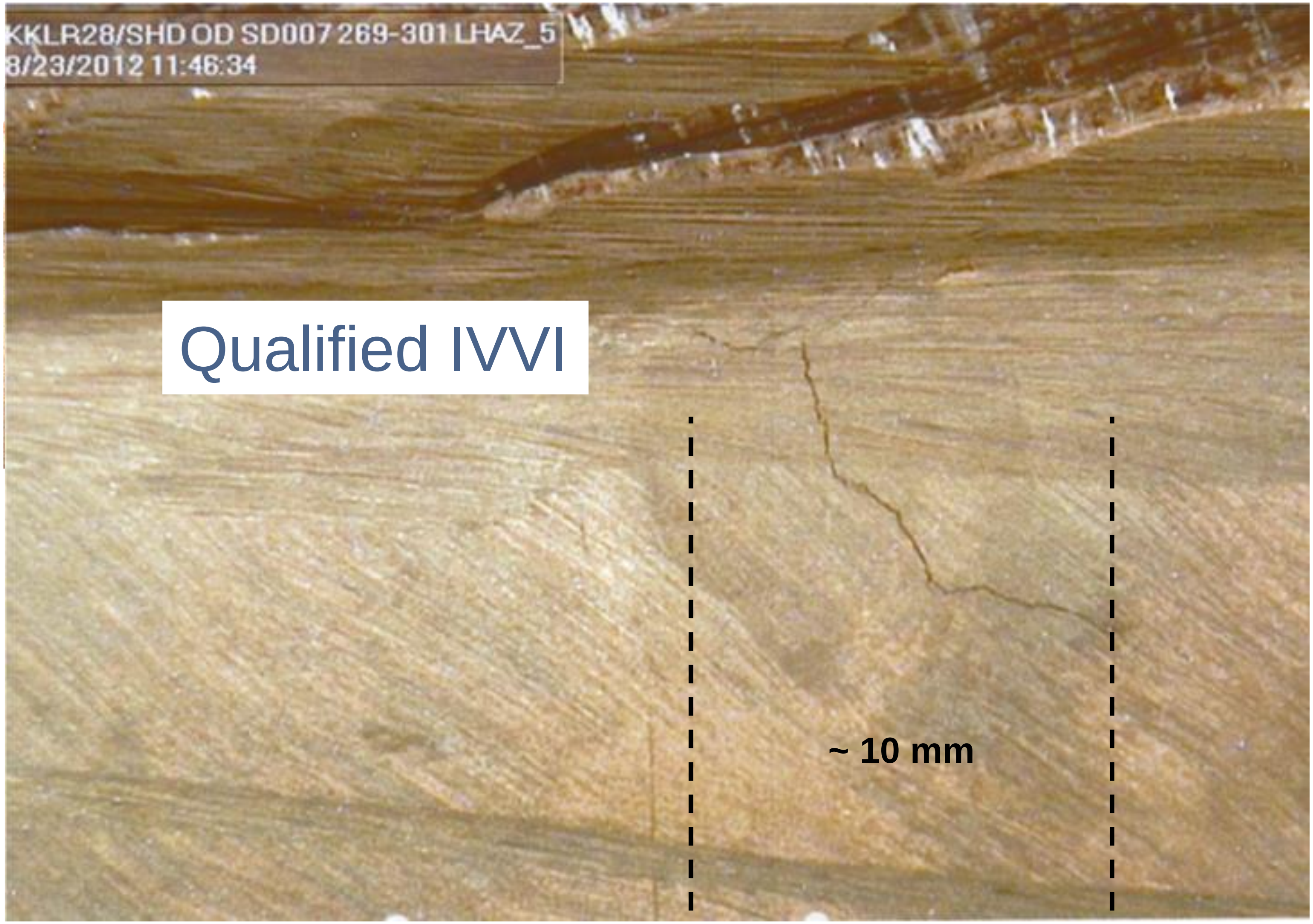


2014





Indications in Core Shroud



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SCC of DMW

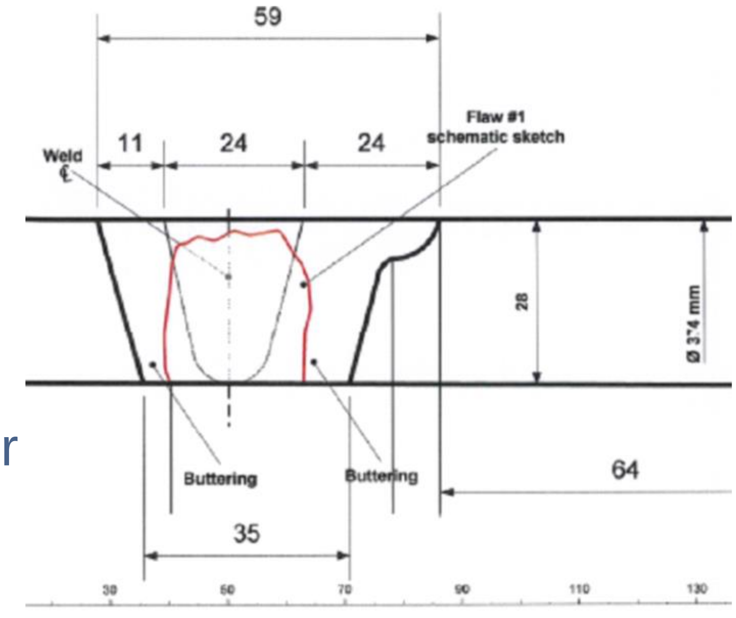
DMW of Feed Water Nozzle to Safe End

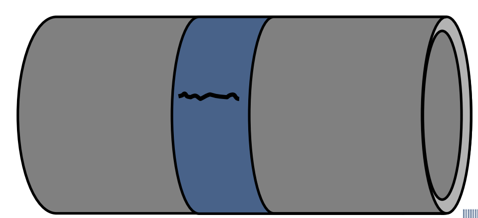
- Ferritic nozzle and safe end
- DMW: Alloy 182 (Butter) / Alloy 82
- No Mechanical Stress Improvement (MSIP)
- ID-connected axial indication found in 2012
- Reevaluation of prior UT-inspection in 2004
  ~1.5 mm/year crack growth
- Full Structural WOL with Alloy 52

RPV Nozzle Dissimilar Metal Welds (DMW)

Outage 2012: Indication overlaid at N5-nozzle

- Axial orientation
- Found in weld metal
- Length 22 mm (*shorter at base?)*
- Depth 26 mm (~ 93% wall thickness)
- Multifaceted and branched
- Emanating from edge of ID weld repair
- Clear ID connection
- Flaw is indicative of interdendritic stress corrosion cracking





Axial orientation (schematic)

After WOL Repair: Additional Laboratory Tests

Material Alloy 52 tested with the identical:

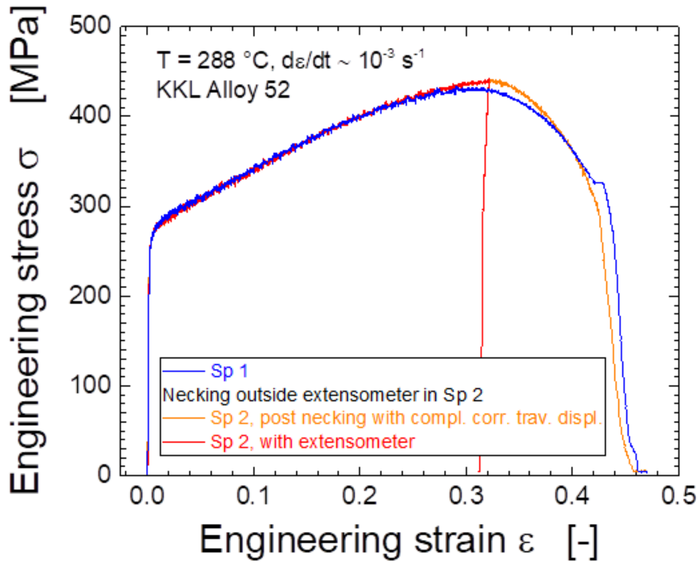
- Chemical composition
- Welding parameters

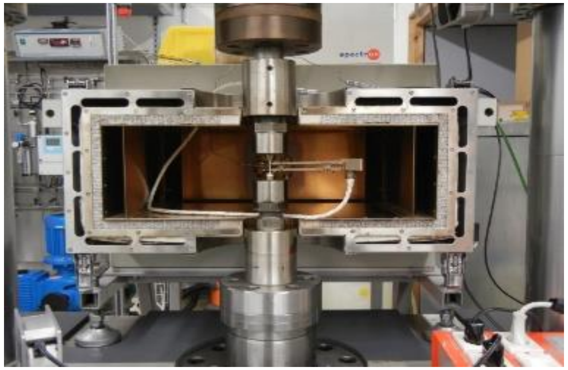
Test conducted:

- Elevated temperature tension tests in air
- Fracture toughness tests in air
- SCC tests under simulated BWR-conditions

Elevated Temperature Tension Tests

Parameter	Sp. #1	Sp. #2	Mean value
E [GPa]	171	167	169
$YS_{0.2}$ [MPa]	260	262	261
UTS [MPa]	430	440	435
FS = (UTS+YS)/2 [MPa]	345	351	348
UE [%]	31	32.5	31.8
EF [%]	45.4	45.7	45.6
RA [%]	77.2	82.9	80.1

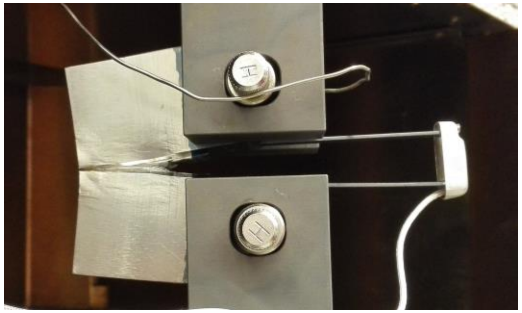




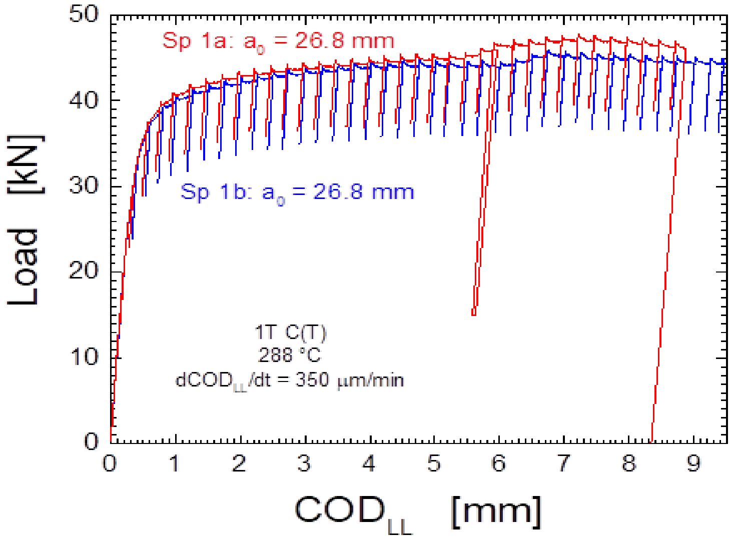
After WOL Repair: Additional Laboratory Tests

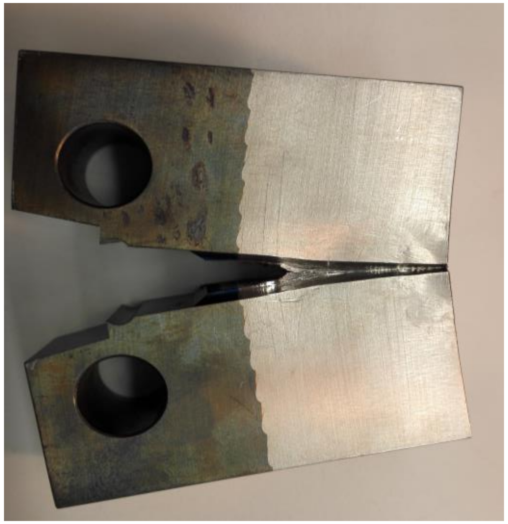
Fracture Toughness Tests according to ASTM E1820-13

Sp	Type	a_0 [mm]	Δa [mm]	Δa_{ULC} [mm]	J_Q [kJ/m^2]
2b	0.5T C(T)	12.37	3.06	3.10*	1089**
2c	0.5T C(T)	13.20	1.30	1.30	1118
2d	0.5T C(T)	13.35	2.65	1.97	948
1a	1T C(T)	26.80	2.80	2.81	1420
1b	1T C(T)	26.80	4.10	3.53	914

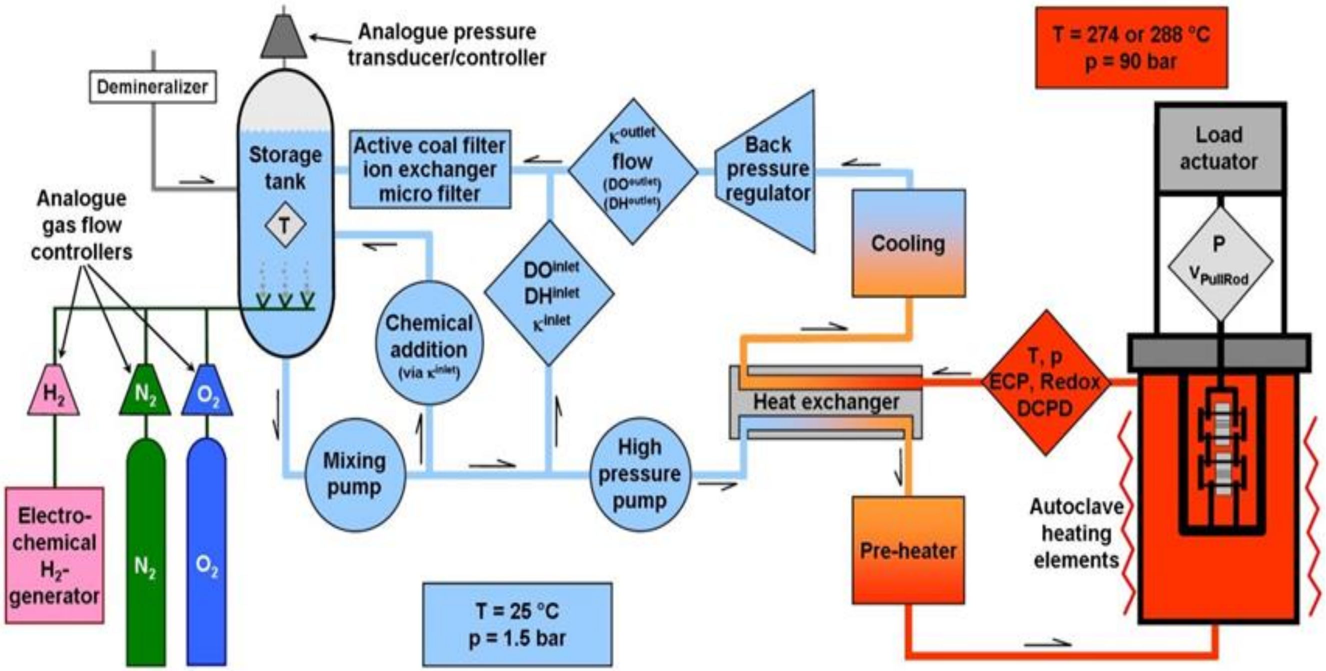


High toughness confirmed





SCC Tests in a high-temperature water loop



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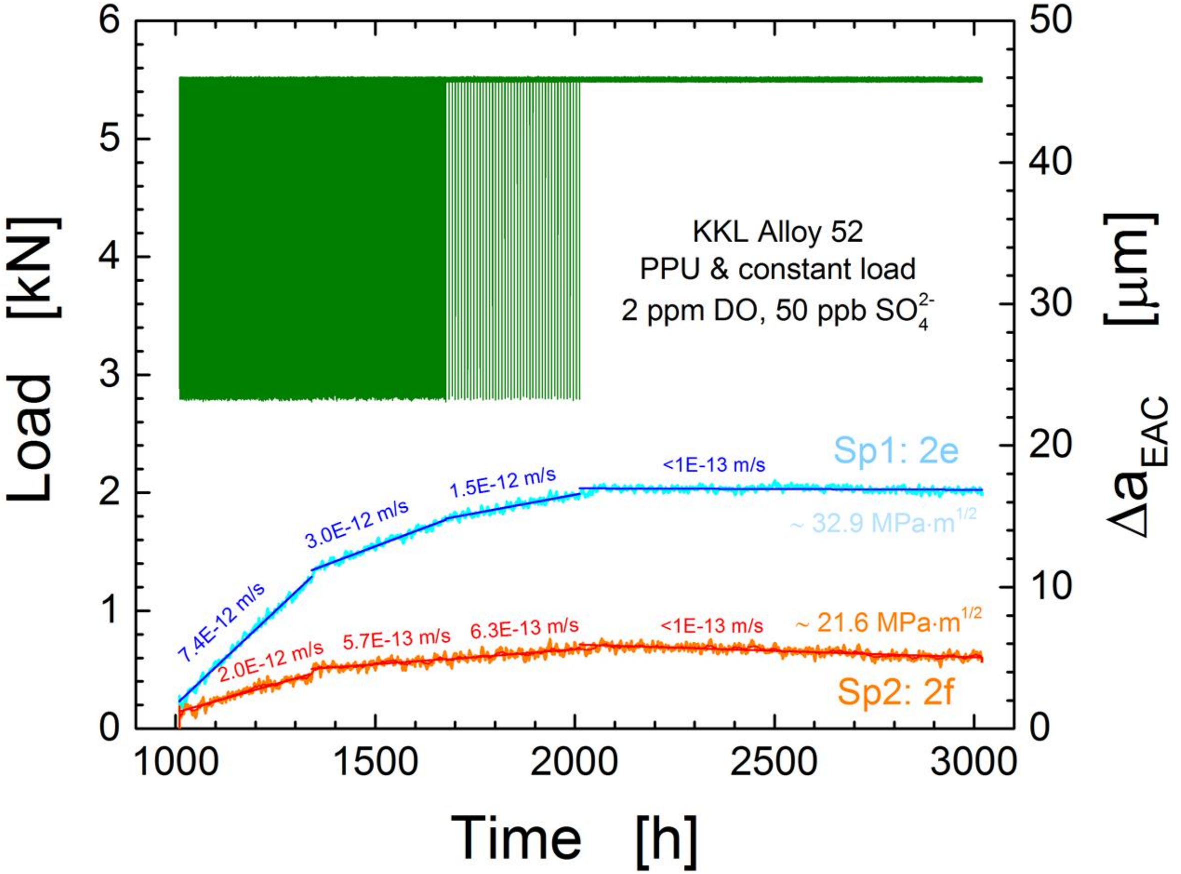
SCC Tests in a high-temperature water loop



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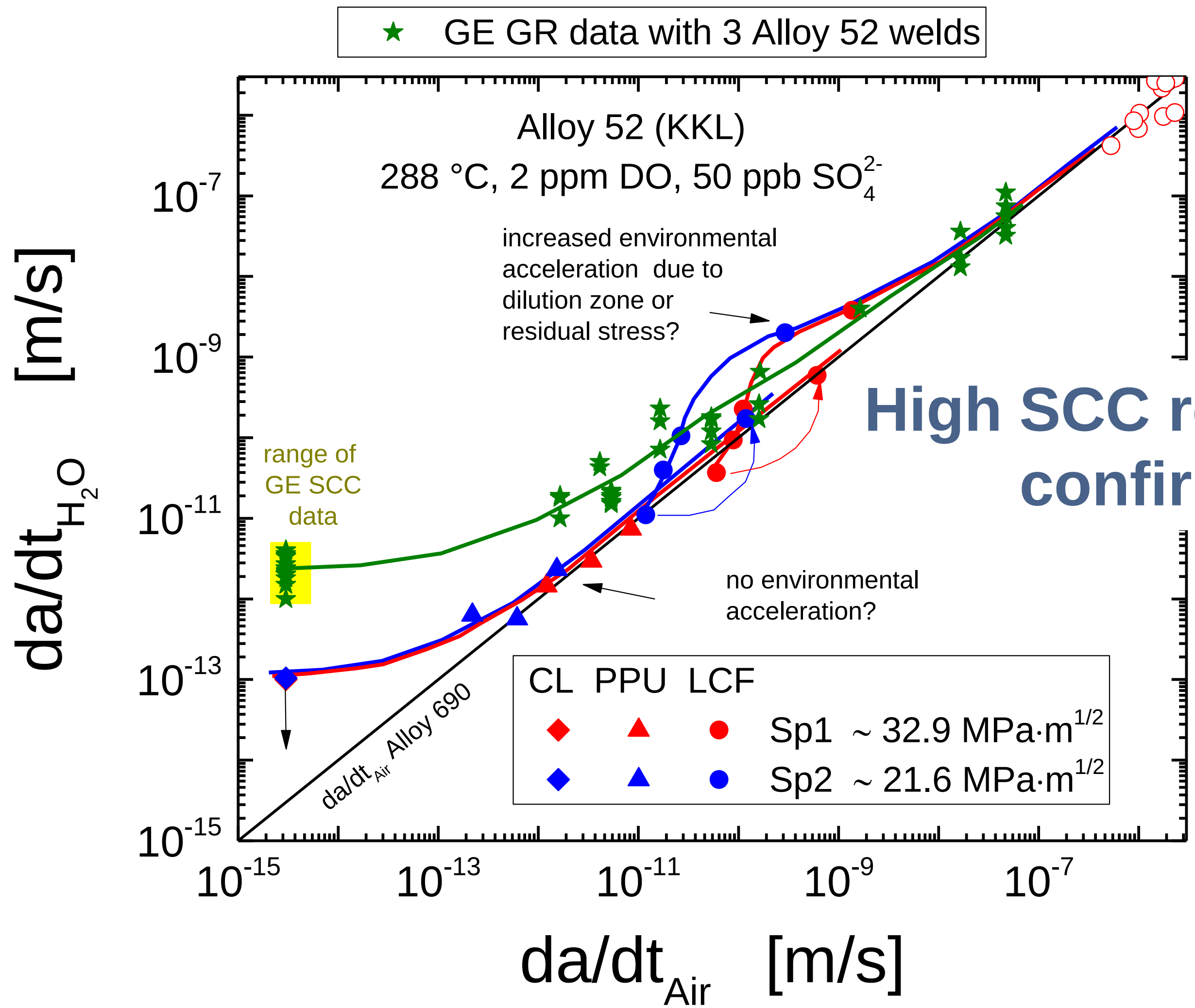
SSC Tests in a High-Temperature Water Loop



High SCC resistance confirmed

After WOL Repair: Analysis on SCC Susceptibility

- **Assessment of all RPV DMW's**
  - \+ Operational experience
  - \+ OLNC / HWC mitigation
  - \+ ID-repairs of DMW's
  - \+ Operational loads at DMW's
    - → supported by a fracture mechanics analysis

- **Provide qualification of a MSIP pilot application to the Swiss regulator**

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RPV Nozzle DMW

DMW: Alloy 182 (Butter) / Alloy 82

Materials			
	Nozzle	**Safe End (SF)**	**SF to Safe End Extension (SFE)**
N2 Recirculation Outlet	SA-508 CL2	SA-336 CL F8	-
N3 Recirculation Inlet	SA-508 CL2	SB-166	SA-336 CL F8
N5 Feedwater	SA-508 CL2	SA-508 CL 1	-
N6 Core Spray	SA-508 CL2	SB-166	SA-508 CL 1
N7 RHR/LPCI	SA-508 CL2	SB-166	SA-508 CL 1
N10 JP Instrument.	SA-508 CL2	SA-336 F8	-
N11 CRD Return	SA-508 CL2	SA-336 F8	-

BWRVIP-75-A

"Technical Basis for Revisions to Generic Letter 88-01 Inspection Schedules"

- Re-assessment of Inspection schedules required by Generic Letter 88-01
- BWRVIP-75-A issued in 2005 and accepted by USNRC

Category	Weld Description	Existing Inspection Frequency of GL 88-01	Proposed Inspection Frequency (Note 1, 2, 3(b))		Scope Expansion
			NWC	HWC/NMCA	
C	Non-Resistant Materials Stress Improved after 2 years of Operation	All within 2 cycles of SI, then all within 10 years, at least 50% within 1st 6 years	25% every 10 years (Note 5)	10% every 10 years (Note 5)	Section 3.3.1
D	Non-Resistant Materials, No Stress Improvement	Every 2 refueling Cycles	100% every 6 years	100% every 10 years, at least 50% in 1st 6 years	Section 3.4.1
E	Cracked - Reinforced by Weld Overlay	Every 2 refueling Cycles	25% every 10 years, at least 12.5% in 1st 6 years	10% every 10 years	Section 3.5.1.1

Assessment of Operational Experience

since 2005 to complete information found in BWRVIP-75-A

- **Information was hard to compile:**
  - different lists, private communications etc.
  - part of information missing (category C / D, inspection history)

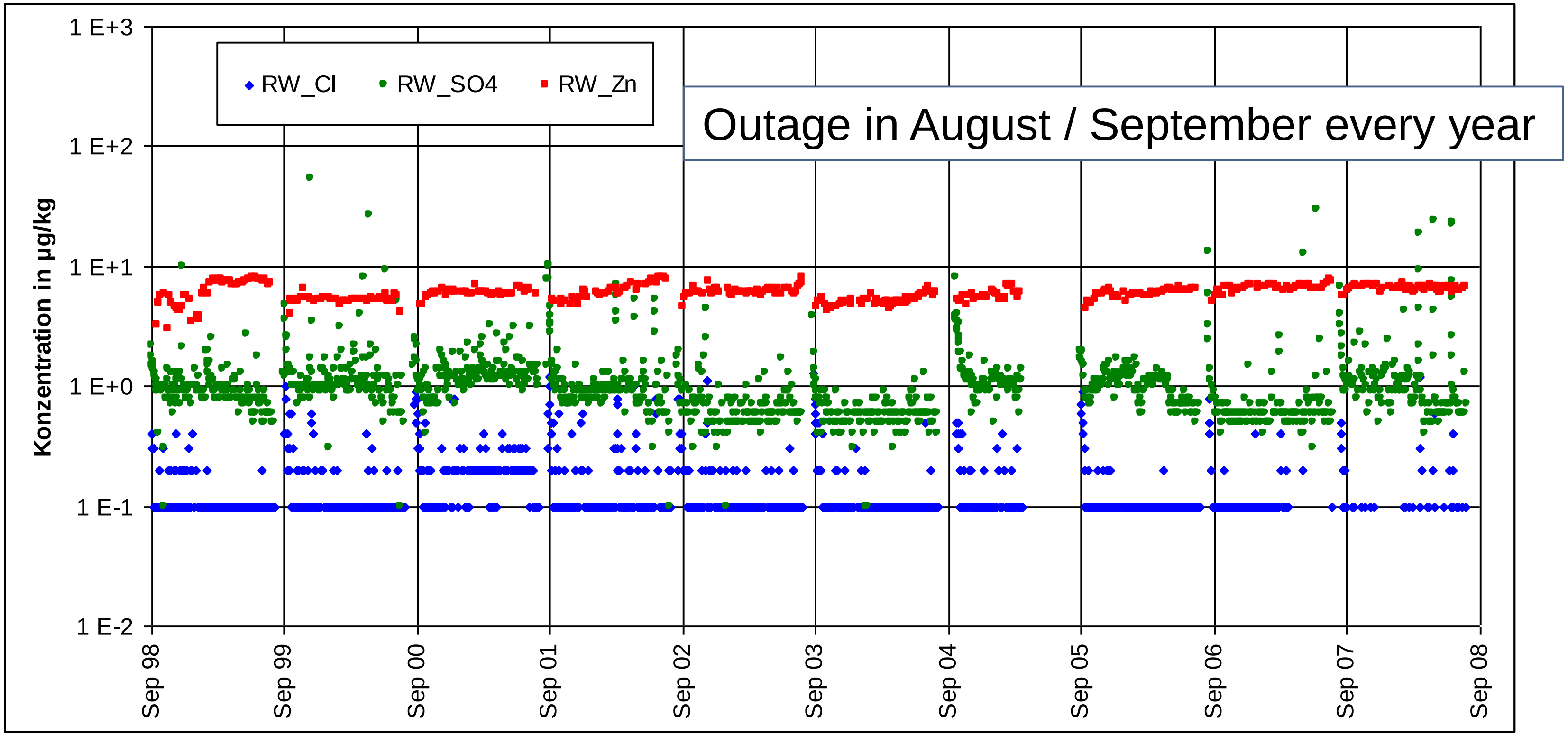
- **Input and assistance from EPRI (C. Wirtz) and additional input from utilities** (provided by Sierra Technologies)

- **Assessment by KKL**
  - Crack initiation in Alloy 182 but also crack growth in Alloy 182
  - No (significant) crack growth in base material (nozzle, SF and SFE)
  - **Very few indications with > 0.75 t since 2005**

Most important: encoded qualified UT-inspection method

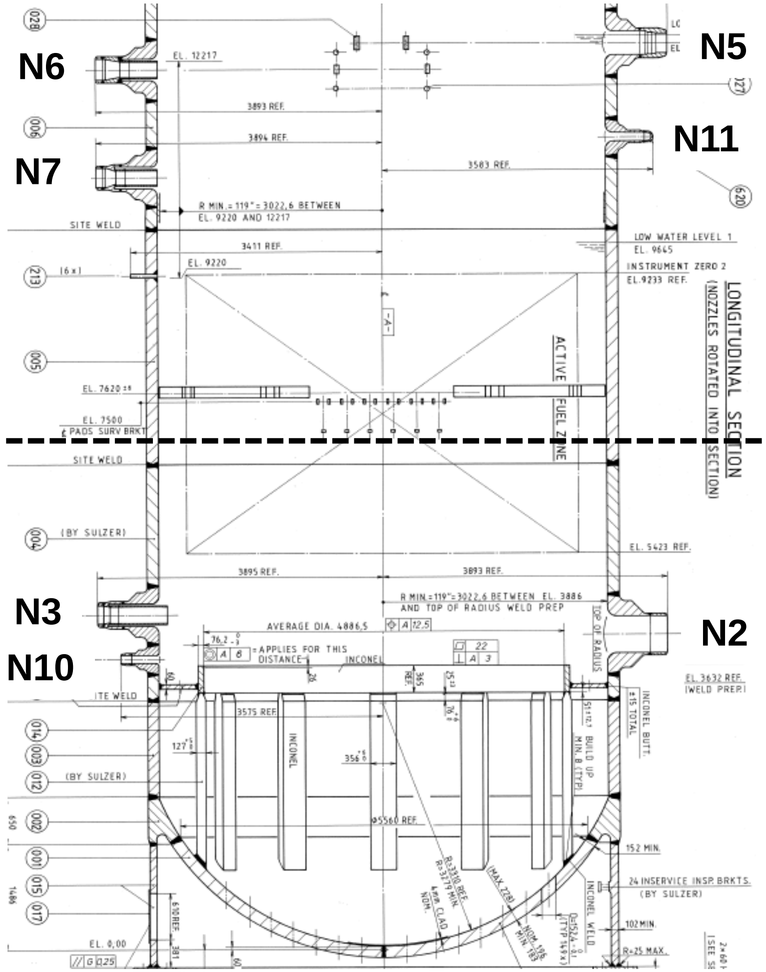
Water Chemistry

Low concentration of chloride and sulfate



Assessment of OLNC / HWC Mitigation

according to BWRVIP-219



KKL-RDB, Ausschnitt aus Zeichnung Z06536

Not mitigated:

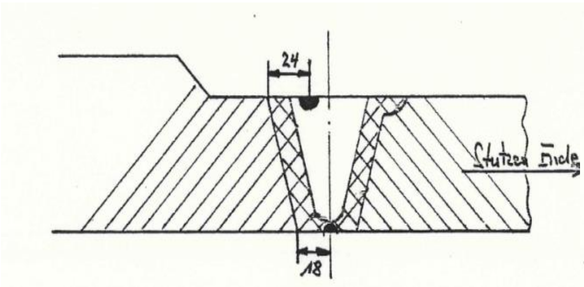
- N5: Feed Water
- N6: Core Spray (HPCS / LPCS)
- N7: RHR / LPCI
- N11: CRD-Return

Mitigated:

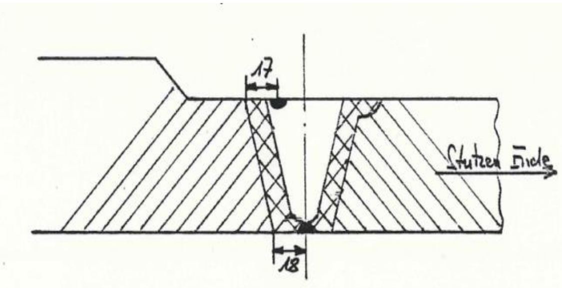
- N2: Recirc Out
- N3: Recirc Inlet
- N10: Jet Pump Instrumentation

Assessment of ID-Repairs

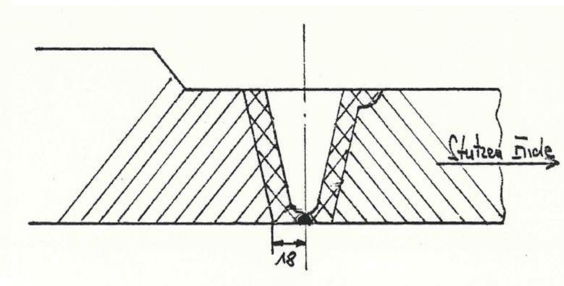
All N5 nozzle to safe end DMW have ID-repairs



30°, max. depth of 5 mm



150°, max. depth of 4 mm



90°, depth of 3 mm

Two other ID-repairs found:

- N2 SF
- N7 SFE (shop weld)

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Operational Stresses

E.g.: hoop stresses σ_h (axial crack growth)

Nozzle	DMW	Outer Dia [mm]	Thickness [mm]	σ_h [MPa]
N2	SF	600	46	57
N3	SF	358	31	49
N5	SF	374	28	58
N6	SF	342	33	45
	SFE	335	23	**65**
N7	SF	354	30	51
	SFE	335	23	**65**
N10	SF	140	21	**27**
N11	SF	136	21	**25**

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Qualitative Assessment

Important Factors:

Operational experience	BWRVIP-75A inspection frequencies
Water chemistry	good practice at KKL
ID-repairs	impact on initiation and growth of SCC
Operational stresses	for SFE > SF («wall thickness»)
Qualified UT-technique	very important

Approach:

BWRVIP-75A as a «base line»

Shorter UT-intervalls for welds: (a) with ID-repair

(b) SFE (if not mitigated by HWC)

Fracture Mechanics Analysis

Calculation of «residual live time»

- Welding Residual Stresses (FE-Analysis*) and operational stresses
- Crack growth by SCC (>> Fatigue CGR)
- Circumferential and axial crack growth

    axial cracks: «natural flaw growth»; crack growth in Alloy 182/82
    circumferential cracks: crack growth in SS and in Alloy 182/82

- Crack growth rates according to BWRVIP-59-A / BWRVIP-114-A
- Acceptable flaw dimensions according ASME Sect. XI, Appendix C
- Initial crack depth: 10% of wall thickness

* As described in:
D. Sommerville et al., Simplified Dissimilar Metal Weld Through-Wall Weld Residual Stress Models for Single V Groove Welds in Cylindrical Components, Paper No. PVP2014-28828ASME, 2014 Pressure Vessels and Piping Conference

Shortened UT-Inspections Intervals

DMW	Inspection [y]	Remarks
N2 Recirc.Outlet SF	10 / 5	Mitigated by HWC 5 years interval because of ID-repair at one weld
N5 Feedwater SF	3	Not mitigated by HWC ID repairs
N6 Core Spray SFE	4	Not mitigated by HWC
N7 RHR/LPCI SFE	4 3	Not mitigated by HWC 3 years for one weld with ID-repair

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Concluding Remarks

Concluding remarks

Important for the assessment of SCC EAC / SCC

- Understanding of the mechanisms / phenomena
- Disposition lines for crack growth

- Operational Experience
- Fabrication History

- NDE capability

Thank you very much for your attention

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