Operation Experience, Operation Procedures In Supercritical And Ultra Supercritical Boilers

Dr M. Bader

E.ON Anlagenservice

Company Profile

The service scope of E.ON Anlagenservice comprises planning and maintenance expertise for complex power generation and industrial plants







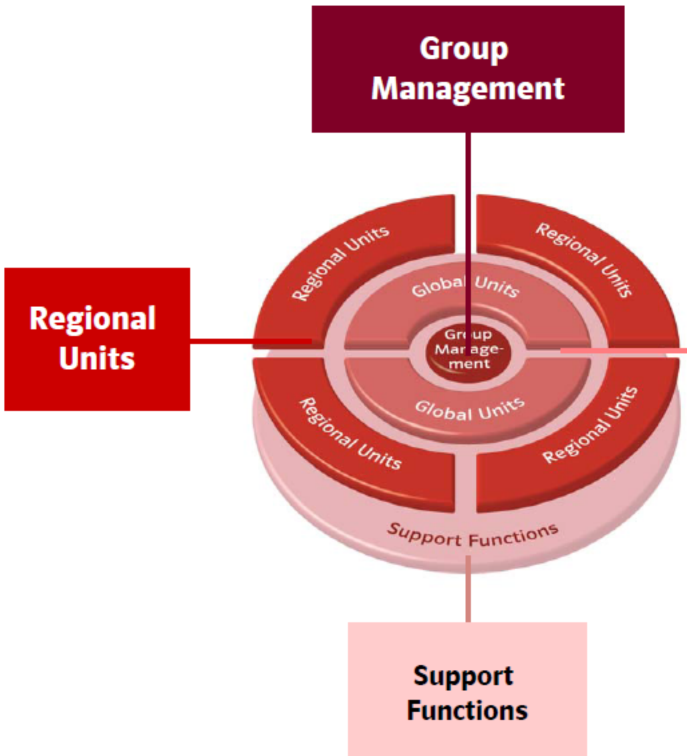

The EAS core business is securing existing power plants
Furthermore, EAS is involved in the construction business for new power plants

EAS is one of the largest Non-OEM service providers in Western Europe

E.ON Anlagenservice

E.ON Anlagenservice is a part of Global Unit - Generation

E.ON group structure



Global Units

- Generation
  - Steam
  - CCGT
  - Hydro
  - Nuclear
  - EAS
- Renewables
- Global Gas
- Trading
- New Build & Technology

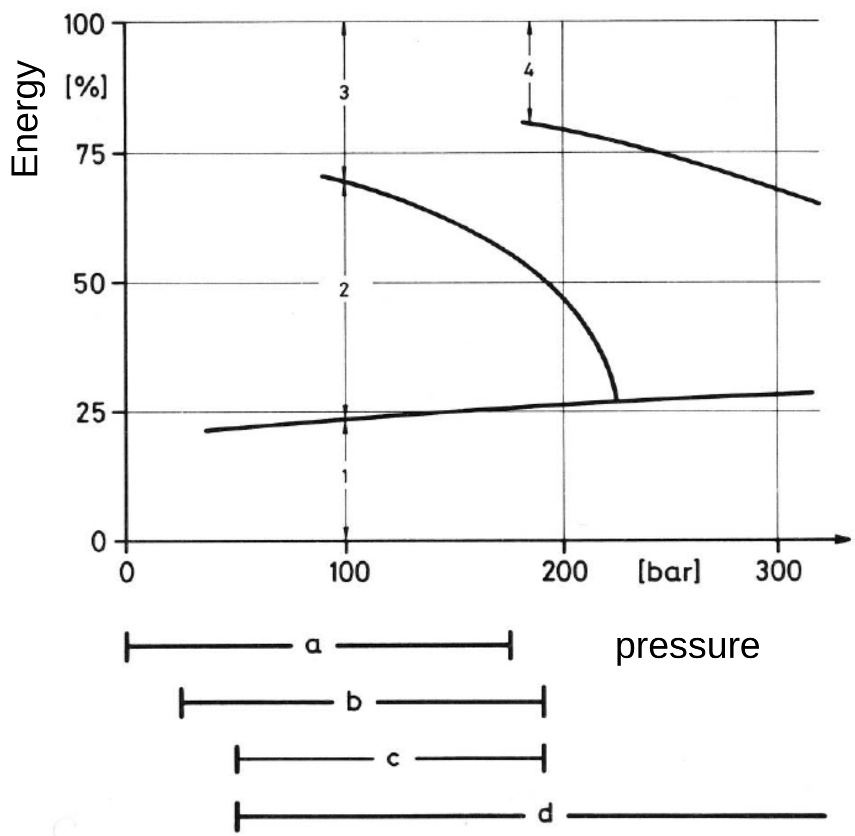
Content

1. Steam Generator – Overview and Examples

2. Material Map

3. Experiences

1 Steam Generator Systems



[Strauß, 2001]

Heat requirement for:

1 Preheat

2 Evaporation

3 Overheat

4 Reheat

Systems:

a Natural circulation boiler

b Assisted-circulation boiler

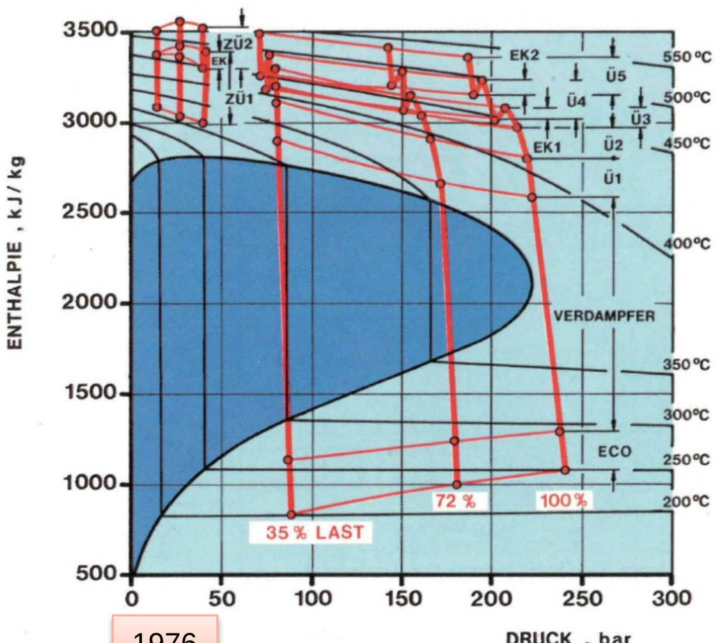
c Assisted-circulation with add. recirculation

d once-through boiler

1 Steam Generator Systems

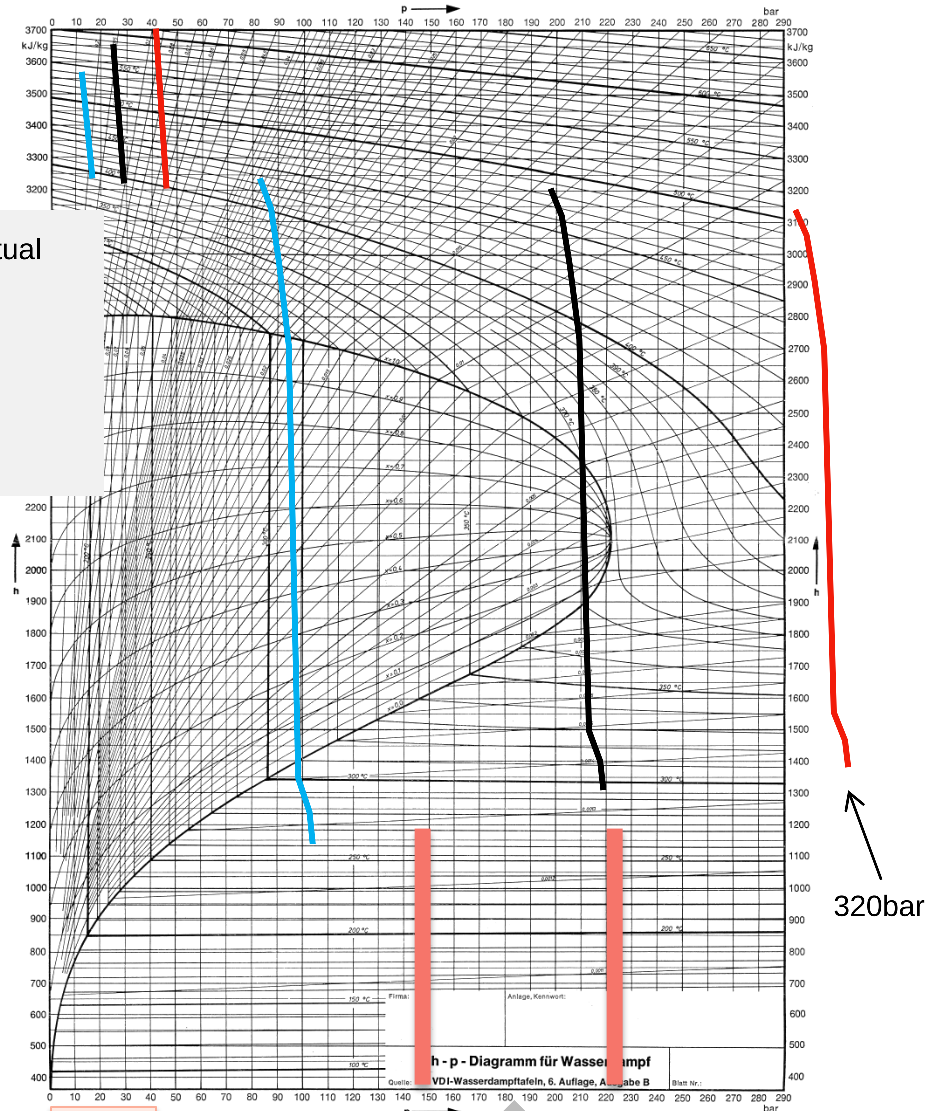
Working h-p-lines of an actual USC-once-through-boiler:

- 100% Load
- 80% Load
- 40% Load



1976

[Whv Reference Book]

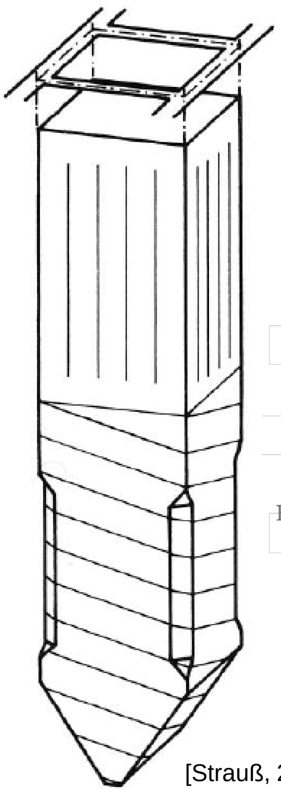


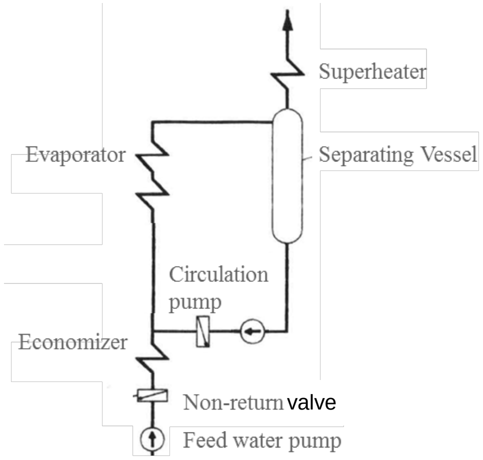
2006

Super-critical-boiler (SC-Boiler)

Ultra-super-critical-boiler (USC-Boiler)

1 Steam Generator Systems



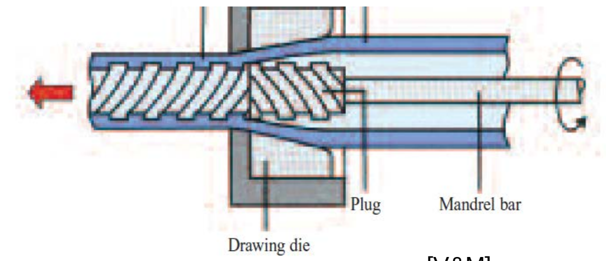


[Strauß, 2001]

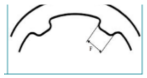
Inclined evaporator membrane wall

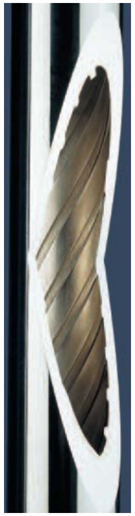
(once-through boiler)

Manufacture of the multi-rifled tube



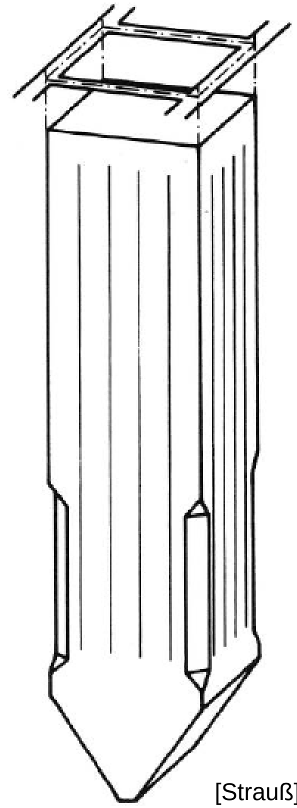
[V&M]





[V&M]

Multi-rifled tubes for the evaporator

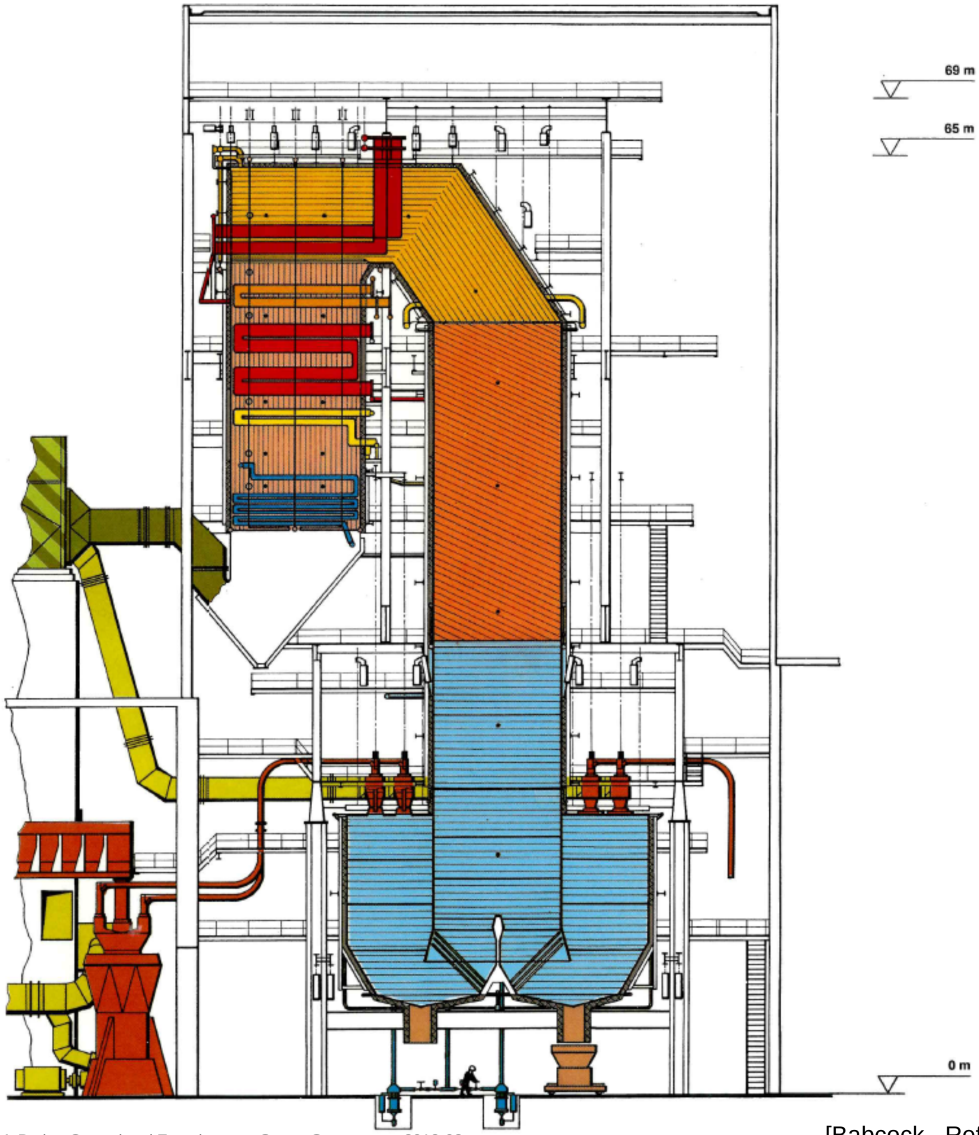


[Strauß], 2001

Vertical wall tubes in the evaporator:

(fixed evaporation point; → natural circulated or assisted-circulation boiler)

1 Examples for Benson® Steam Generators – Two Pass Boiler

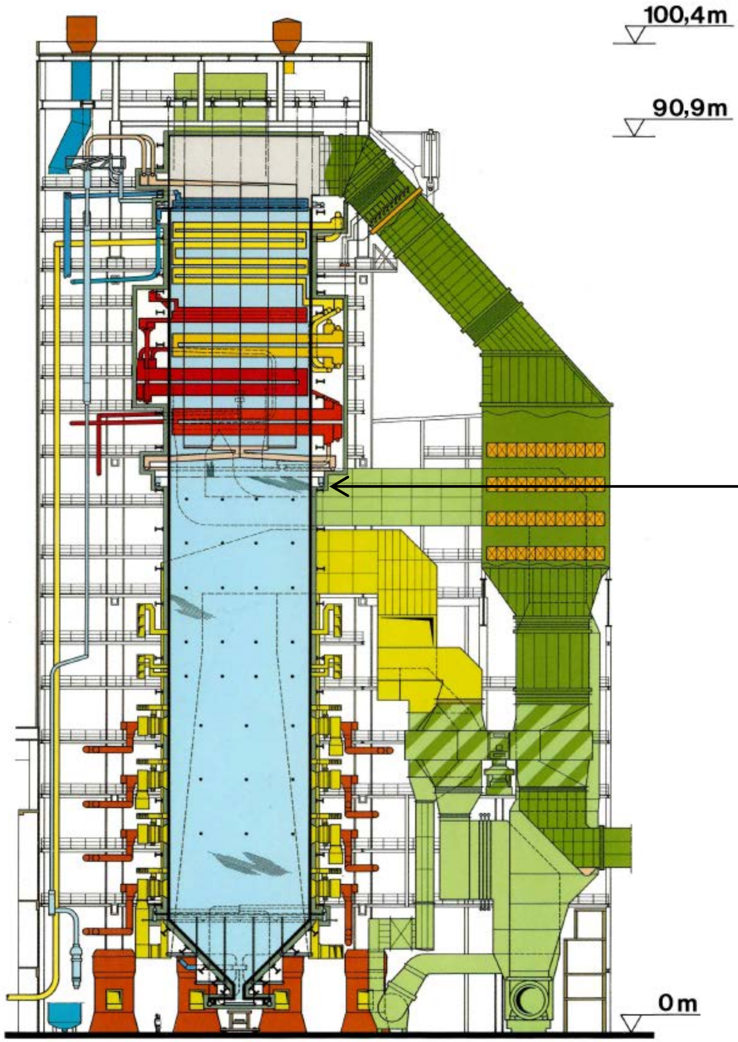


Old Design:

The high was limited by the construction (installation) capabilities

[Babcock - Reference Sheets]

1 Examples for Benson® Steam Generators – Single Pass Boiler



Design from the end of 70s:

Single pass boiler

Better functionality

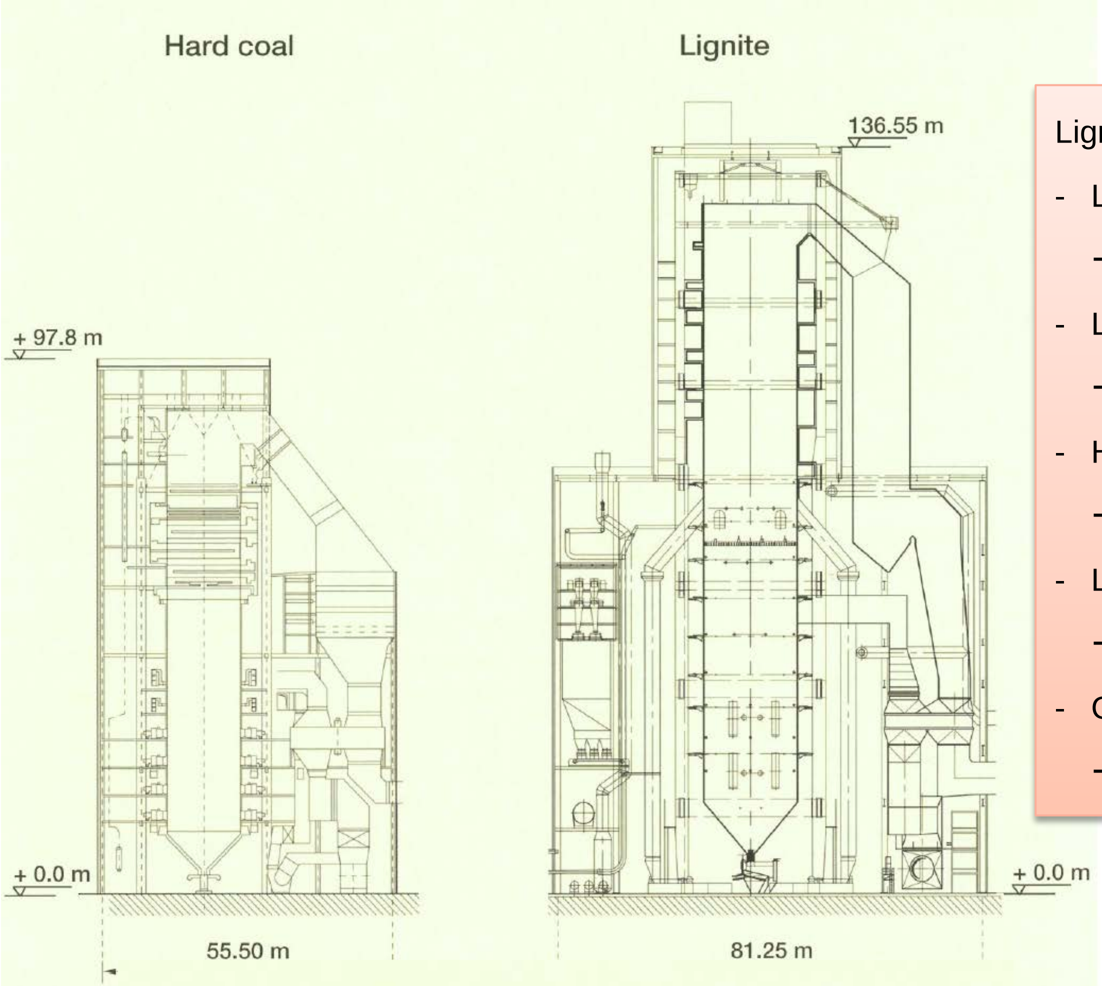
Special feature:
Additional ring header – to reduce the thermal and pressure differences between the single tubes of the membrane wall

[Babcock - Reference Sheets]

1 Discussion Points For The Comparison Of Single Pass And Two Pass Steam Generator:

- Overall height
- Constructive expenses (boiler structural steelwork, suspension)
- Suspension of expansion by the own weight, the fluid weight, the heat
- Working with the 3D-differential expansion in the edge and at the boundaries of the heating surface sections of the evaporator and the super heater
- Arrangement of the catalyst and the regenerative air heater
- Arrangement of the economizer
- Furnace outlet temperature
- Arrangement of the final super heater
- Prevention of an over heating of convection heating surface during the igniting phase before start of the evaporation
- Flue gas flow: avoiding of deposition of ash
- Accessibility of the combustion chamber (inspection platform)
- Accessibility of the convection heating surface tubes
- Height of the fall of slag

1 Comparison Of Lignite And Hard Coal Fired Steam Generator



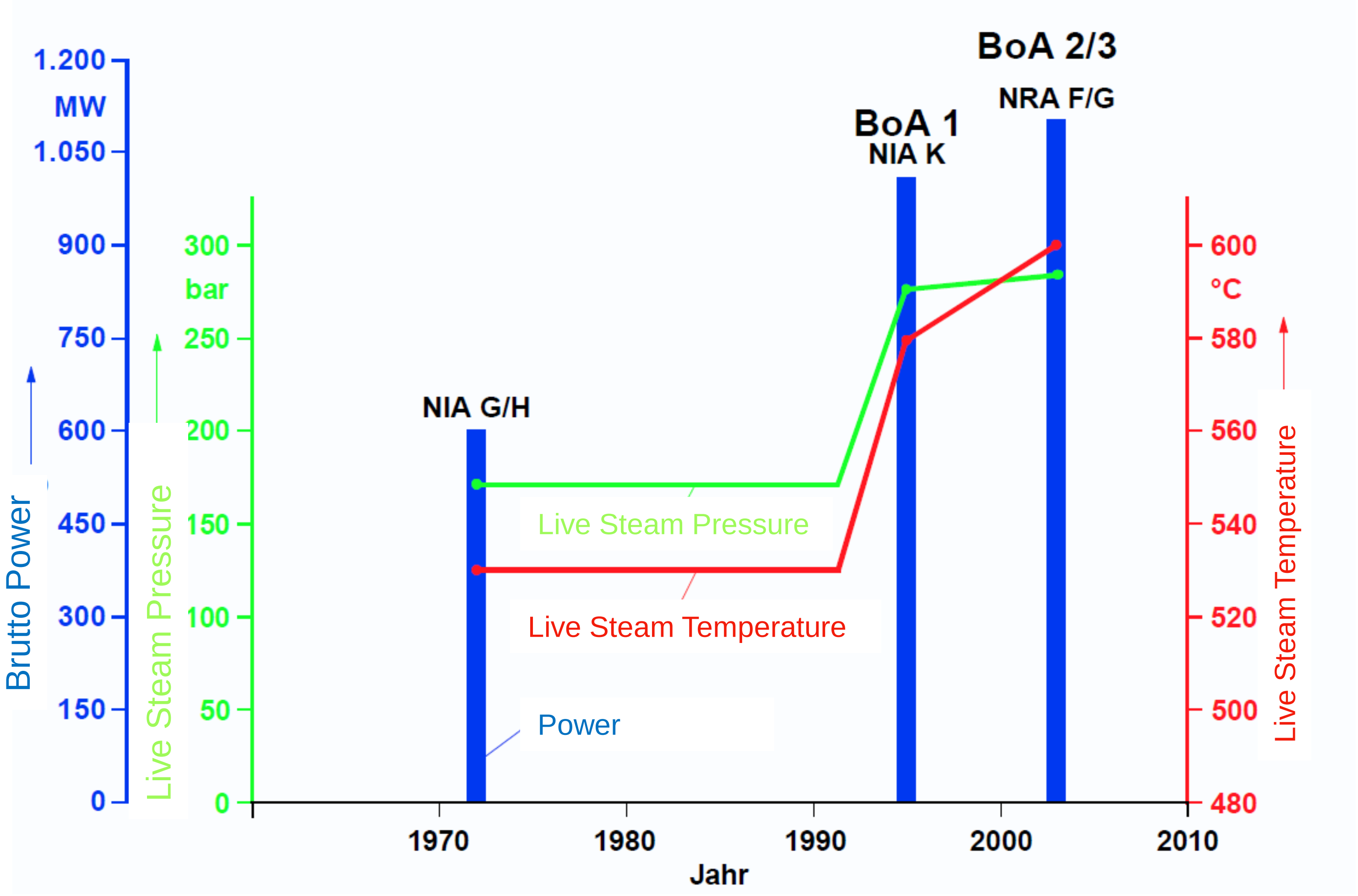
Built-on area (m^2):	2400	3900
Building volume (m^3):	170 000	414 000

Lignite:

- Lower ash softening temp.
  → bigger combustion chamber for lignite
- Lower inlet temp. into convective heating surface
  → bigger heating surface dim. (reheater)
- Higher SiO2 content in ash
  → increased wear (flue gas duct should be bigger)
- Lower fuel gas speed
  → bigger heating surface dimension (Eco)
- Greater flue gas volume flow (+45%)
  → bigger volume of convective part

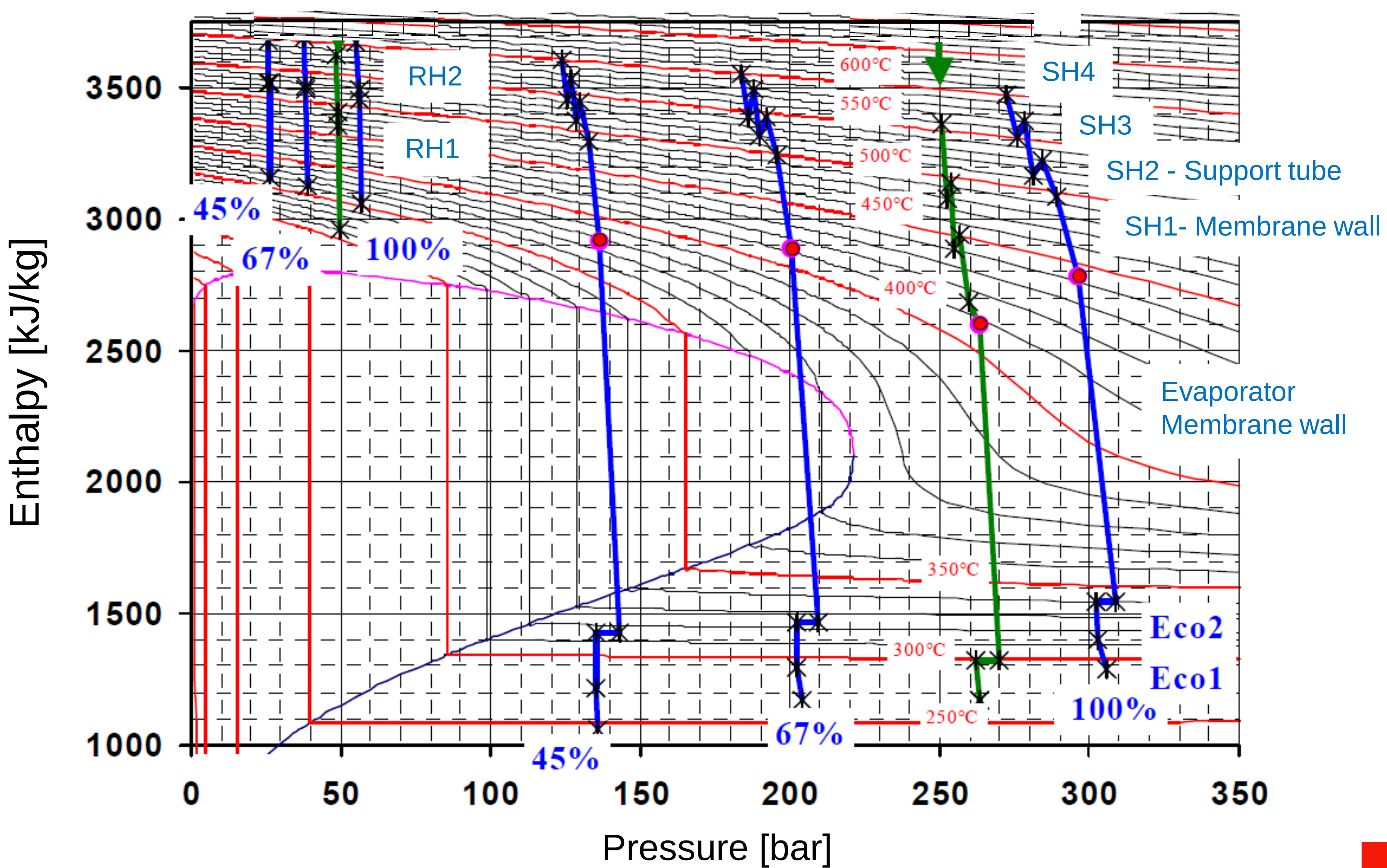
[Schkopau Reference Book, 1998]

1 Development Of Lignite Coal Fired Steam Generator



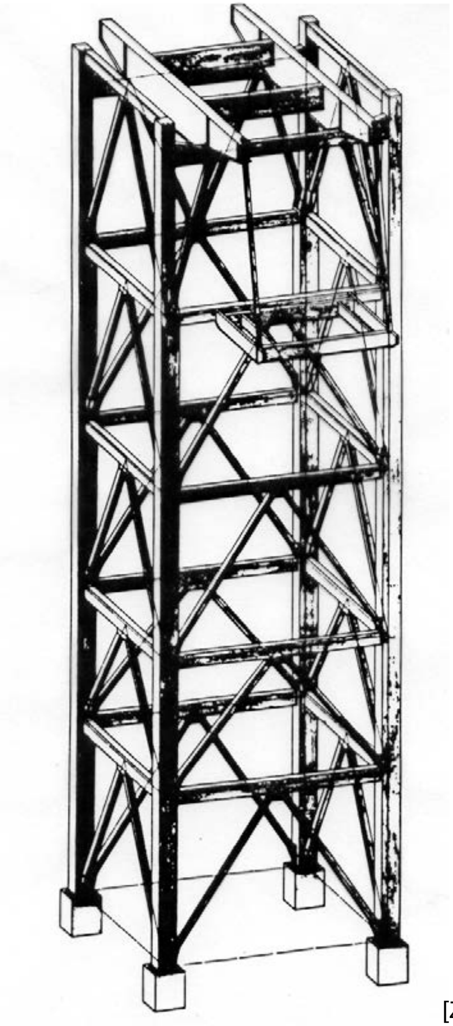
[HPE, Alstom, RWE; Götte et. al.]

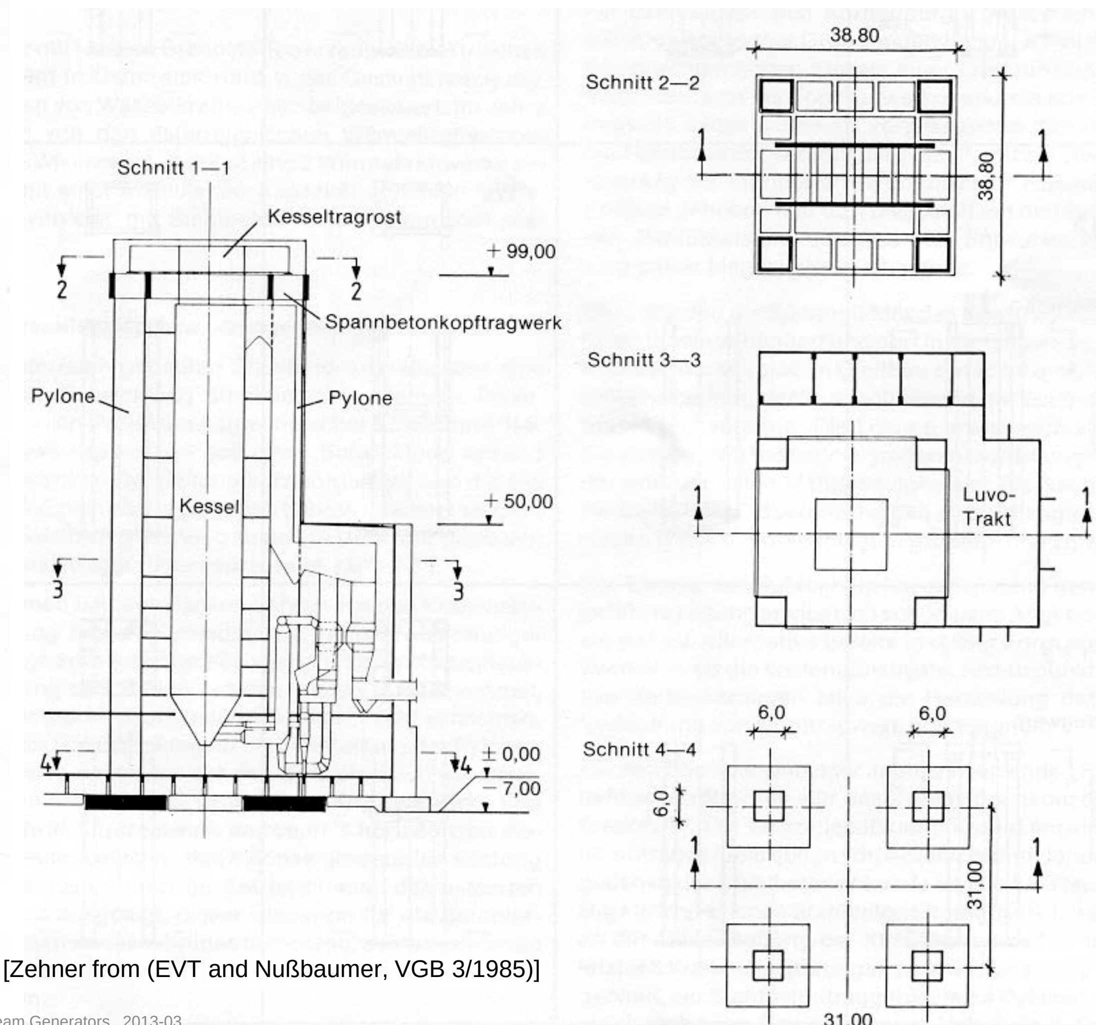
1 Actual Status - Lignite Coal Fired Steam Generator (p-h-Diagram)



[HPE, Alstom, RWE; Götte et. al.]

1 Boiler House And Boiler Structural Steel Work





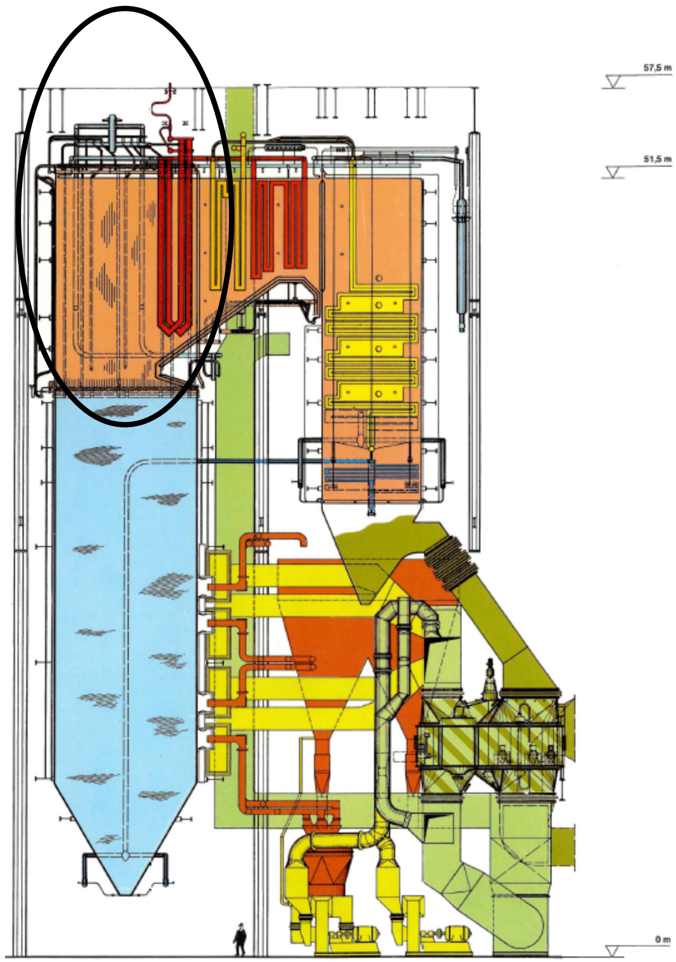
[Zehner from (EVT and Nußbaumer, VGB 3/1985)]

Steel:
- Most common
- additional masonry lift gear and stair tower necessary (emergency exit)

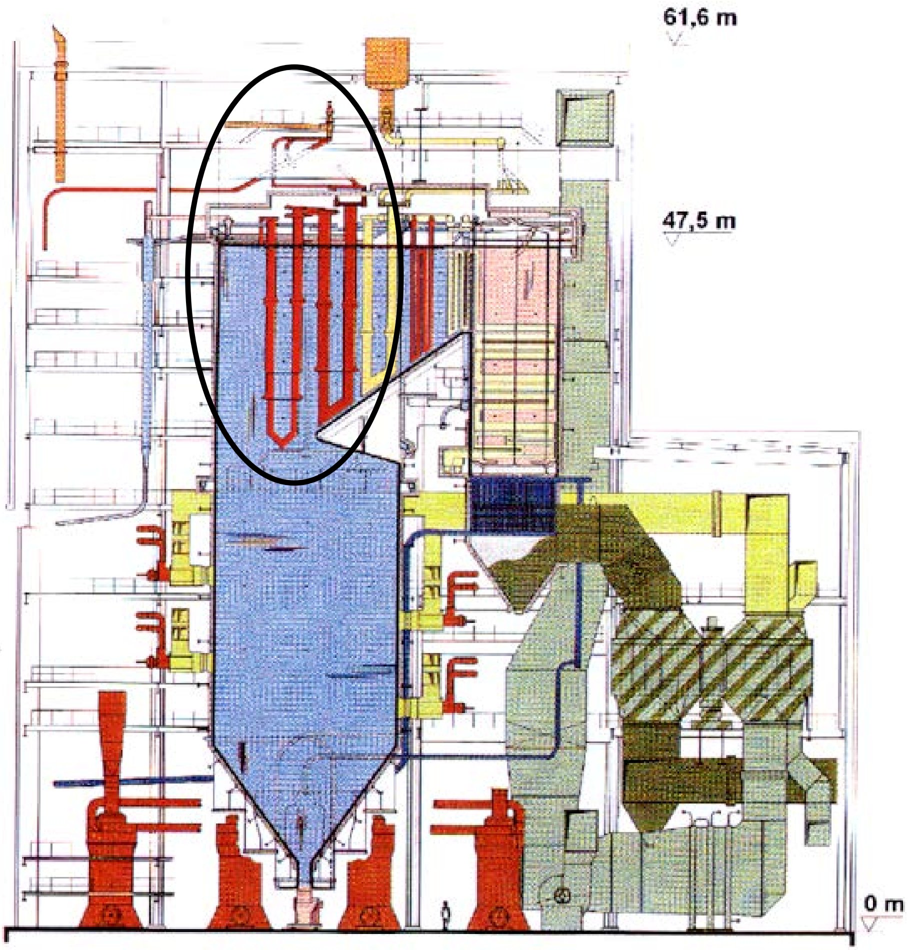
Concrete:
- Pylons are usable as lift gear and stair tower

Decision:
cost related

1 Superheater (Schotten) – Arrangement



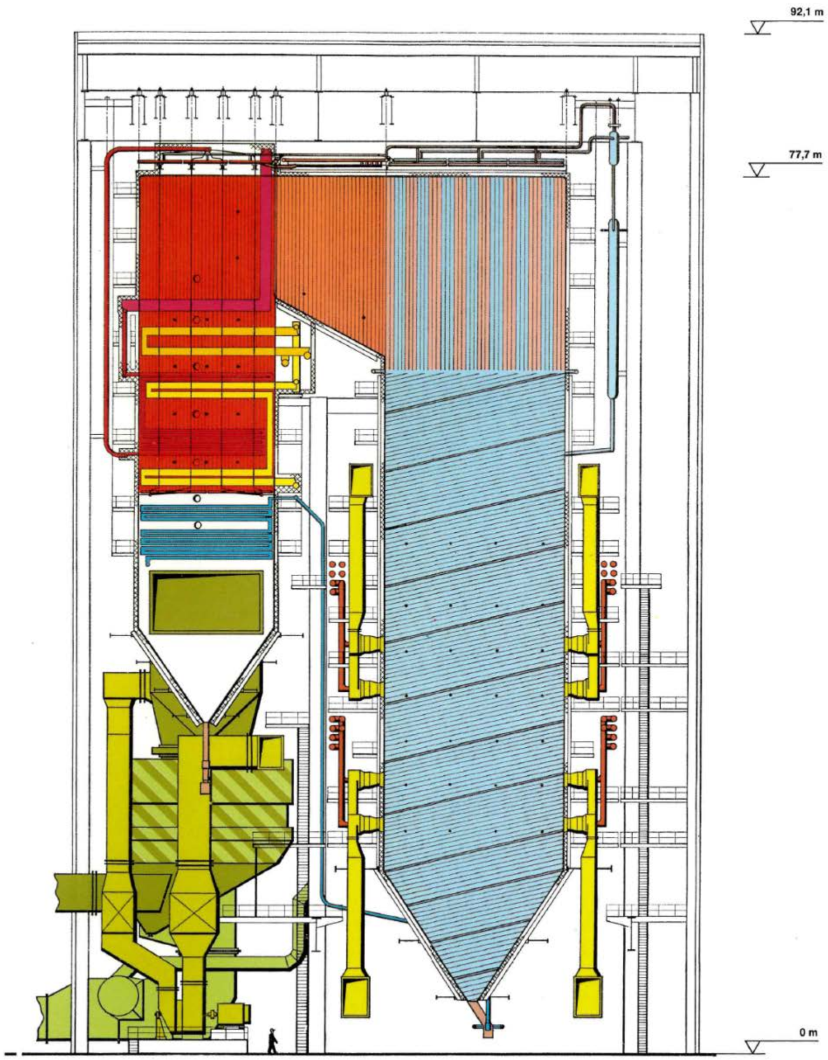
KW Farge, Kiel, 325 MW, Ge



KW Amager 1, DK

Enough space for combustion / influence of the radiation zone

1 Examples for Benson® Steam Generators – Two Pass Boiler



[Babcock - Reference Sheets]

Wilhelmshaven (720 MW)
Super Critical Power Plant

High Pressure Part

Steam rating	2170	t/h
Allowed working pressure	210	bar
SH-outlet temperature	530	°C

Reheater

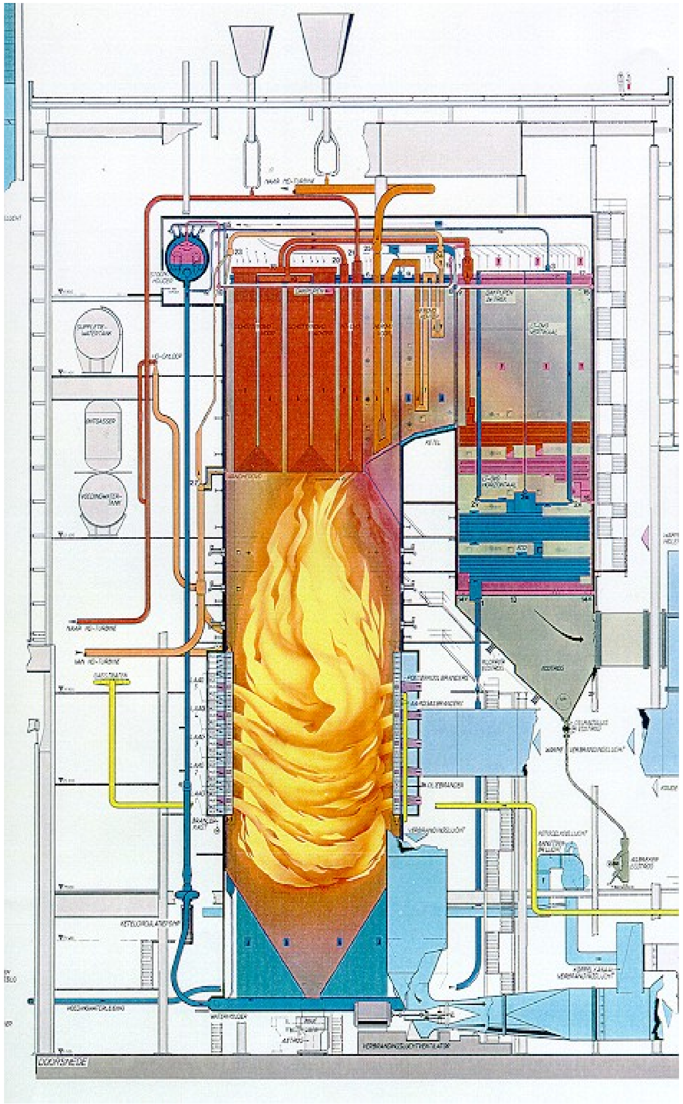
Allowed working pressure	55	bar
RH-outlet temperature	530	°C

Fuel
Bituminous coal, oil

Manufacturer
Babcock

Commissioning Year 1976

1 Examples For An Assisted-Circulation Boiler – (Two Pass boiler)



[MPP1 /2]

MPP1/MPP2 (540MW)
Power Plant

High Pressure Part

Steam rating	470 kg/s
Working pressure	180 bar
SH-outlet temperature	540 °C

Reheater

Allowed working pressure	46 bar
RH-outlet temperature	540 °C

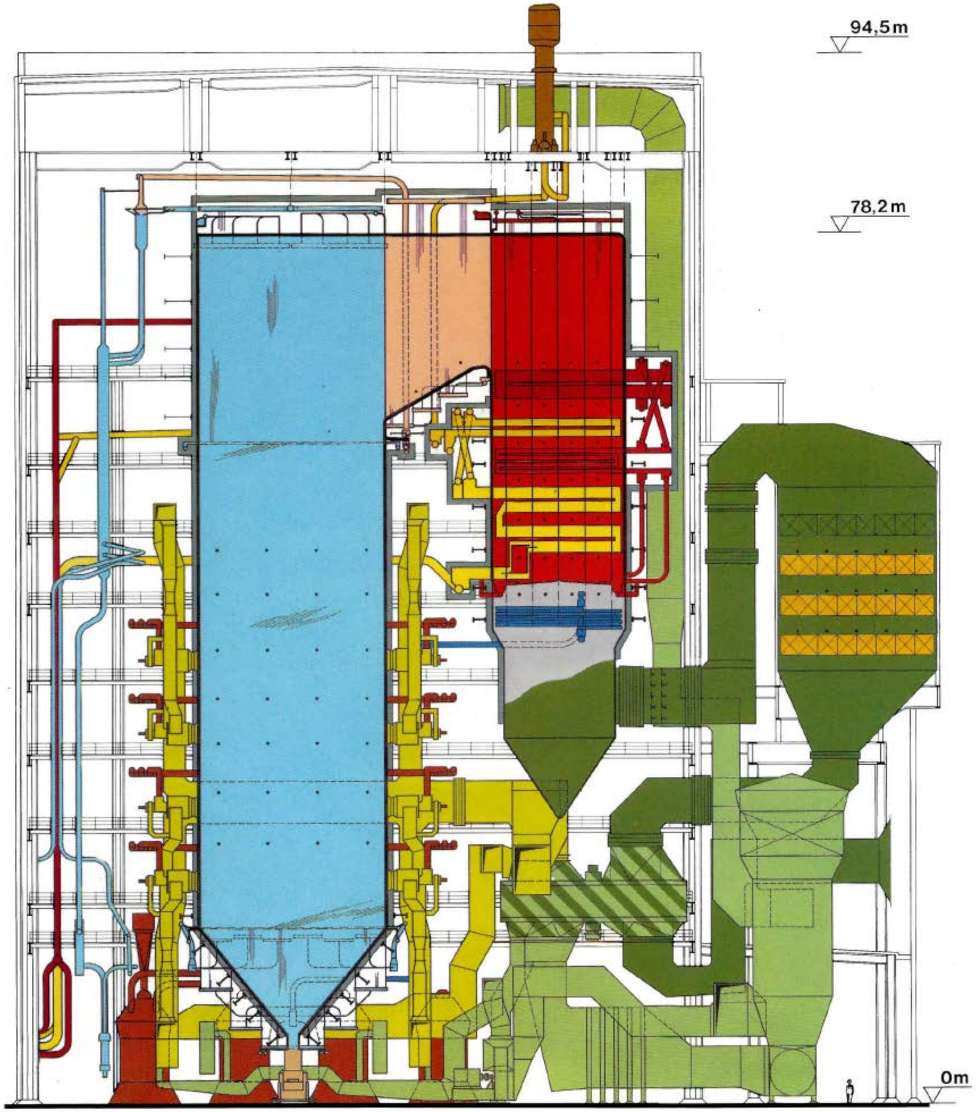
Fuel

Bituminous coal, oil

Commissioning Year

1987 / 1988 (COD)

1 Examples for Benson® Steam Generators – Two Pass Boiler



Heyden Unit 4 (900 MW)
Super Critical Power Plant

High Pressure Part

Steam rating	2405	t/h
Allowed working pressure	215	bar
SH-outlet temperature	535	°C

Reheater

Allowed working pressure	53	bar
RH-outlet temperature	535	°C

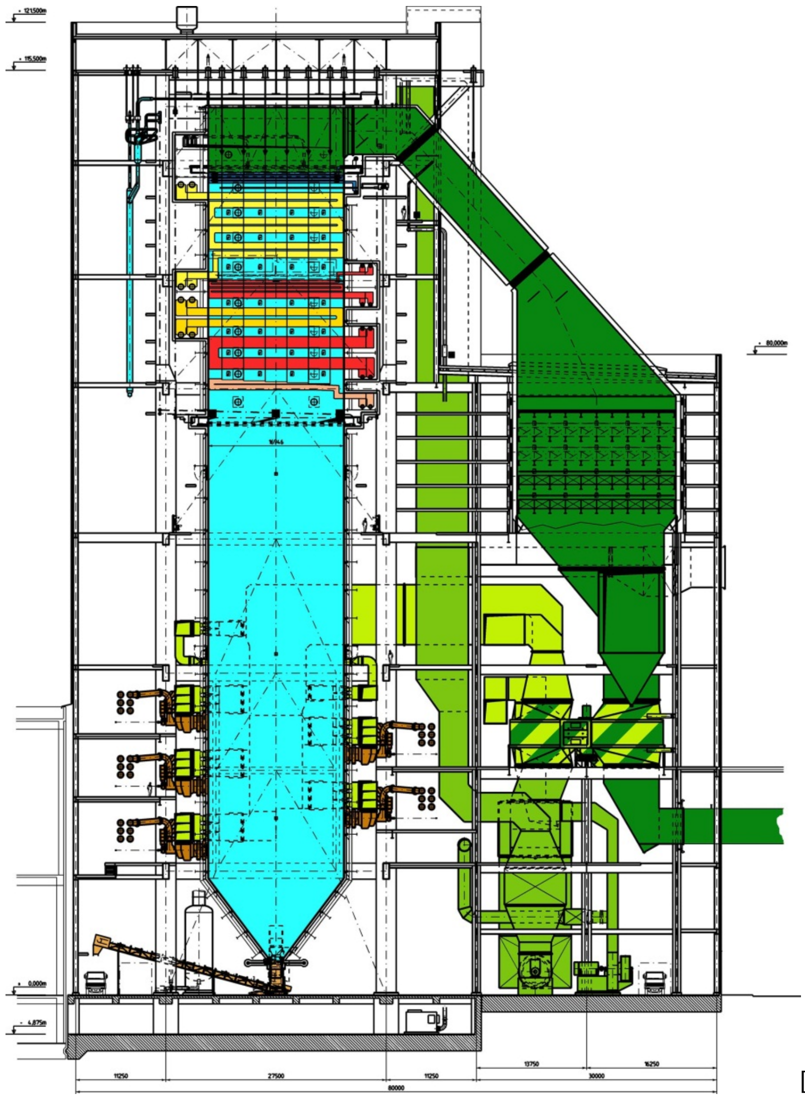
Fuel
Bituminous coal

Manufacturer
Babcock

Commissioning Year 1987

[Babcock - Reference Sheets]

1 Examples for Benson® Steam Generators – Single Pass Boiler



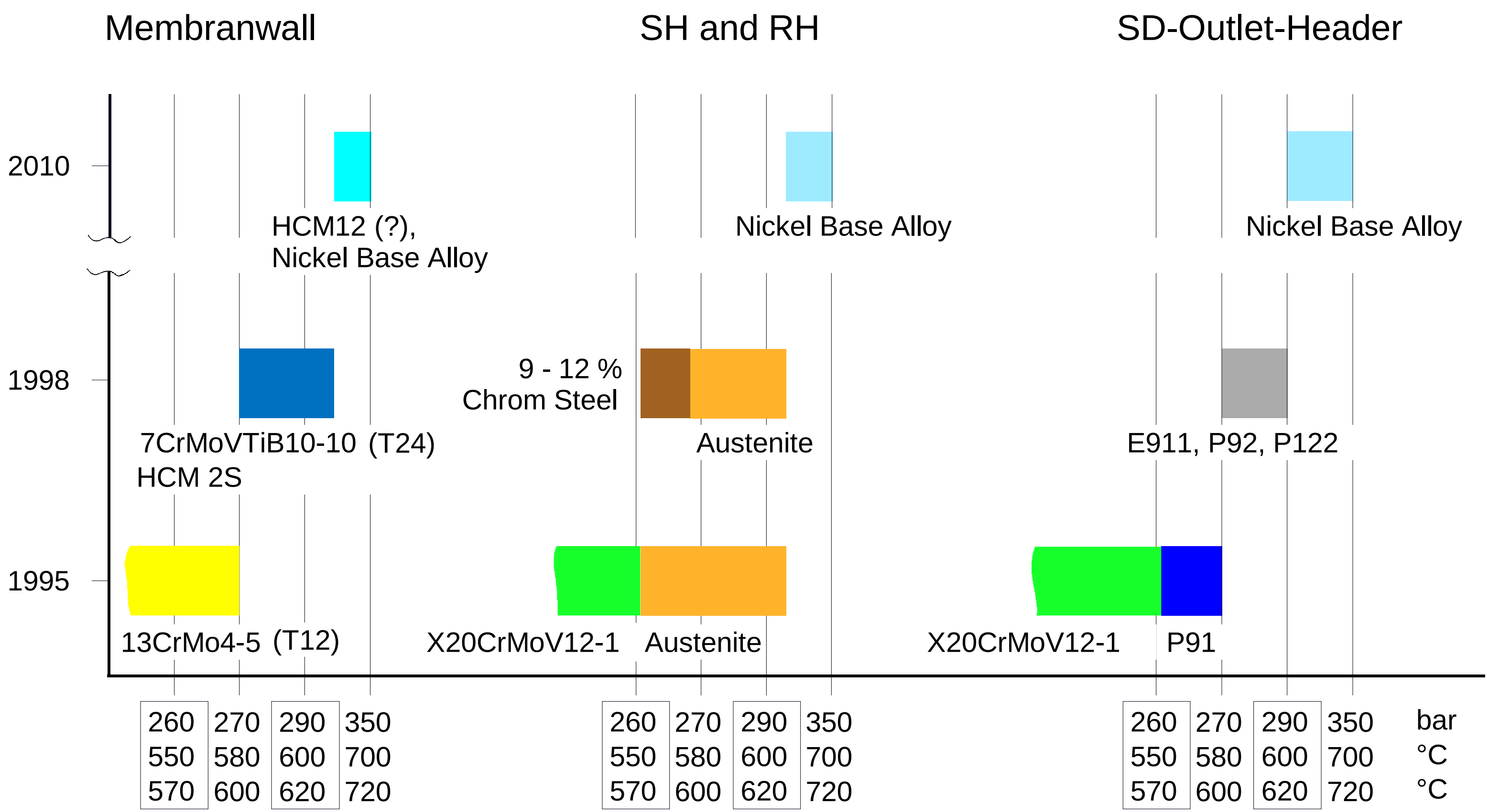
[HPE, Da4]

Actual Design 600/620°C
For Hard Coal:

- 1100 MWel
- Steam 2939 t/h
- Once-through steam generator, Benson®

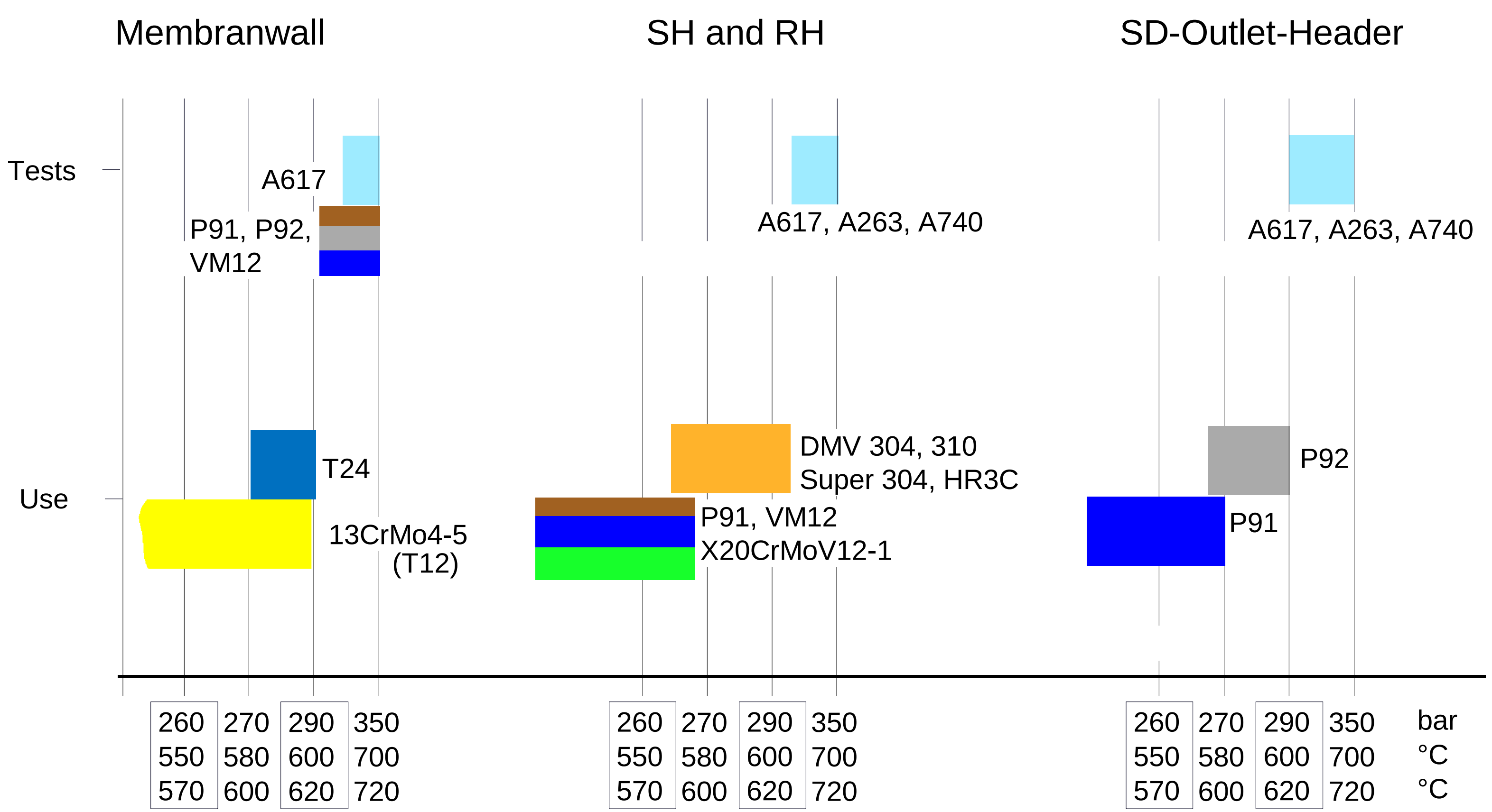
- Design parameters:
  SH: 600 °C / 285 bar
  RH: 620 °C / 58 bar

2 Material For Steam Generators – Development Status 2002

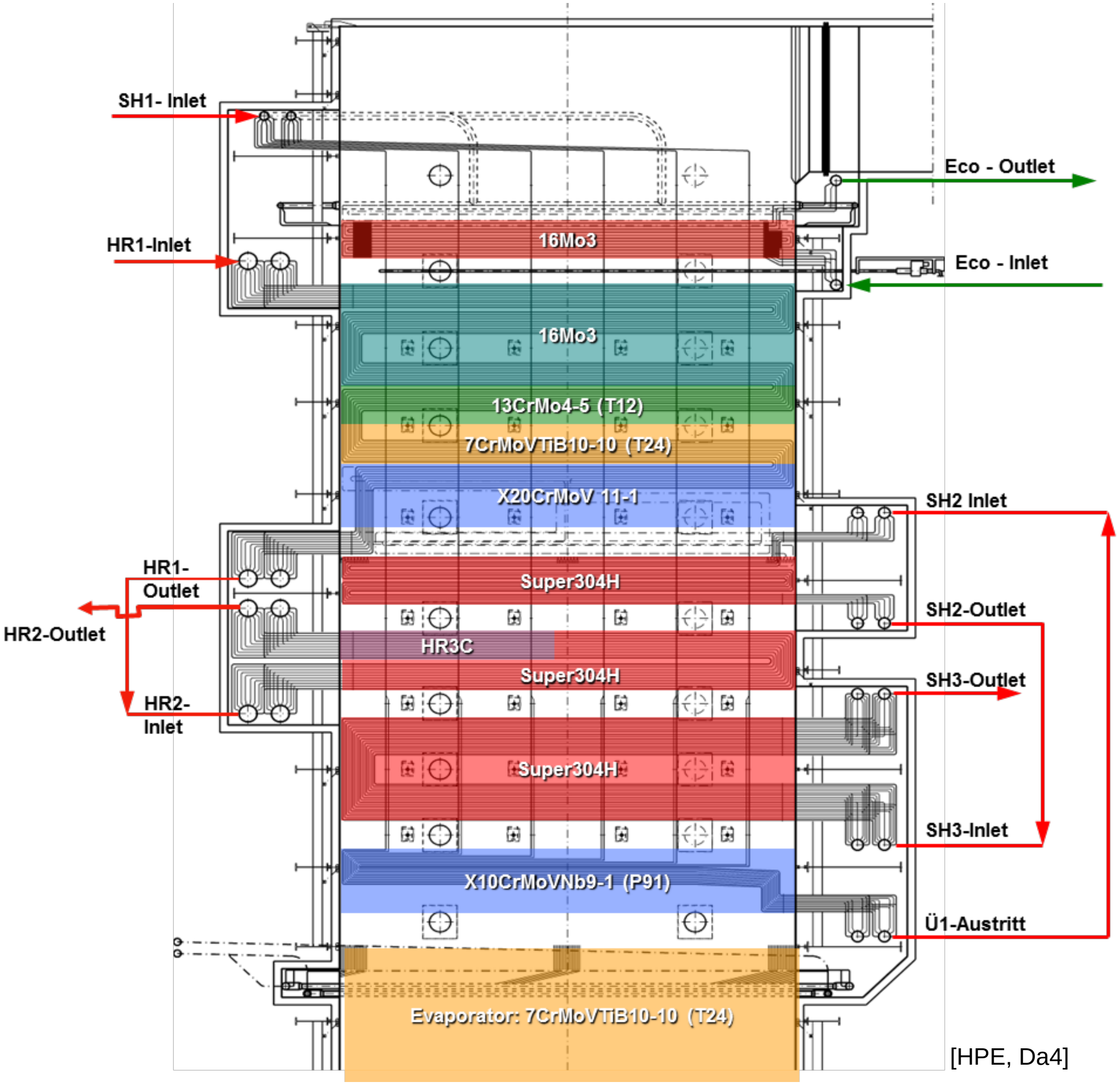


[Based on source: Alstom, 2002]

2 Material For Steam Generators - Status 2012



2 600°C/620° Power Plant The Material Mapping

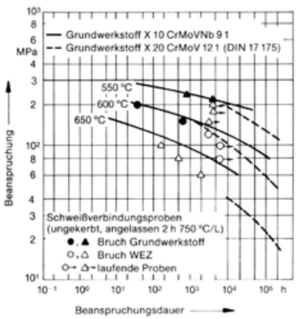


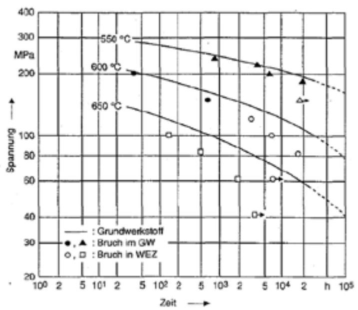
[HPE, Da4]

$$s_{wall} = \frac{p \cdot D}{2 \cdot R_{m,2\cdot 10^5}}$$

2 Piping – Material P91

(Qualification and application in Germany)

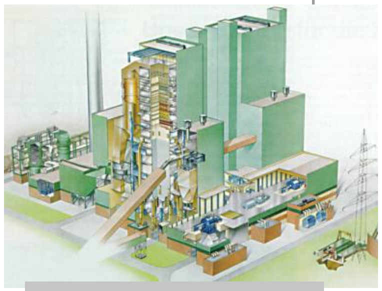




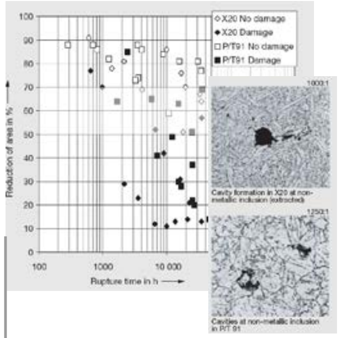
Mechanical test
especially creep test
also weld specimens

HAZ is weak
At ~ 600°C

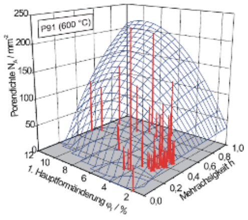
Discussion about
different visual nature of
martensitic structure,
especially thick walled
parts

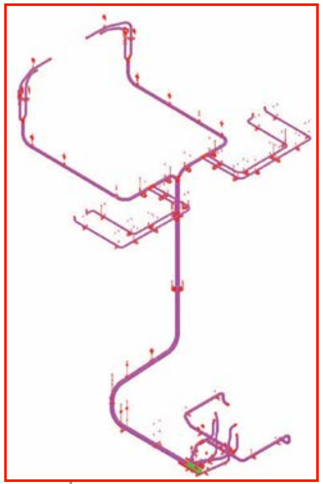


Main Steam Piping
Hot Reheat Piping



Creep Damage Analysis
→Reflection for Replica
→VGB TW 507





Longitudinally welded
P91 pipes
for hot reheat piping

1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008

VdTÜV $R_{1E5,600°C}$=90MPa

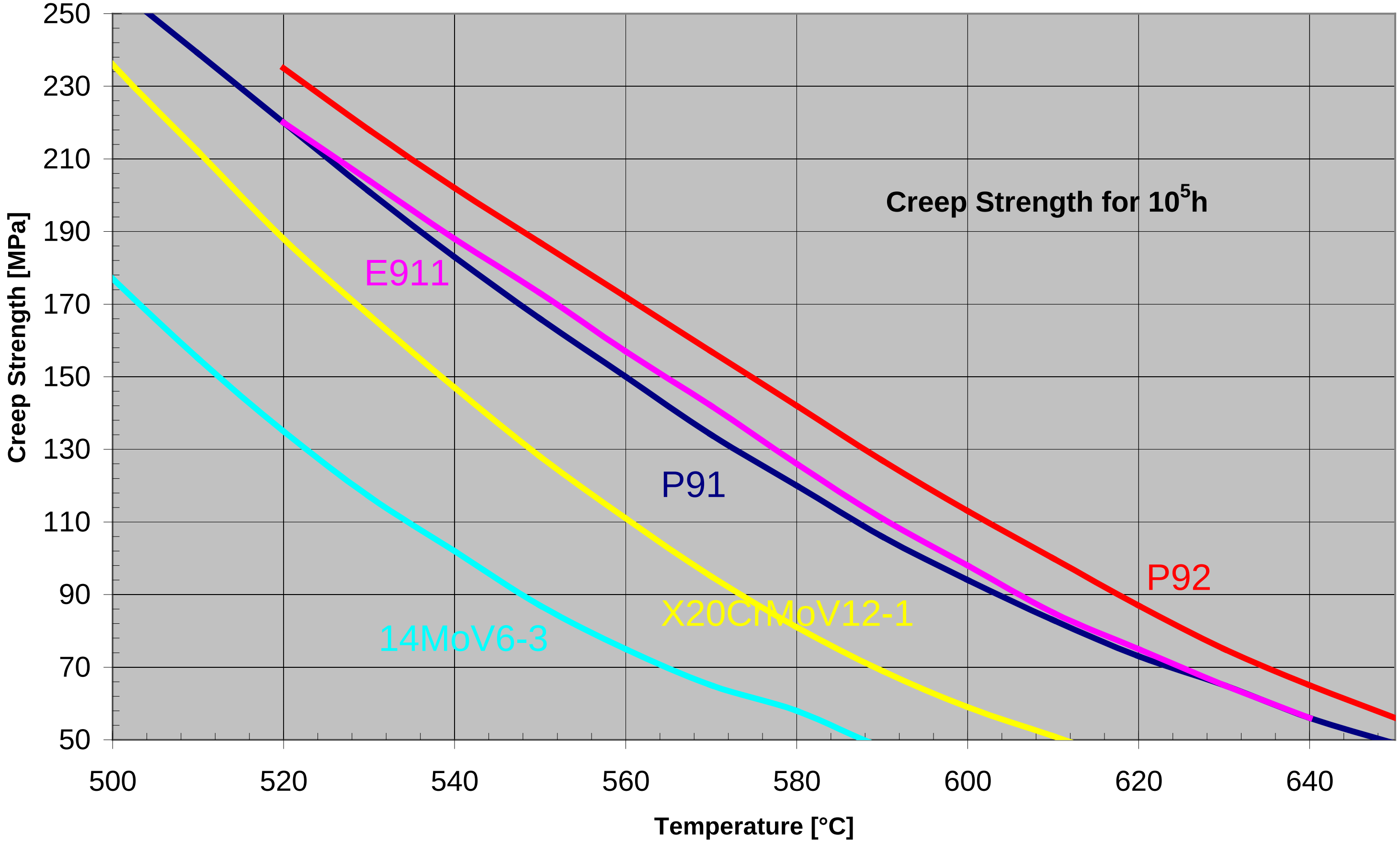
X20CrMoV12-1

P91

P92

E911

2 Piping Material - P92 for the 600/620°C power plants

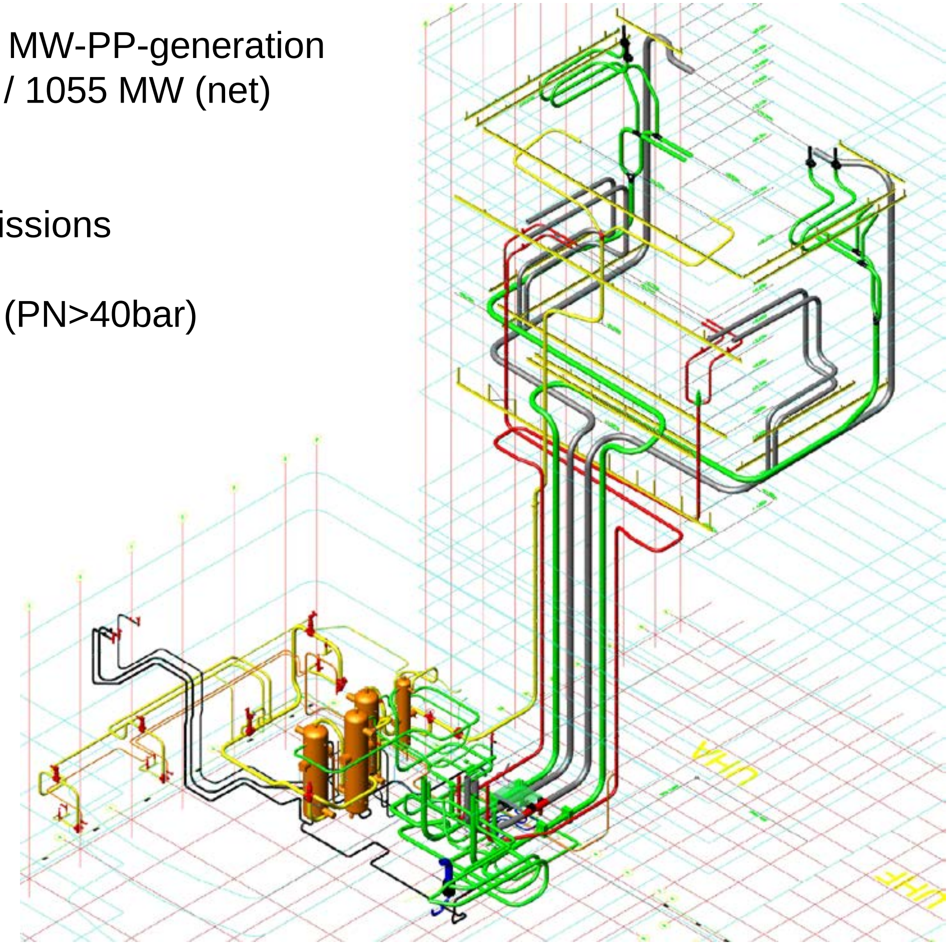


Best-in-class material for piping of USC-PP

2 Piping Material - P92 Examples MPP3 and Da4

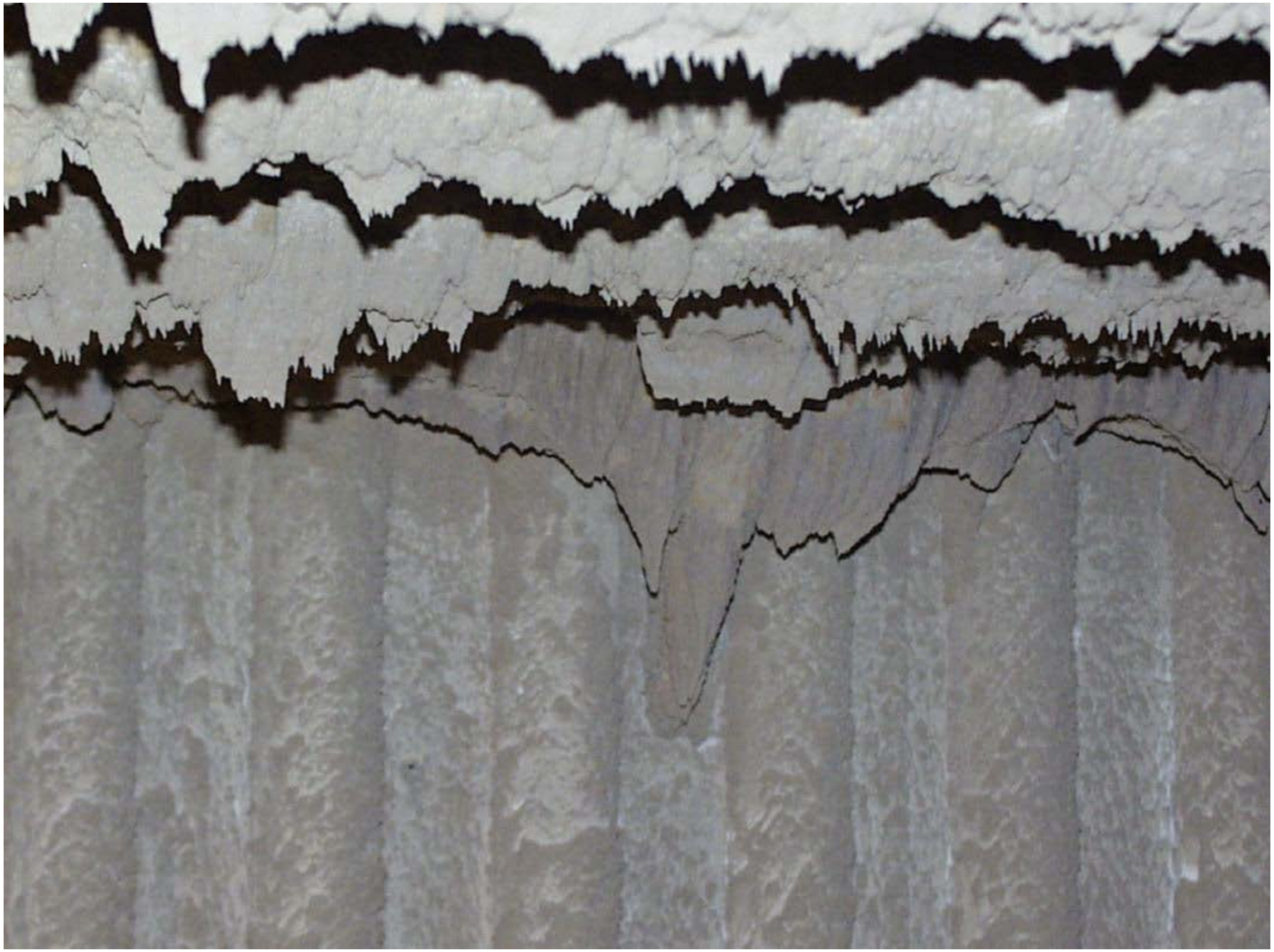
- Characteristic data of the actual 1.100 MW-PP-generation
  - Capacity: 1100 MW (gross) / 1055 MW (net)
  - Efficiency: 45.6 %
  - Parameter MS: 600°C / 285 bar
  - Significant reduction of the CO_2-emissions

- Material used or high pressure piping: (PN>40bar)
  - X10CrWMoVNb9-2 (P92)
  - 10CrMo9-10 (P22)
  - 13CrMo4-5 (P12)
  - 15NiCuMoNb5-6-4 (1.6368)
  - 16Mo3 (P01)
  - P235GH (~H1)



High end material for 360°C HP-feedwater line

3 Experiences: Slag



[Clyde Bergmann, 2013]

3 Experiences: Slag

Combustion of bituminous coal from international sources, a common problem on many sites

Broad fuel range

with

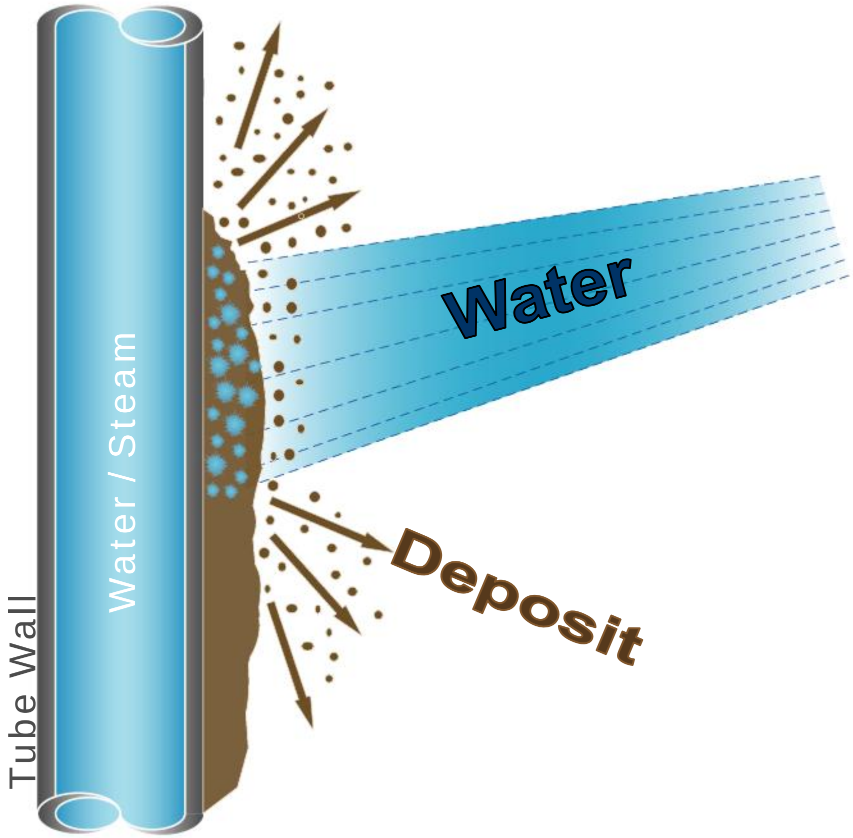
varying quality

- Change of fouling behaviour
- Slagging at the burners
- Increase of furnace exit gas temperature

[Clyde Bergmann, 2013]

3 Experiences: Slag- Cleaning With Water Canon

Sudden evaporation



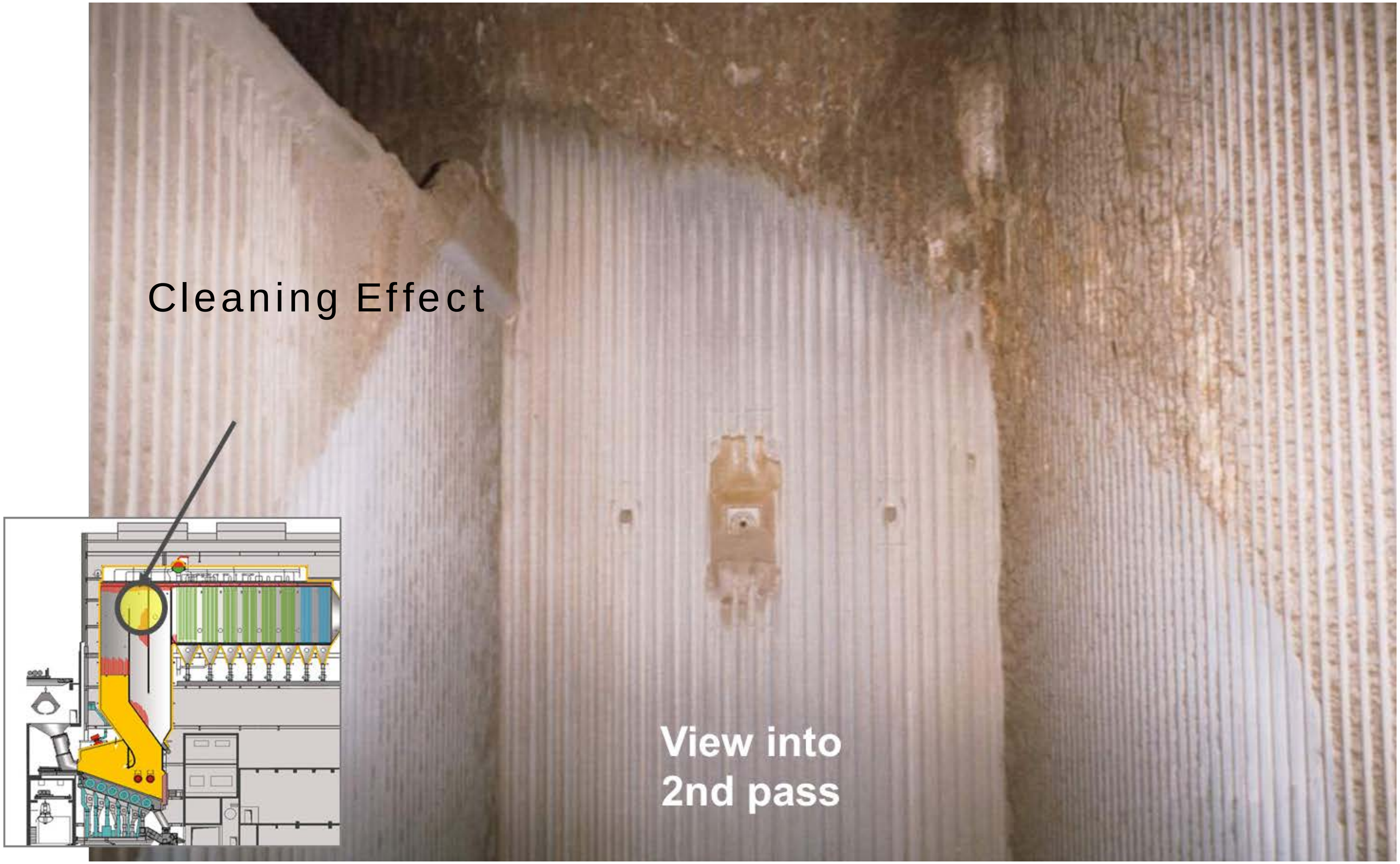
Cleaning Mechanism

- Water impacts on surface
- Water penetrates into pores of deposit
- Deposit layer "explodes" from wall
- Parameter for successful cleaning
  - Impact water quantity
  - Impact area
  - Jet progression speed
  - Characteristics of deposits

The goal:
Optimum penetration of deposits

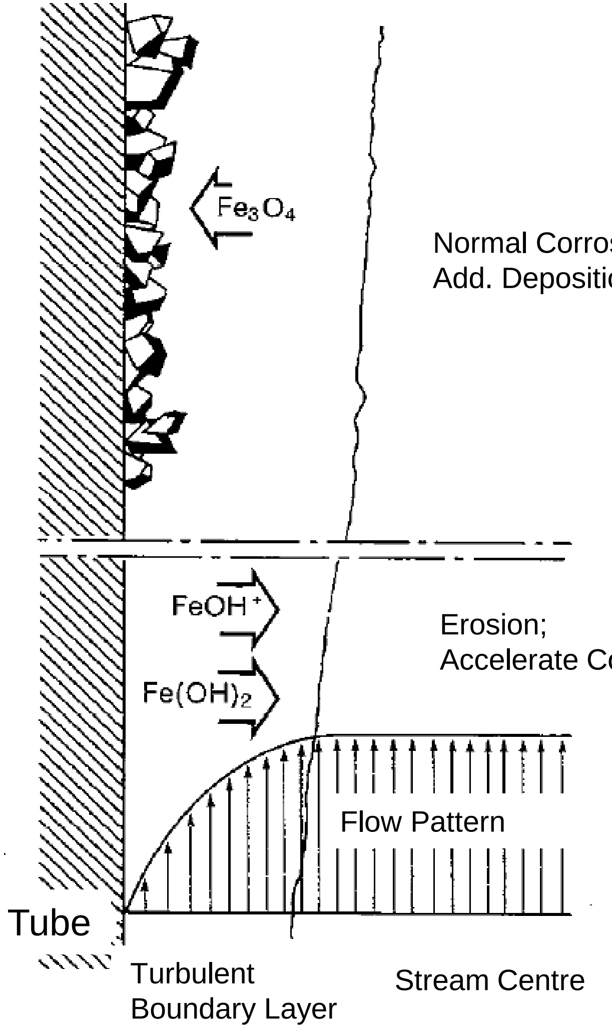
[Clyde Bergmann, 2013]

3 Experiences: Slag



[Clyde Bergmann, 2013]

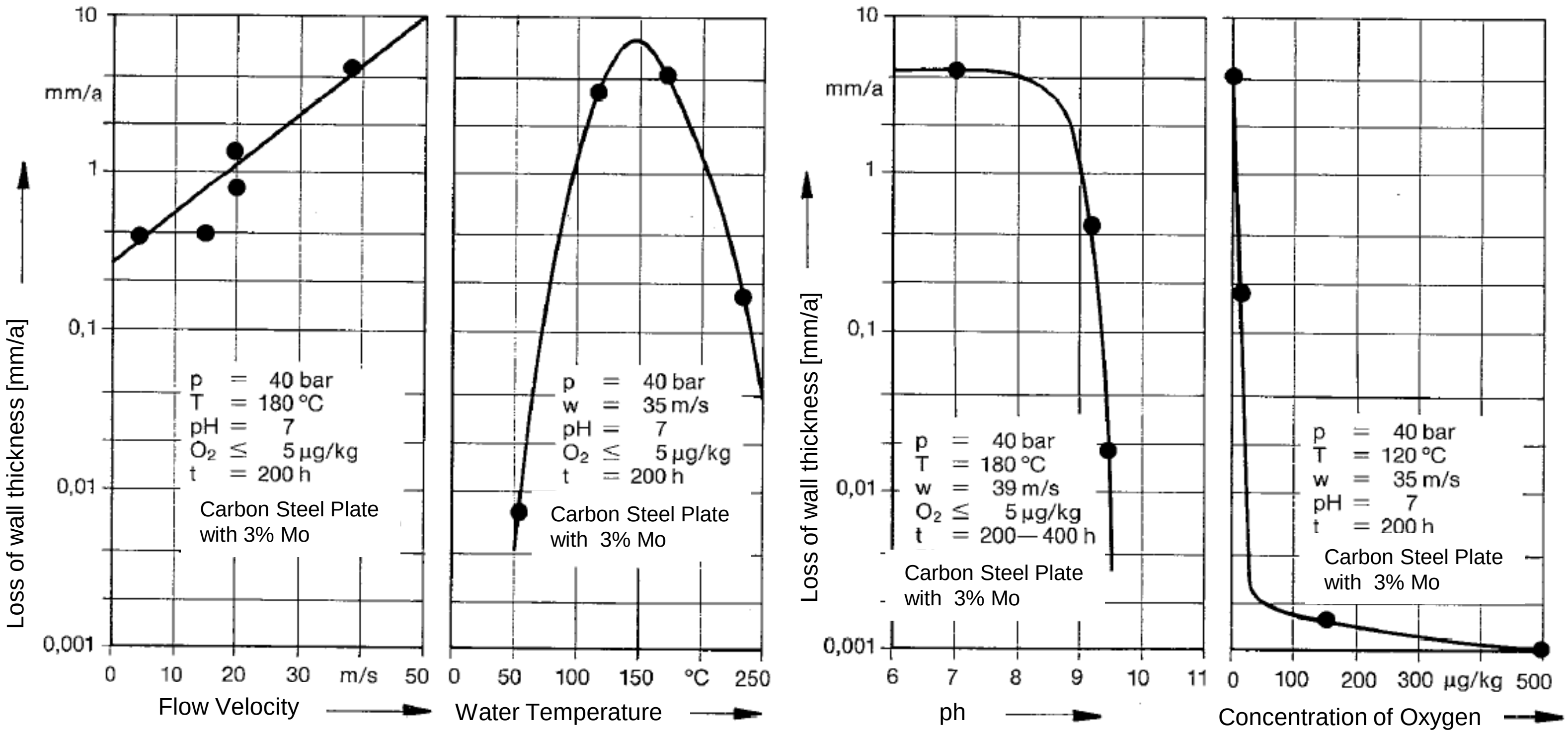
3 Experiences: Flow Accelerated Corrosion (FAC)



[Kastner et. al., 1990]

3 Experiences: Flow Accelerated Corrosion (FAC)

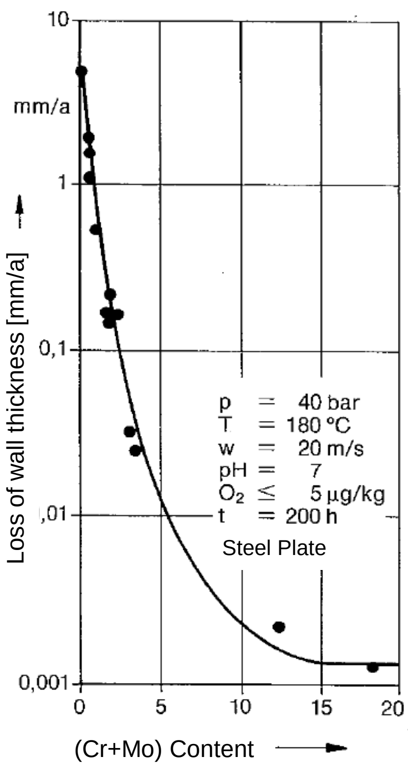
Prevention of FAC by
Correct Process Engineering | Correct Water Chemistry

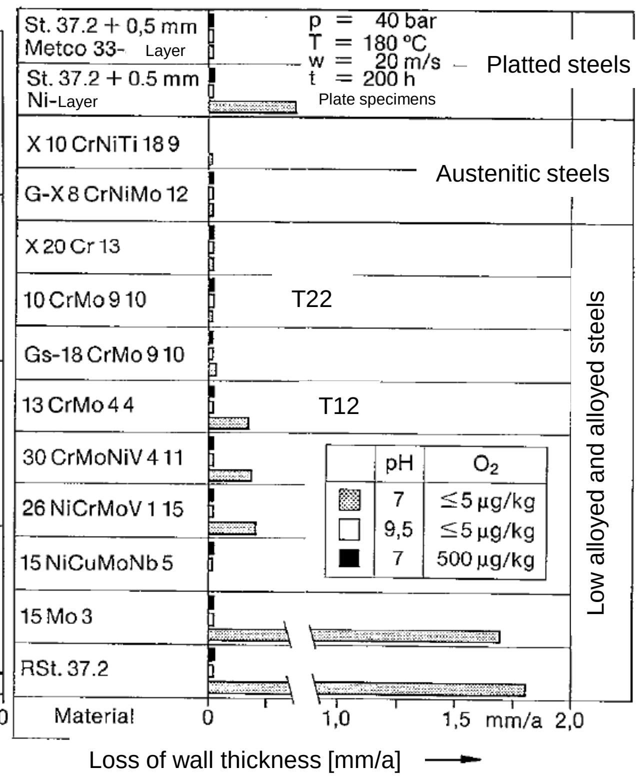


[Kastner et. al., 1990]

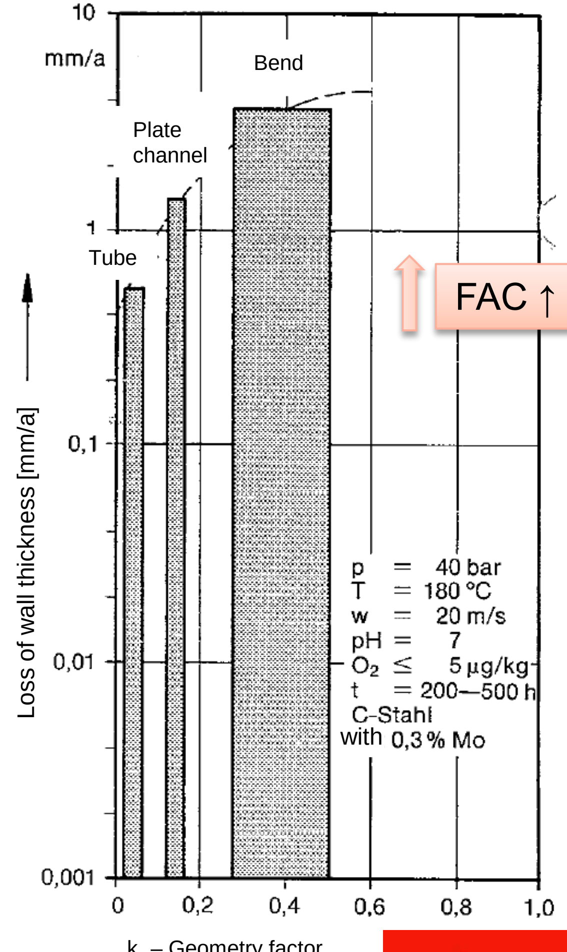
3 Experiences: Flow Accelerated Corrosion (FAC)

Prevention of FAC by material selection



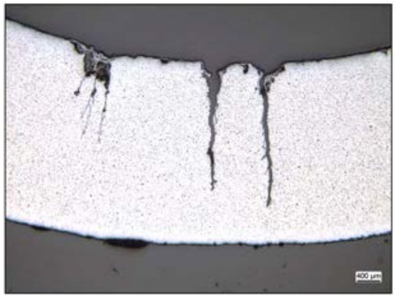


Influence of the geometry



[Kastner et. al., 1990]

3 Experiences: Corrosion Fatigue (CF)

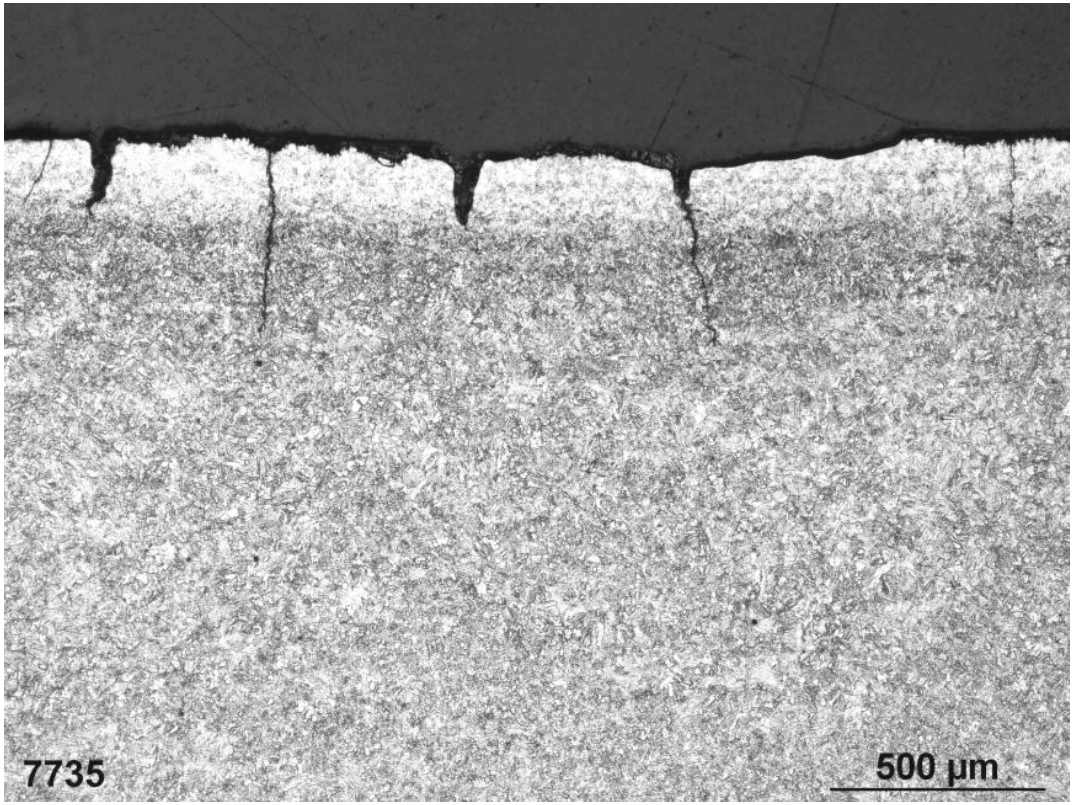


44,5 mm ä Ø x 5,0 mm

Example: drain line

T~250°C; p=260bar; t=200.000h

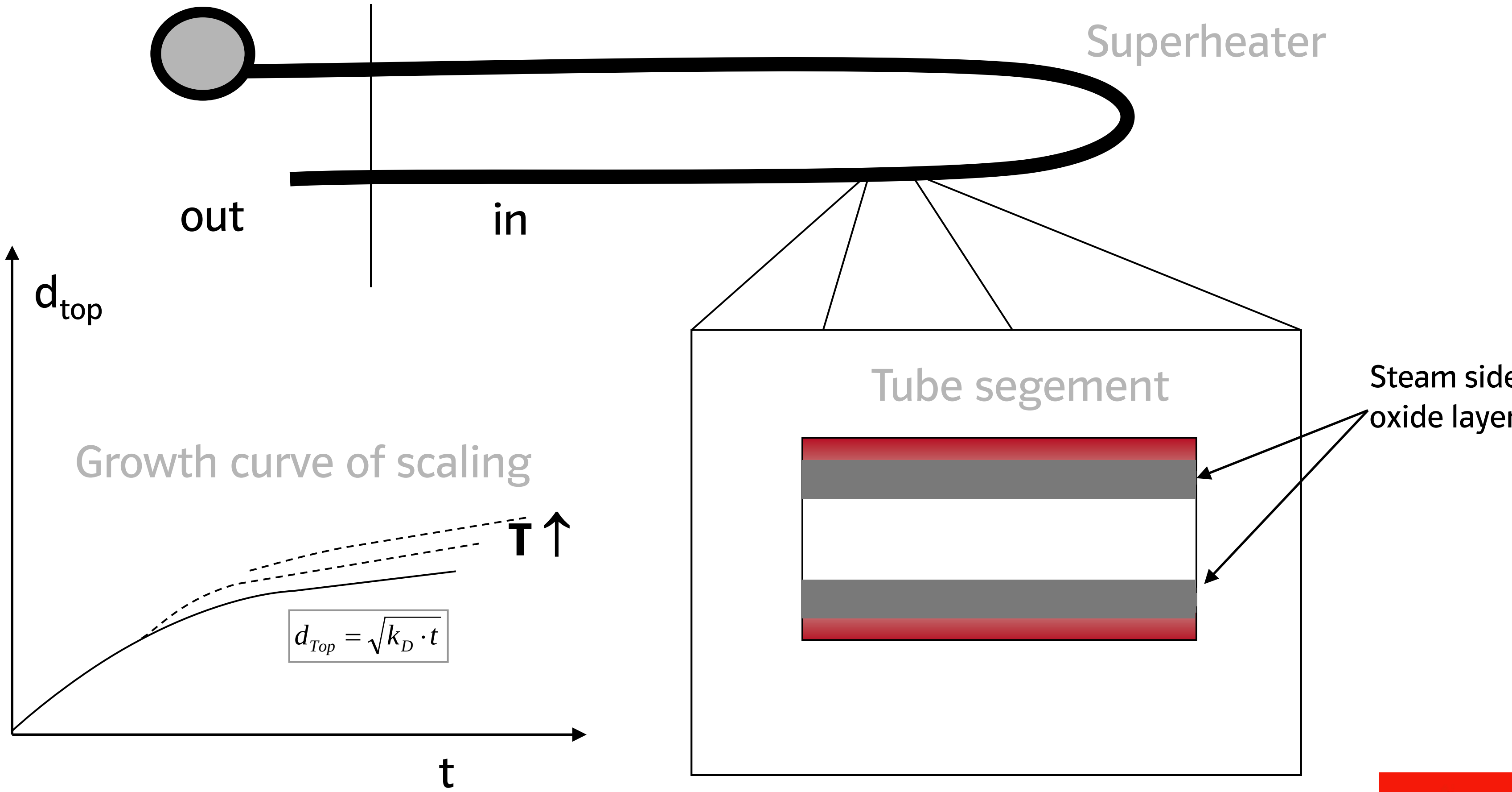
3 Experiences: Stress Corrosion Cracking (SCC)



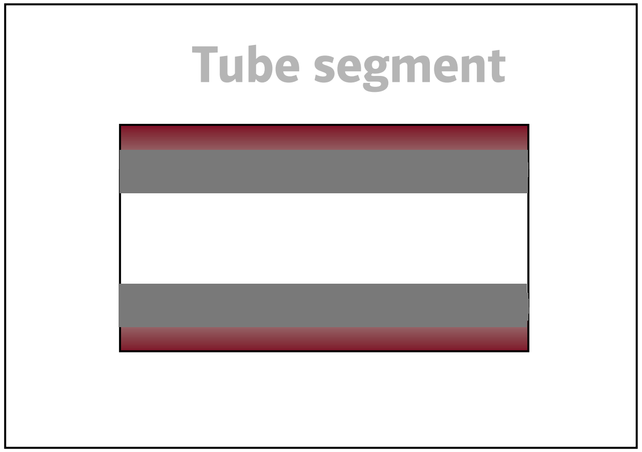
Evaporator tube

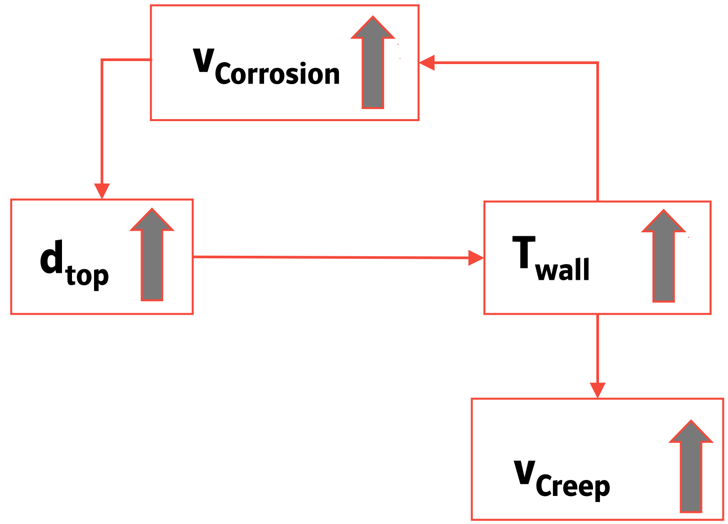
3 Experiences: High Temperature Corrosion (HTC)

- High temperature corrosion in the steam generator

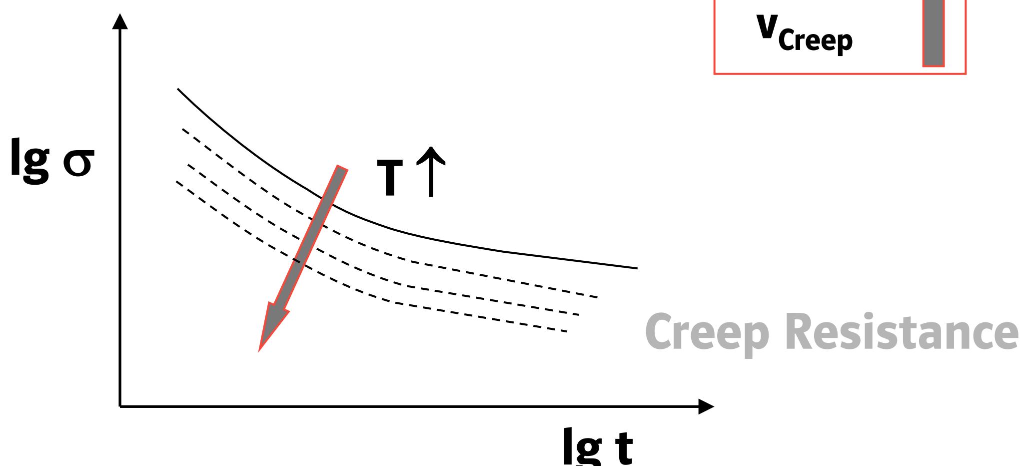


3 Experiences: Steam Side Scaling And Creep (The Interaction)





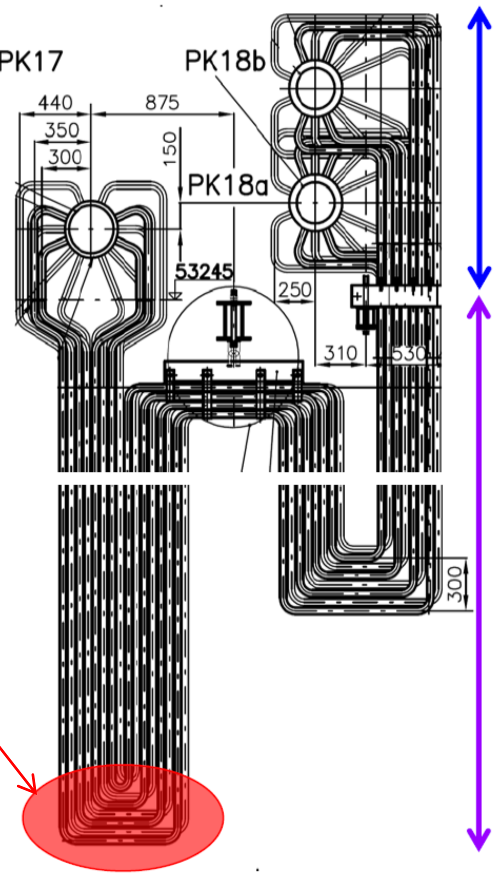
- The creep velocity increases with the scaling growth



3 High-Temperature Corrosion - Special Effects → Exfoliation

Boiler parameters:

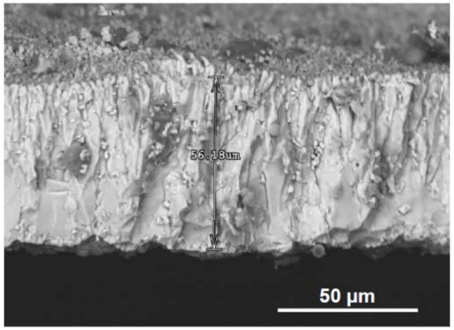
Nominal heat rate:	437 MW
Nominal rate:	547 t/h
Maximum continuous rate:	575 t/h
Superheated steam pressure: MPa	18,1
Superheated steam temp.:	575°C
Hot reheated steam pressure:	3,6 MPa
Hot reheated steam temp.:	580°C
Feed water temperature:	249,5°C



X10CrMoVNb9-1 (T91)

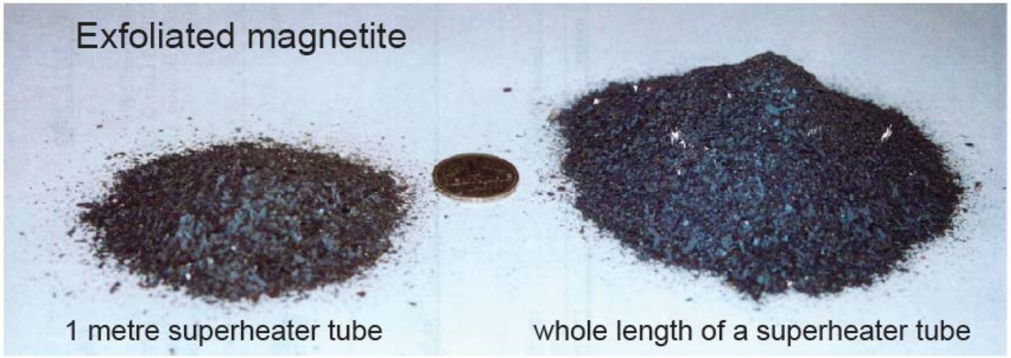
X6CrNiMo17-13 (1.4910)

Deposit of the delaminated magnetite layer



[VGB, Lüdenbach, 2011]

3 Exfoliation Of Magnetite Layer Of Austenitic RH-Material



[Dong, Larsen, 2008]

3 Exfoliation Of Magnetite Layer Of Austenitic RH-Material

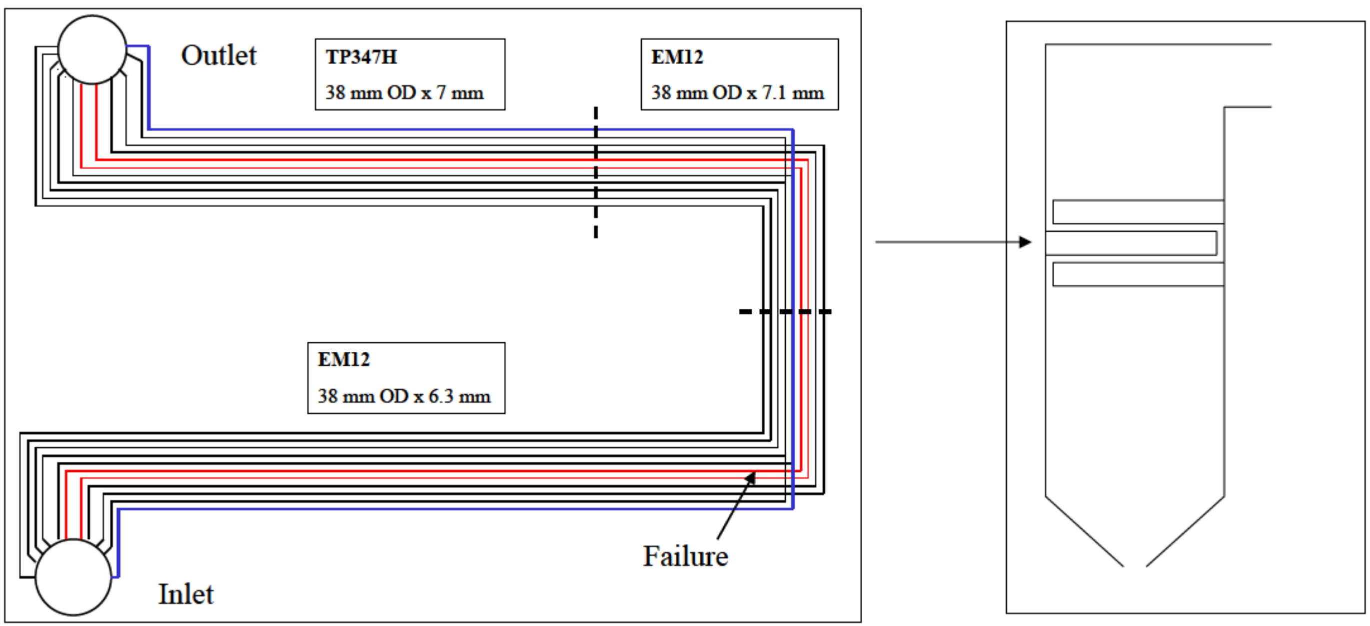
Esbjergværket Unit 3

Year of commissioning: 1992

Fuel: Pulverised coal

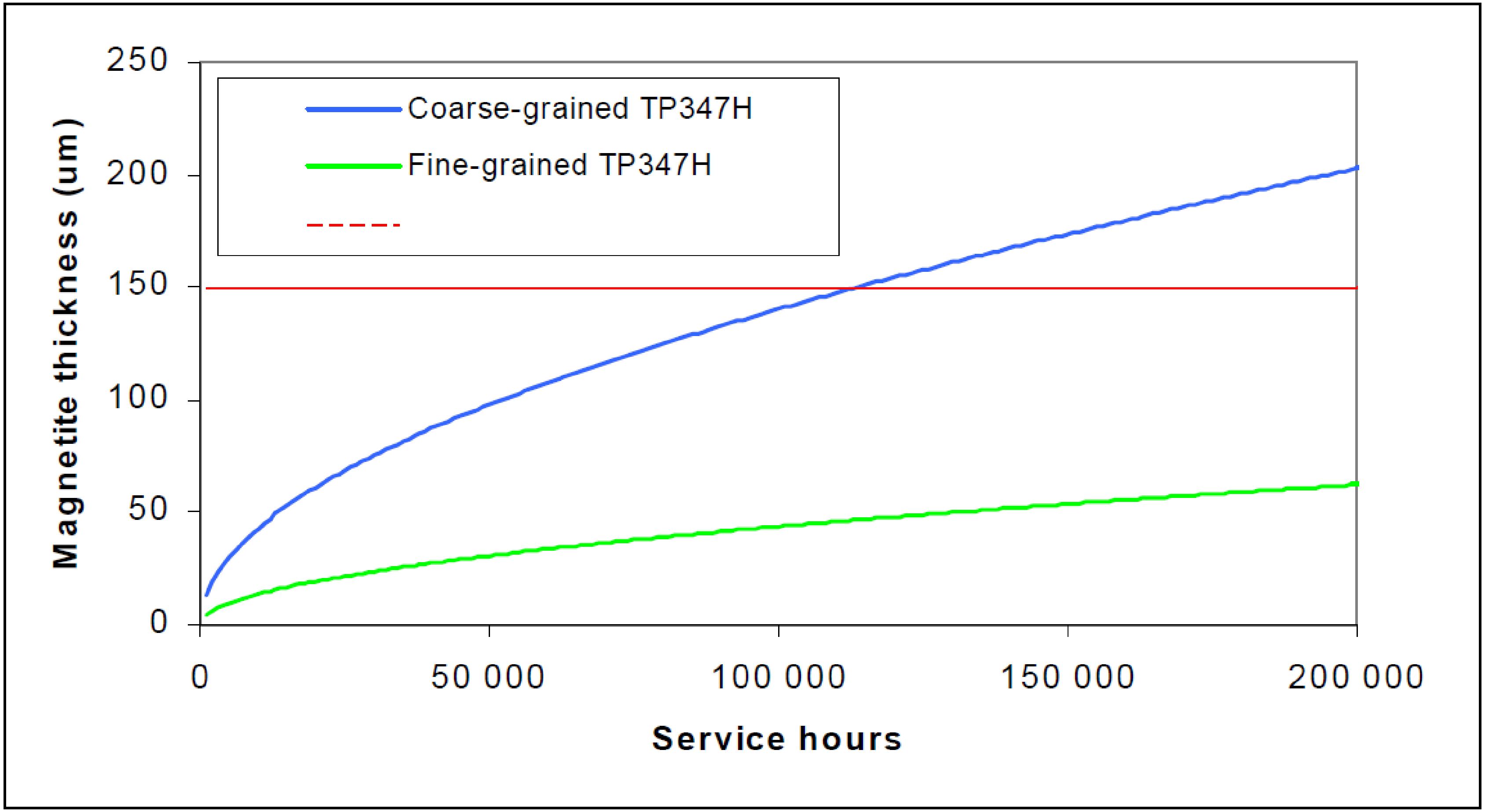
Capacity: 400MW_{el}

Steam data: 260 bar/560 °C/ 560 °C



[Dong, Larsen, 2008]

3 Exfoliation Of Magnetite Layer Of Austenitic RH-Material

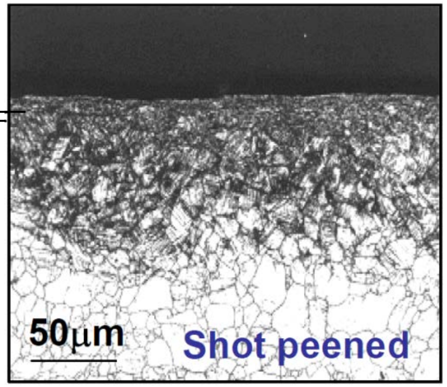


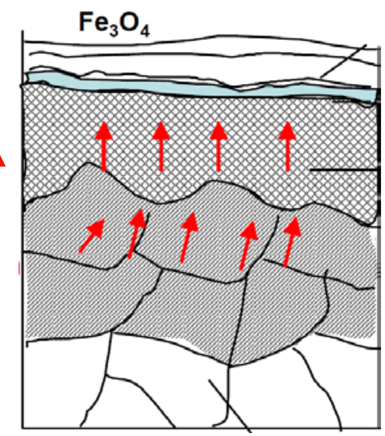
[Dong, Larsen, 2008]

3 Special Application Of Super304H And DMV304HCu

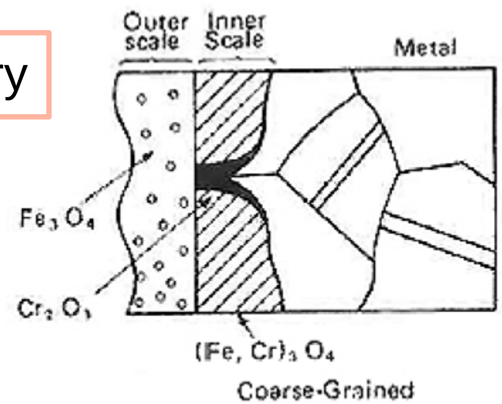
Practise

Small Cr_2O_3-layer



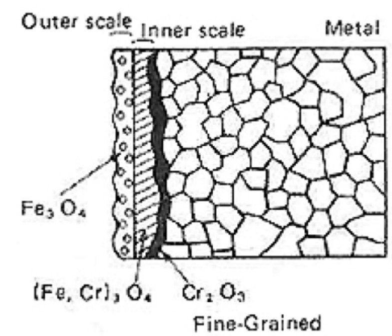


Theory



High deformation region – high dislocation density, more subgrains and smaller grains

More grain boundaries – more faster ways to bring Cr to the surface



Only small islands of Cr_2O_3 in the inner oxide layer

A closed Cr_2O_3 layer

[Based on source: HPE, Husemann, 2007]

Résumé

- EU: Small steam generators are generally natural circulation boiler or forced circulation boiler. Big steam generators are mostly once-through boiler.
- The single pass boiler are more popular since the late 70s.
- The different load situation in the boiler leads to different failure mechanism and also to different failure chains.
- Most of the actual issues are related to the flexibility.