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Archer
Advanced Reactor
for Cogeneration of
Heat & Electricity-R&D

Deliverable D-44.21:
Review of the availability of materials data for SG design above 600 °C steam

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Advanced High-Temperature Reactors for Cogeneration of Heat and Electricity R&D

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Summary

This document contains the available data from former built HTR SG's (High Temperature Reactor Steam Generators). The information has been made available to the project by ALSTOM.

Inputs and information were taken from actual / former built and operated SG's and actual built Heat Exchangers.

Material selection and design for this HTR SG will be kept under review within the project, and maybe changed based on results from later investigation.

Approval

Rev.	Short description	First author	WP Leader	SP leader	Coordinator
0	First issue	D. Ponca (ALSTOM)	D. Ponca (ALSTOM)	D. Buckthorpe (AMEC)	S. Groot (NRG)

Distribution list

Name	Organisation	Comments
All technical participants	ARCHER	Through internet workspace
WP44 Participants	ARCHER	Through internet workspace

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1 Introduction

High-temperature metallic materials or alloys used in process heating equipment like Steam Generators have significant effect on thermal efficiency, productivity and operating cost of the equipment.
A number of factors must be considered to select appropriate materials to improve energy efficiency of the equipment while extending their life at the minimum cost. These factors include mechanical properties, oxidation or hot corrosion resistance, use of cast or fabricated components, and material availability. Technical data describing the properties of heat-resistant alloys are necessary guides for selection. However, the behavior of alloys during long exposure to various high-temperature environments is complex. This behavior is not always completely predicted by laboratory tests alone. Service experience with high-temperature equipment is needed to judge the relative significance of the many variables involved.

2 Summary of Contents

2.1 Contribution from ALSTOM

2.1.1 Introduction

The focus of this review has been to search for available information on already built SG's, which have been in operation for some years.
This present report concentrates on the available data on the HTR SG, and particularly seeks to consider the mechanical and thermal design of a SG. As such it provides additional input data along with Deliverable D44.21 of the ARCHER Project "Review of SG operating / transient conditions from previous HTR reactor designs" for the WP44 investigations.
The Steam Generator is designed according to a forced circulated system. The heating surface consists of so called helical coiled heat exchanger tubes. The tubes are arranged in concentric assembled cylinders. The primary gas flows from the bottom part of the SG in parallel flow through the low pressure part and afterwards in a cross flow through the high-pressure part. The evaporation takes place on the secondary system part of the SG.

2.1.2 Thermal data's

Operating / performance data's of one SG are:

Thermal Power	128 MW
Reactor Cooling Gas	Helium
Gas Temp. Inlet	750 °C
Gas Temp. Outlet	250 °C
Gas Pressure (bef. SG)	38.5 bara
Pressure loss (Gas)	0.4 bar
Massflow Gas	49.25 kg/s
Live Steam	550 °C, 187 bara
Reheater Inlet	365 °C, 55 bara
Reheater Outlet	535 °C, 49 bara
Feedwater	152 t/h

2.1.3 Key Requirements

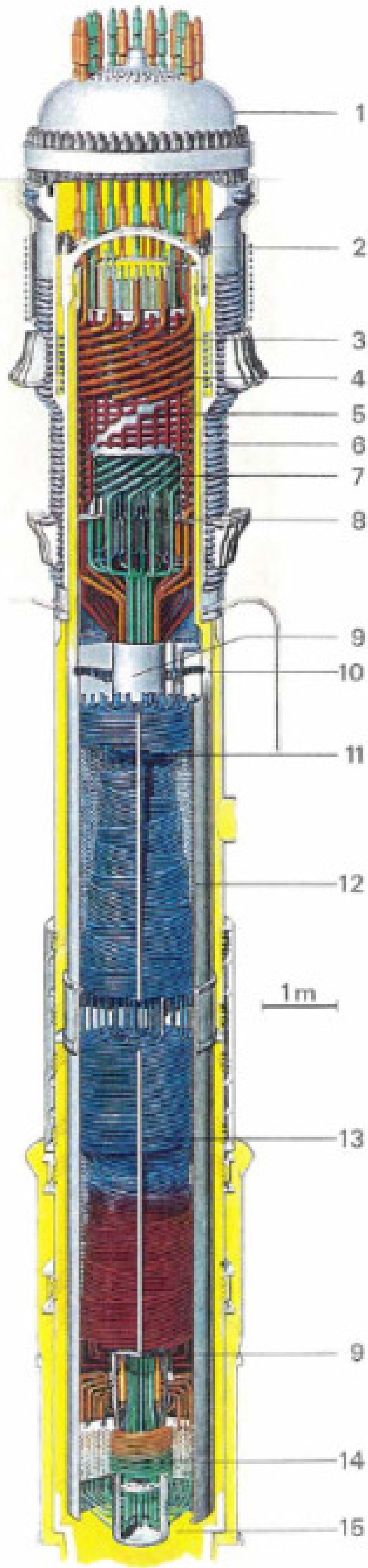
Key product specific. items:

Pressure Vessel Code:	assuming ASME; CODAP 2000 or similar
Material Choices:	assuming free, i.e. result of concept studies
Lifetime Steam Generator:	assuming ~ 200'000 hours (EOH) except the "hot" parts ~ 100'000 hours
Plant Operation Type:	assuming Baseload & gradients < 3-4 K / min

Arrangement and max. Dimensions assuming free, i.e. result of concept study

2.1.4 Previous Concept

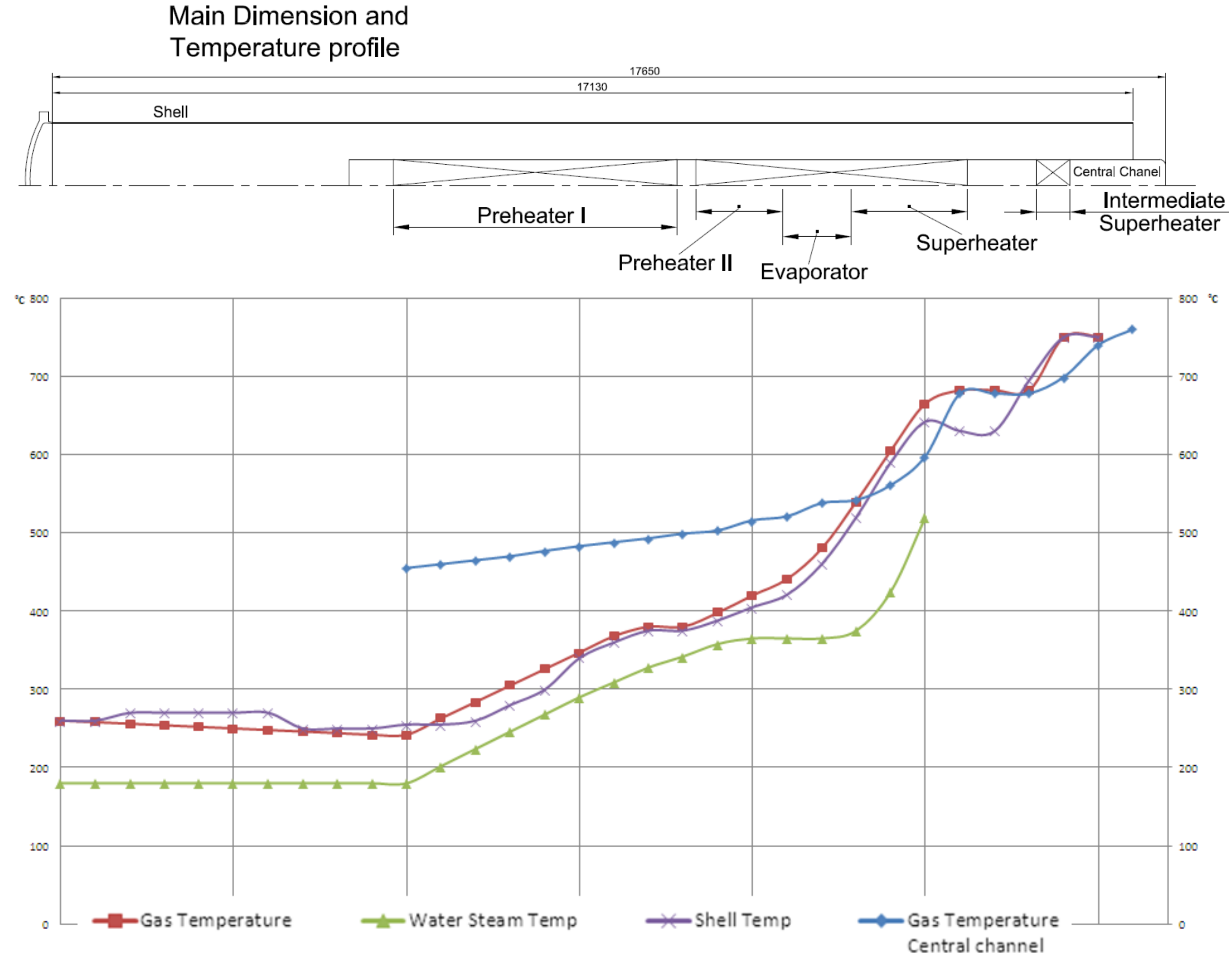
1. Main pressure shell
2. Inner shell
3. Intermediate superheater steam outlet
   (535 °C, 49 bar)
4. Expansion zone
5. High pressure steam
   (550 °C, 186 bar)
6. Support
7. Intermediate superheater steam inlet
   (365 °C)
8. Feedwater inlet
   (180 °C)
9. Central pipe
10. Helium outlet
    (250 °C)
11. HP I Bundle
12. Steam generator shell
13. HP II Bundle
14. Intermediate superheater bundle
15. Helium Inlet
    (750 °C)



Picture 1 SG Arrangement

2.1.5 Temperature profile

Operating Temperature
Temperature is often the first (and sometimes the only) data point given in order to select the material for the design. However, one cannot successfully choose a material based on temperature alone. Nevertheless, one simple guide to selecting a material is an estimate of the maximum temperature at which a given material might have useful long-term engineering properties.



Picture 2 Temperature Profile SG

2.1.6 Material selection

Tube-side mechanical design parameters are still tentative and therefore material selection on the tube side is still under investigation.
The remaining parts (plates, forgings, etc) have to be selected according to the required pressure vessel code. But the code itself is not sufficient.
Material selection should be the best compromise between:

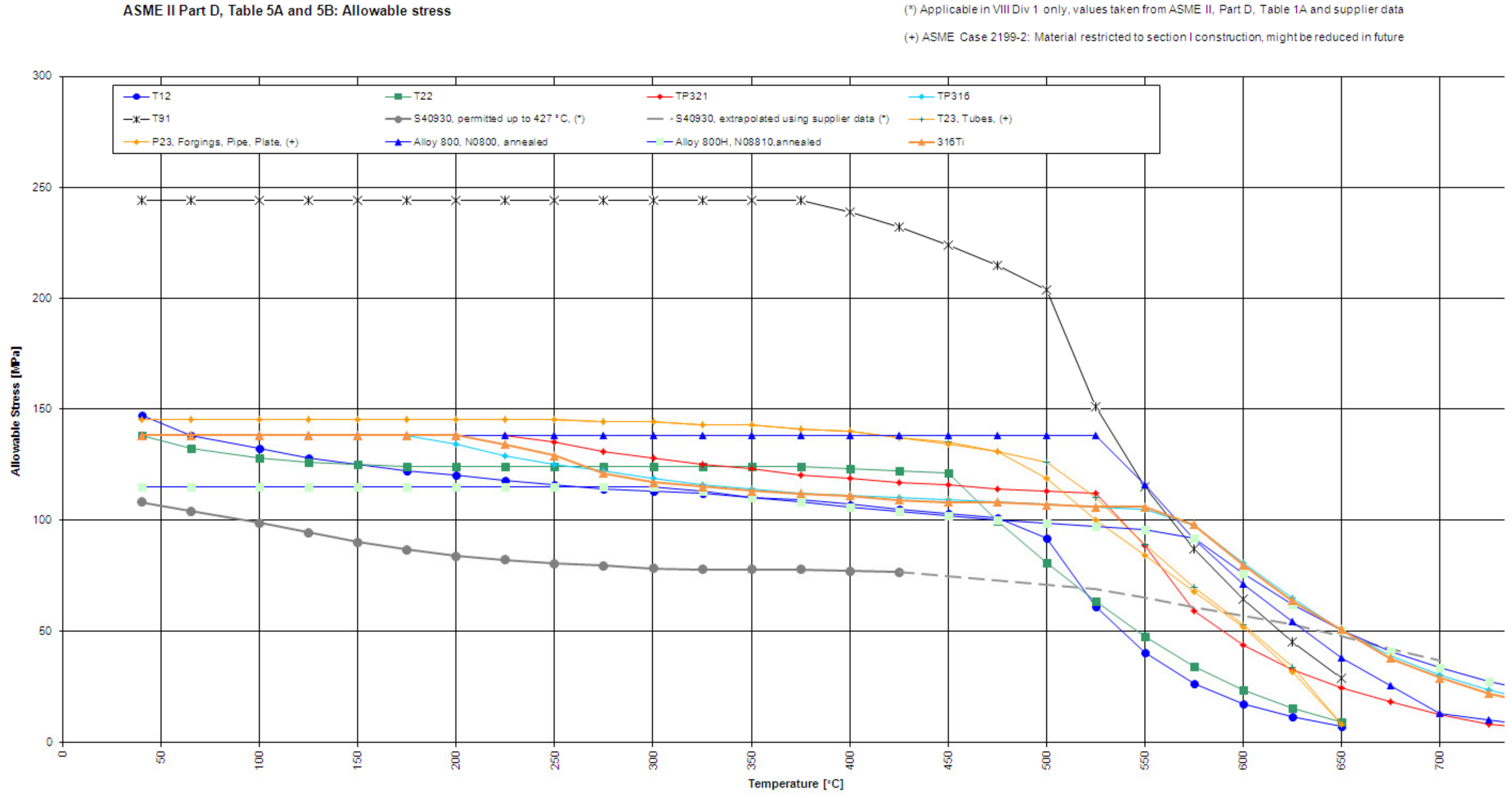
▪ Design parameters	▪ Maintenance / Repair
▪ Material properties	▪ References / ERS
▪ Code acceptance	▪ Customer Specification
▪ Manufacturing / Welding Lifetime	▪ First cost

Thermal Stability
After long exposure to temperatures in the range of 1,100-1,600°F (590-870°C), many of the higher chromium alloys precipitate a brittle intermetallic compound known as sigma phase. Molybdenum contributes to this phase. Sigma reduces room-temperature impact strength and ductility. The quantity and morphology of the sigma phase determines the severity of embrittlement. Usually the metal is brittle only near room temperature, and it retains reasonable ductility at operating temperatures between 600-1000°F (315-540°C). Higher nickel grades, such as N08811, N08330, N06600 or N06601, are not susceptible to embrittlement by sigma and because of higher carbon content, which causes carbide precipitation, cast heat-resistant alloys lose ductility in service.

Strength
Creep-rupture properties at temperature are usually available from the various producers, and many alloys are covered by the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code.
Allowable stresses are often based on ASME design codes. For most thermal processing equipment, design stress is either one-half of the 10,000-hour rupture strength, or one-half of the stress to cause a minimum creep rate of 1% in 10,000 hours. Above about 1,000°F (540°C), creep or rupture is the basis for setting design stresses. At this temperature, materials are no longer elastic, but deform slowly with time.

Thermal Expansion
A major cause of distortion and cracking in high-temperature equipment is failure to adequately address the issue of thermal expansion, and differential thermal expansion. Temperature gradients of only 200°F (110°C) are sufficient to strain metals beyond the yield point.
The following Materials are selected for SG design:

Nominal Composition	Product Form	Spec. No.	Type/ Grade	Werkstoff-nummer	Kurzname	Max. Use Temp.
1Cr-0.5Mo	Plate	SA-387	12	1.7335	13CrMo4-5	649
1Cr-0.5Mo	Plate	SA-387	12			649
1Cr-0.5Mo	Smls. Tube	SA-213	T12			649
2.25Cr-1Mo	Plate	SA-387	22	1.7375 /	12CrMo9-10	649
2.25Cr-1Mo	Smls. tube	SA-213	T22	1.7380	10CrMo9-10	649
16Cr-12Ni-2Mo	Plate	SA-240	316			816
16Cr-12Ni-2Mo-Ti	Plate	SA-240	316Ti			816
16Cr-12Ni-2Mo	Plate	SA-240	316L			454
18Cr-10Ni-Ti	Plate	SA-240	321	1.4541	X10CrNiTi189	816
18Cr-10Ni-Ti	Plate	SA-240	321H			816
18Cr-10Ni-Ti	Forgings	SA-182	F321H			816
9Cr-1Mo-V	Plate	SA-387	91	1.4903	X10CrMoVNb9-1	649
42Fe-33Ni-21Cr	Smls. tube	SB-163		1.4876	X10NiCrAlTi32-21	816
42Fe-33Ni-21Cr	Smls. tube	SB-163				899



Picture 3 Material properties

Tube bundle

Hot part:
With a ferritic material oxidation at high temperature and exfoliating oxides are expected.
Therefore: austenitic material
The cold part must be Alloy 800 (see below). The evaporator section can move over the whole tube bundle depending on the operation point.
Therefore: alloy 800 (DIN 1.4876)

Cold part:
Austenitic material has a potential to stress corrosion in the economiser and evaporator since oxygen and chlorides cannot be excluded from the feed water. Daily start and stop operation with one to two hours operation with not ideal water chemistry must be expected.
Ferritic material would be preferred for the water steam side. For the Helium side ferritic material cannot be accepted because the risk of exfoliation must be minimized.
Therefore: super alloy material: alloy 800 (DIN 1.4876)
This material is not prone to stress corrosion (water steam side) and has the lowest risk of exfoliation
Shell, internals, (tube sheets)

Shell, internals:
Helium side oxidation and the danger of exfoliation must be prevented; ferritic material does not comply with this requirement at this temperature:
Therefore: austenitic material, titanium stabilised
either: 316Ti (DIN 1.4571) or: 321 (DIN 1.4541)
The 316Ti material contains compared to the 321 material 2% MO.

3 Conclusion

Material selection issues have been investigated.
The main conclusions arising from these investigations are as follows:

- Tube-side mechanical design parameters are still tentative and therefore material selection on the tube side is still under investigation.
- Suggestions have been made for the remaining parts (plates, forgings, etc).
- Design rules are available for SG based on former built HTR SG and from existing Combined Cycle power Plants. Design and materials for a SG are further defined by applicable Codes and Standards.
- The temperature limit for the material for the SG is considered to be 750°C.
- Remaining design parameter such as pressure, massflow, delta P has to be confirmed or defined with the ongoing process analysis.

4 Recommendations

Concept material selection for a new SG based on the available data's is only partially possible. However there is sufficient information from actual and older built SG available in order to propose a new SG in regards of material and design for latest HTR.
This situation will be kept under review within the project and may be changed should results from later reviews lead in some changes on the specific planned conceptual design.