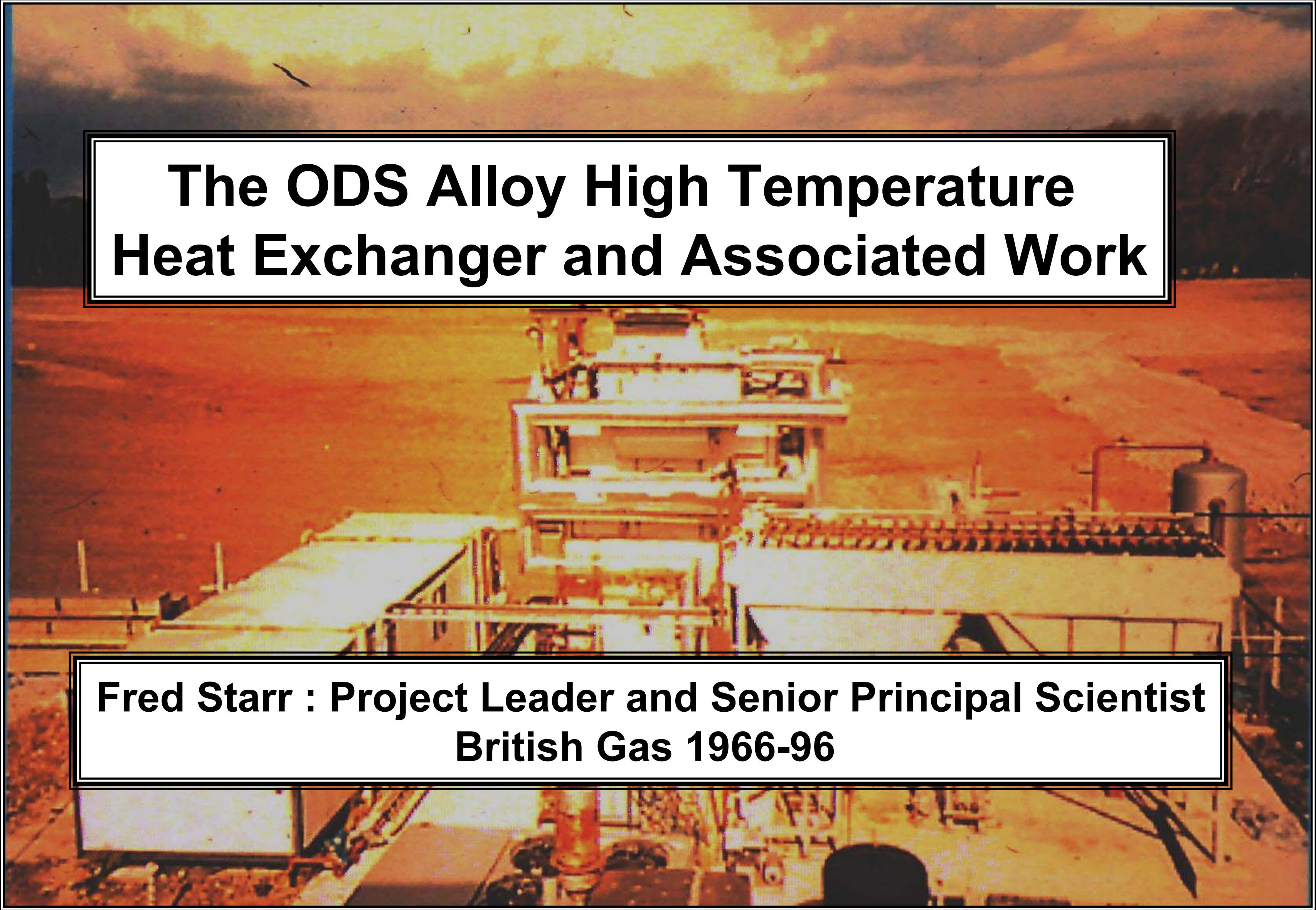
The ODS Alloy High Temperature Heat Exchanger and Associated Work

Fred Starr : Project Leader and Senior Principal Scientist
British Gas 1966-96



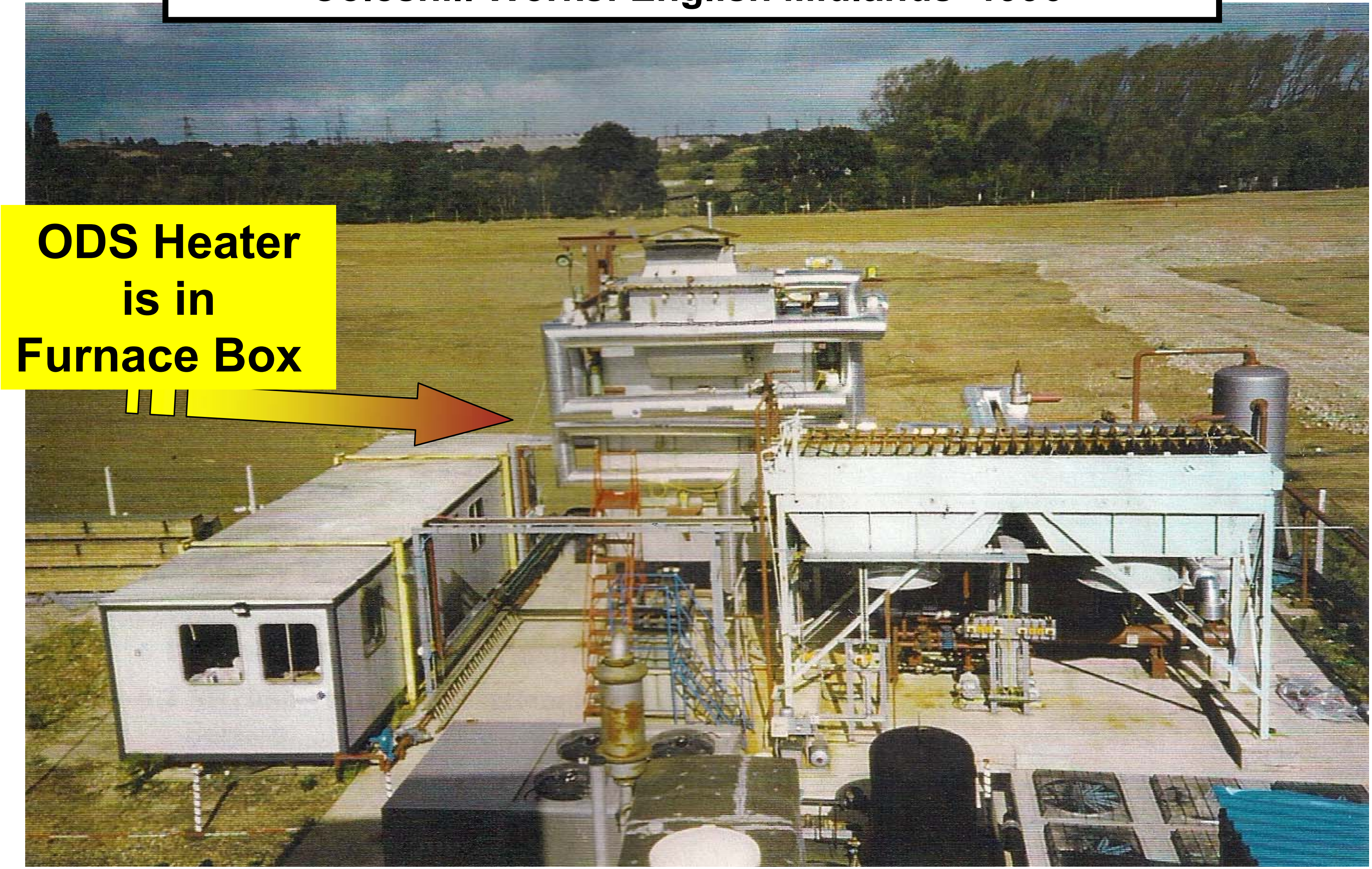
Presentation

The ODS Heat Exchanger Programme and how it came about

Some of the results of the long term testing

Future possibilities for ODS alloys and what developments are needed

The Closed Cycle Gas Turbine Demonstrator
Coleshill Works: English Midlands 1996



In 1986 GH Gibson: Assistant Director, London Research Station said

"LRS on behalf of British Gas needs to develop more advanced power and energy conversion concepts"

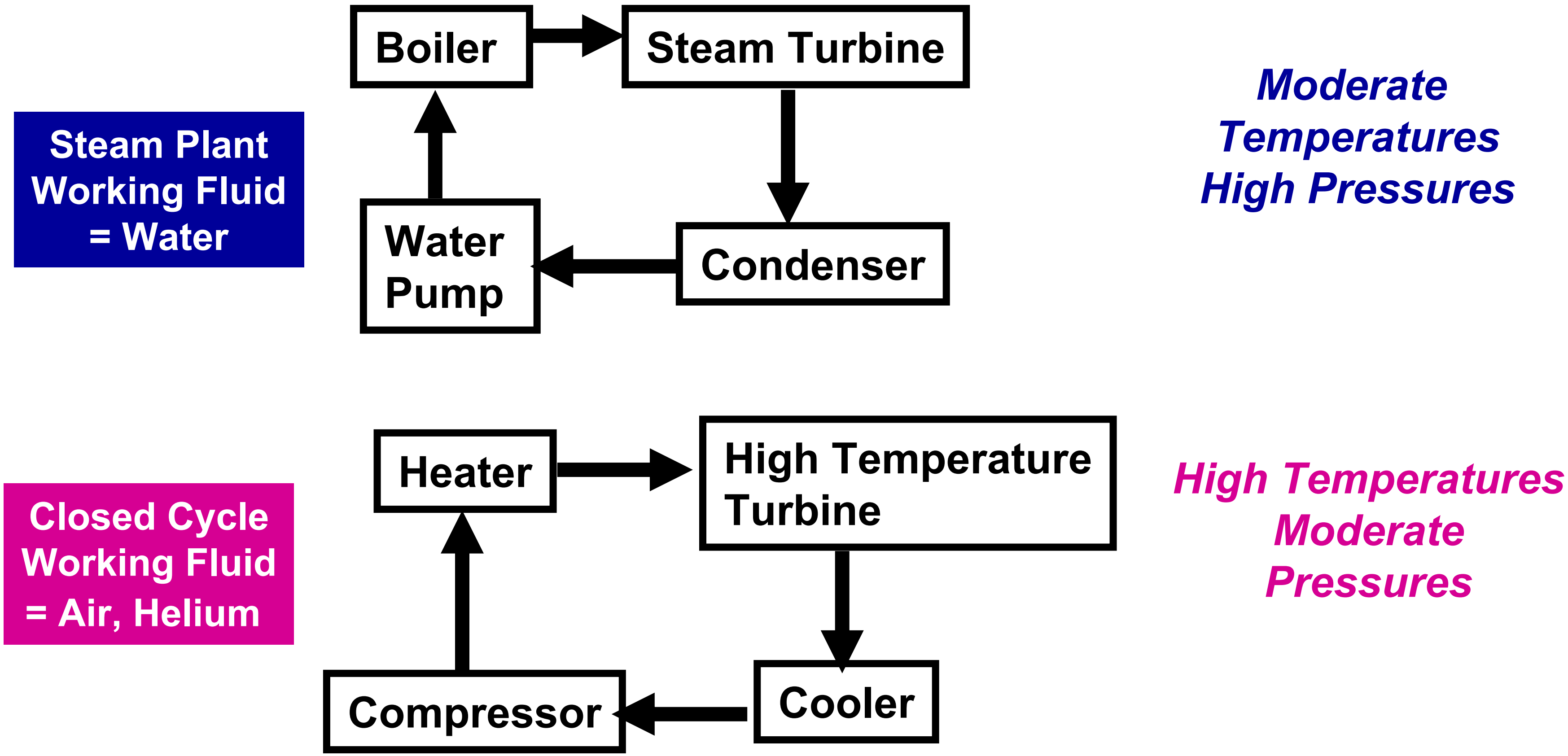
F.Starr : Senor High Temperature Materials Scientist said

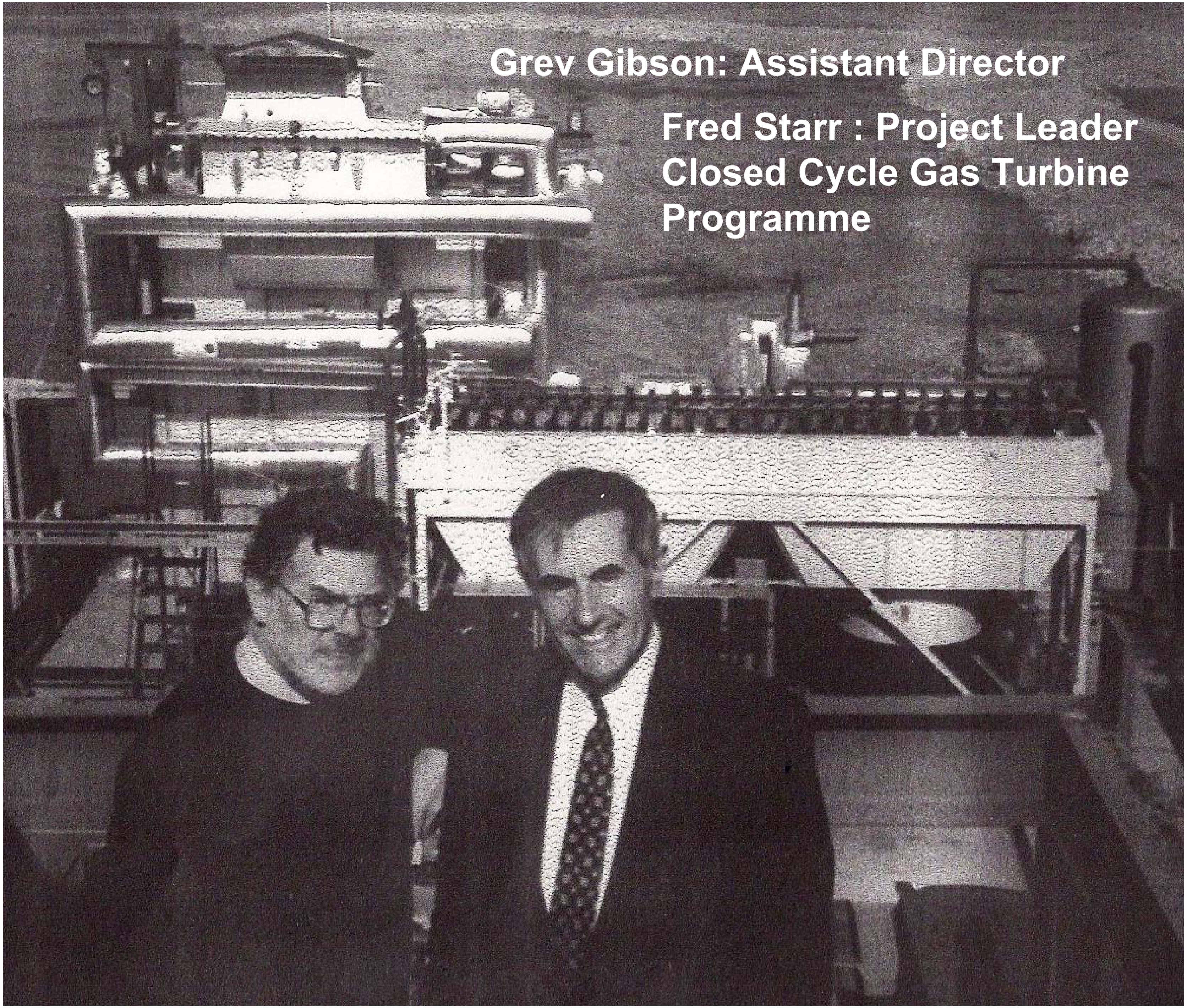
"Let us use **ODS alloys** to improve the **Closed Cycle Gas Turbine** and the Stirling Engine"

Yes We Can!

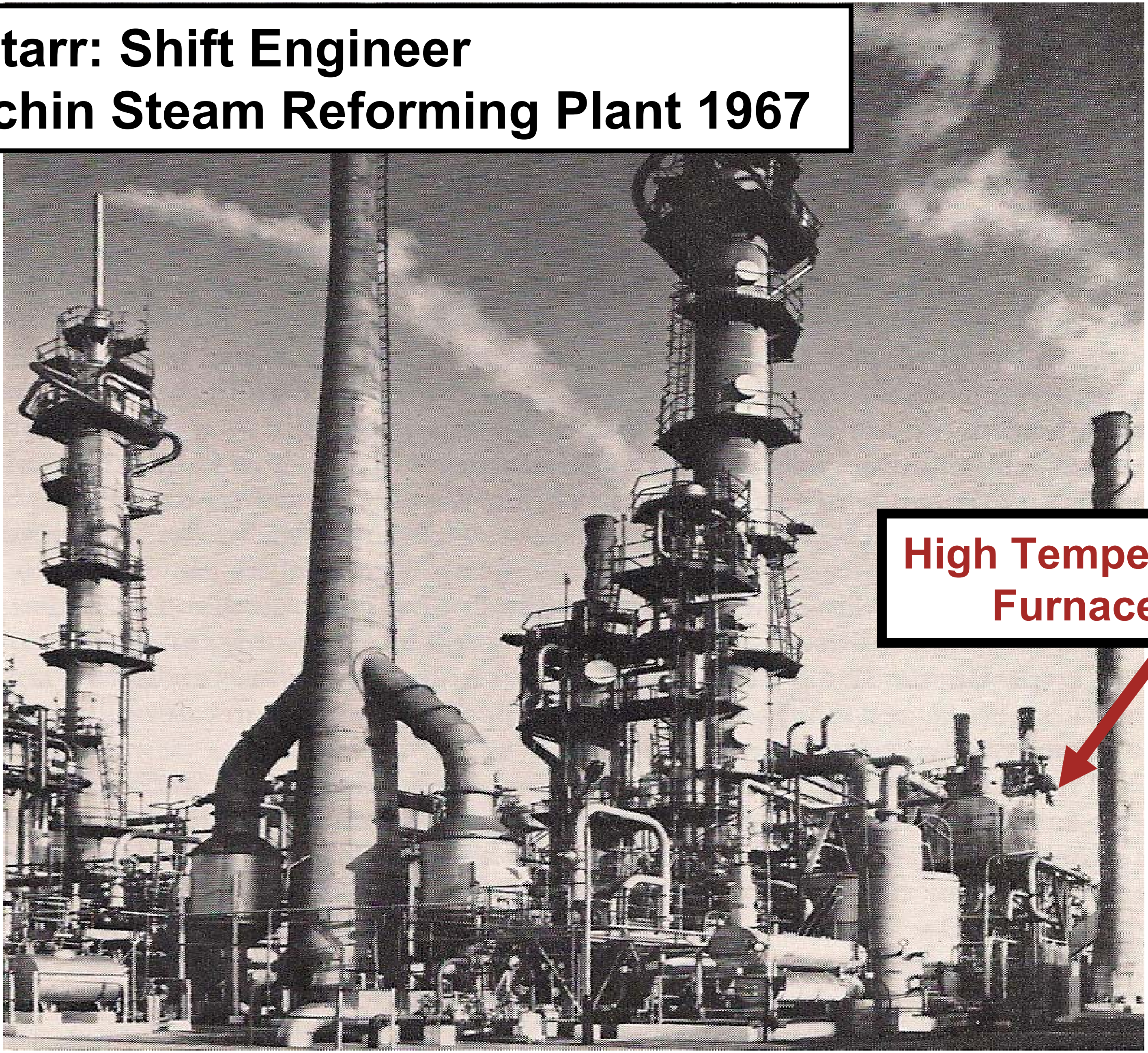
Build Equipment, not paper concepts !	Obtain Reliable Long Term Engineering Data	Get Help From Outside Experts

Steam Plant and Gas Turbine Closed Cycles



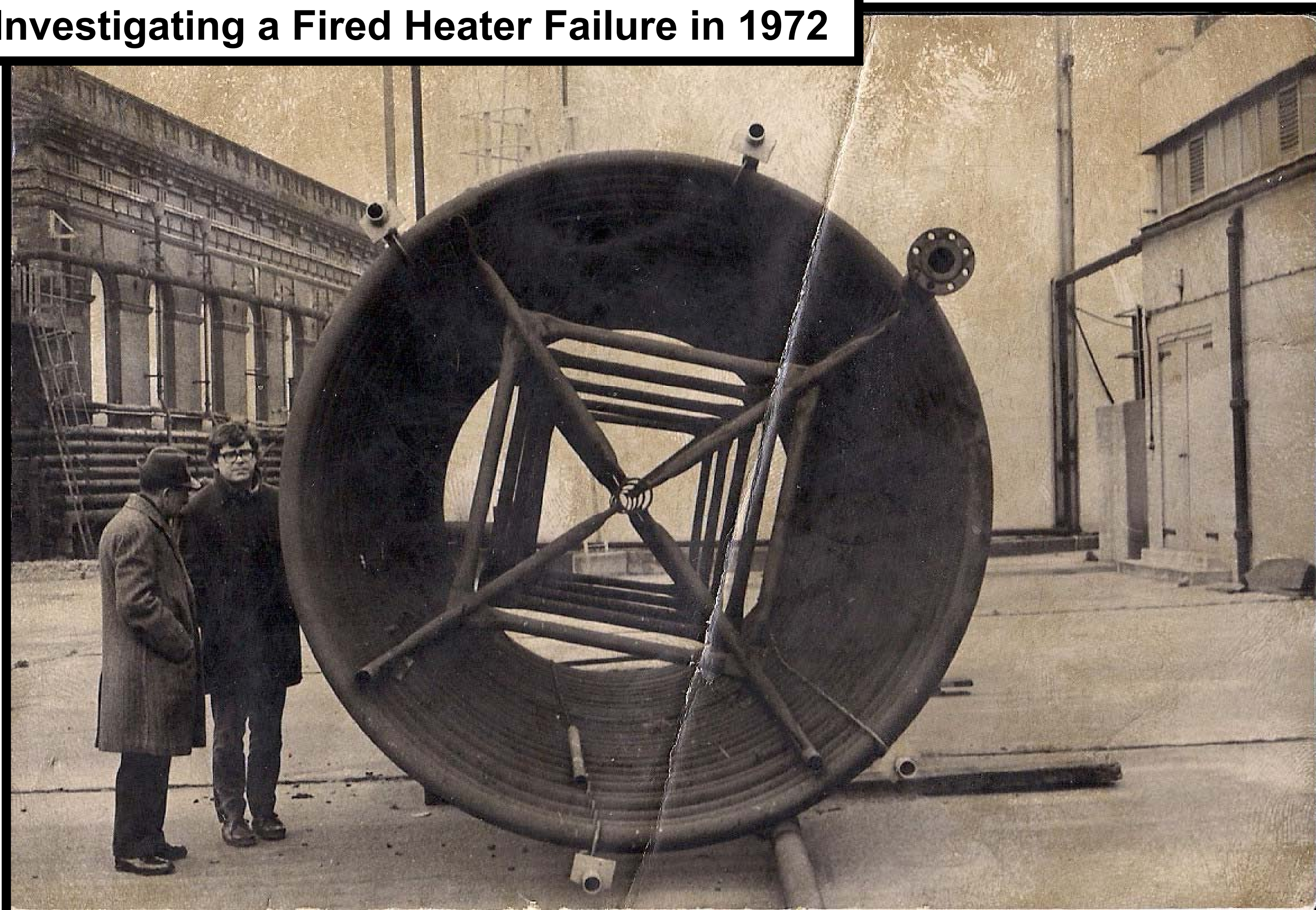

Grev Gibson: Assistant Director
Fred Starr : Project Leader
Closed Cycle Gas Turbine
Programme

F Starr: Shift Engineer
Hitchin Steam Reforming Plant 1967

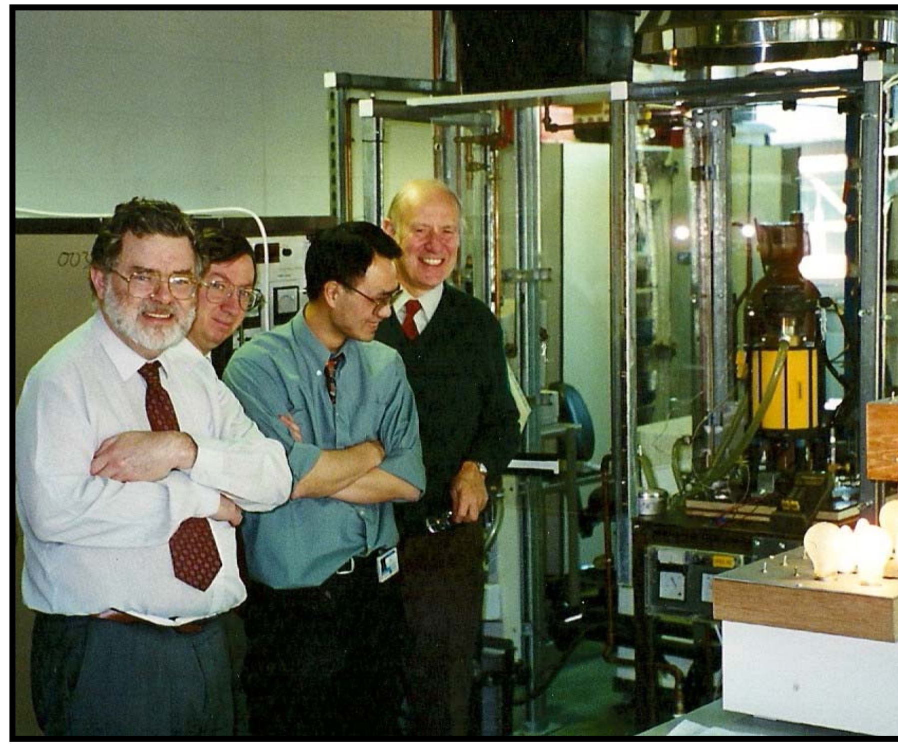


High Temperature Furnaces

Investigating a Fired Heater Failure in 1972



Micro Stirling Engines For In-House Cogeneration 1987-96



High Temperature Heat Exchangers were Vital !

The Closed Cycle Gas Turbine Demonstrator 1987-1996

Main Aims

- To lead to a 100 MW generating plant with an efficiency of 60%
- To identify the key technical challenges

↓

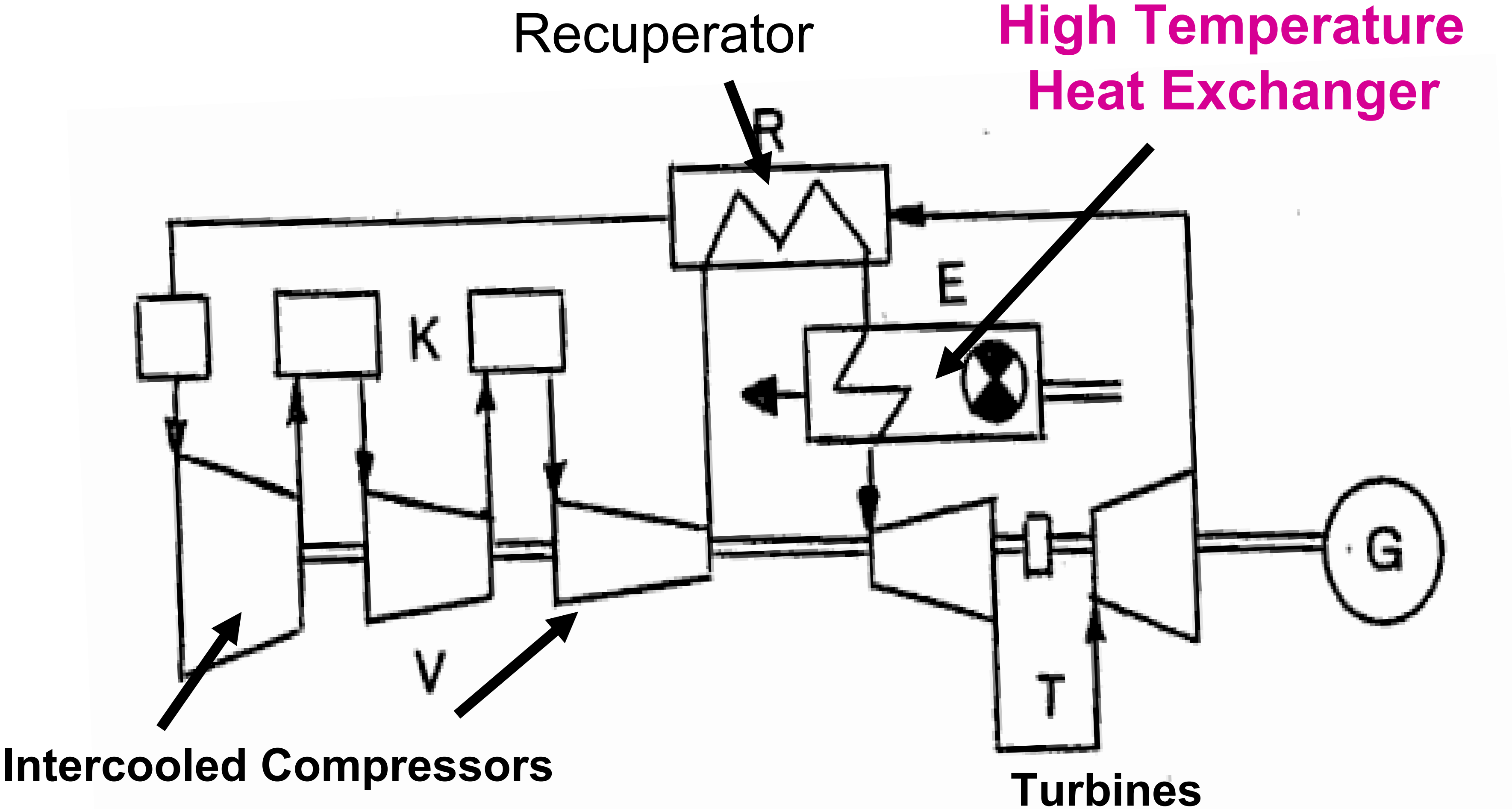
Uncooled 1100°C Helium Turbine
High Effectiveness Pressurised Recuperator
High Temperature ODS Heater

↓

Heater Requirements : 1100ºC Outlet, 30-50 bar pressure, 1MW heat input

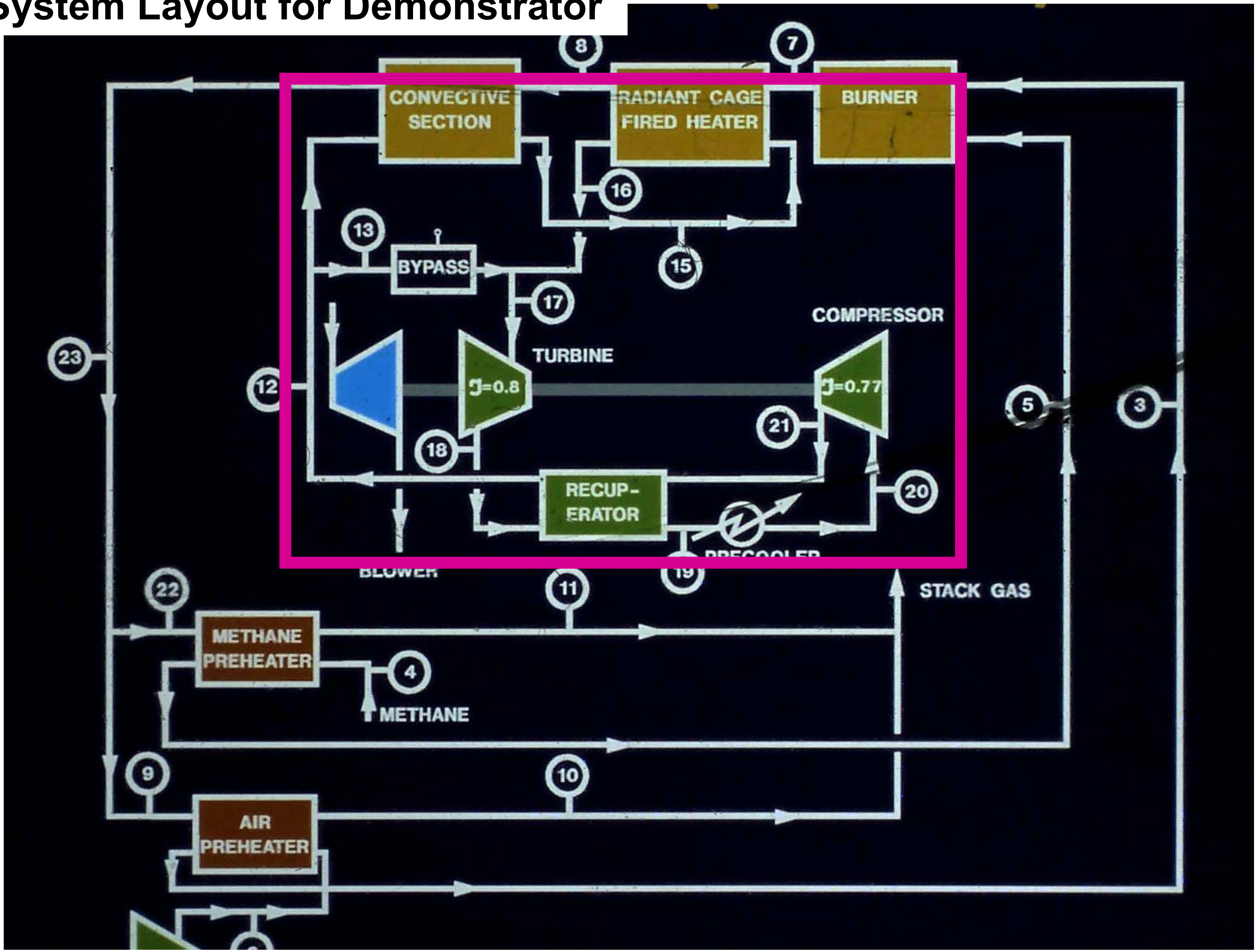
Alloy Requirements: 25-40 MPa at 1150ºC for 100000 hrs
No oxidation or corrosion

Basic Closed Cycle Gas Turbine Loop

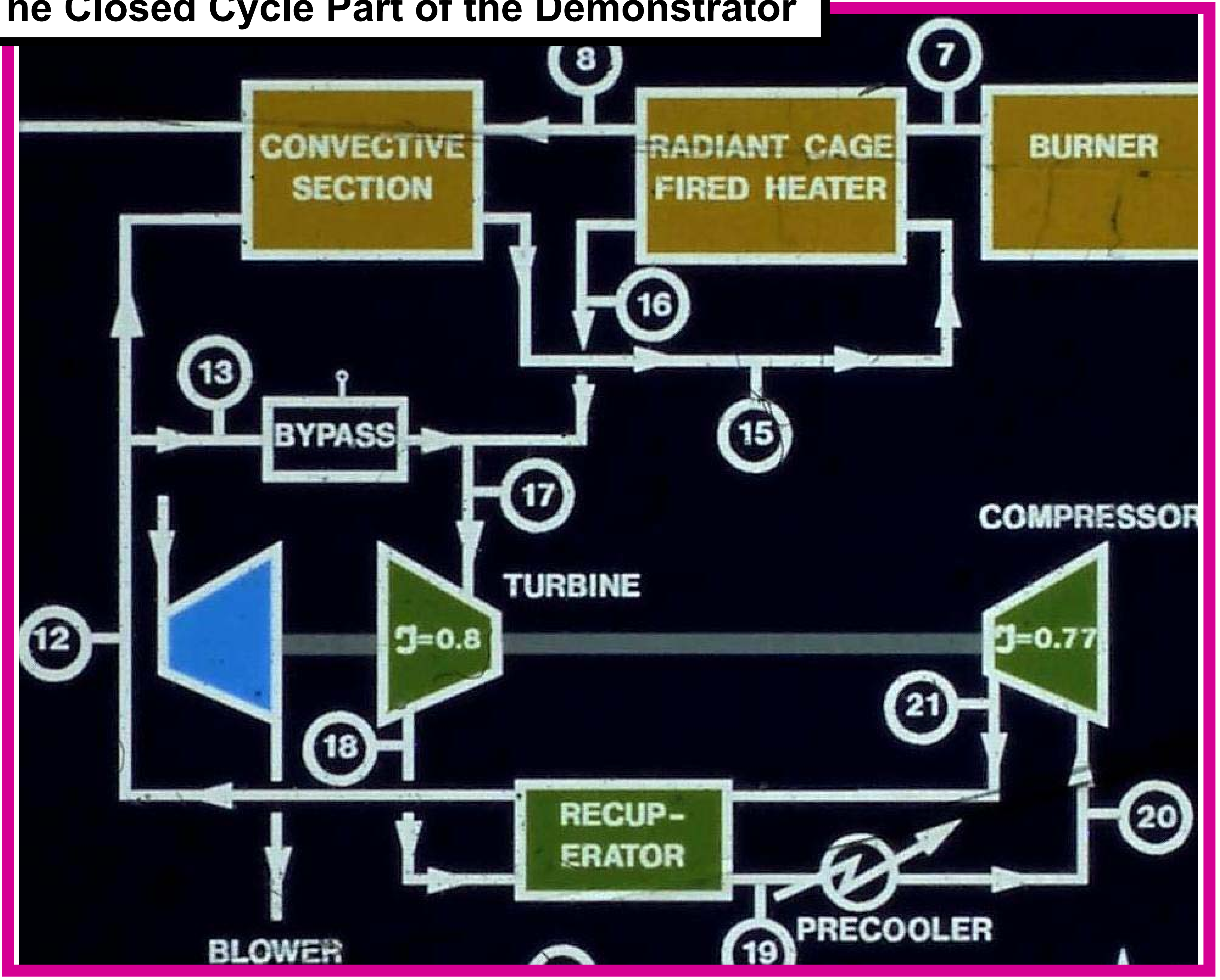


Efficiency : c.30% at T_{INLET} of 700ºC but 60% at T_{INLET} of 1100ºC

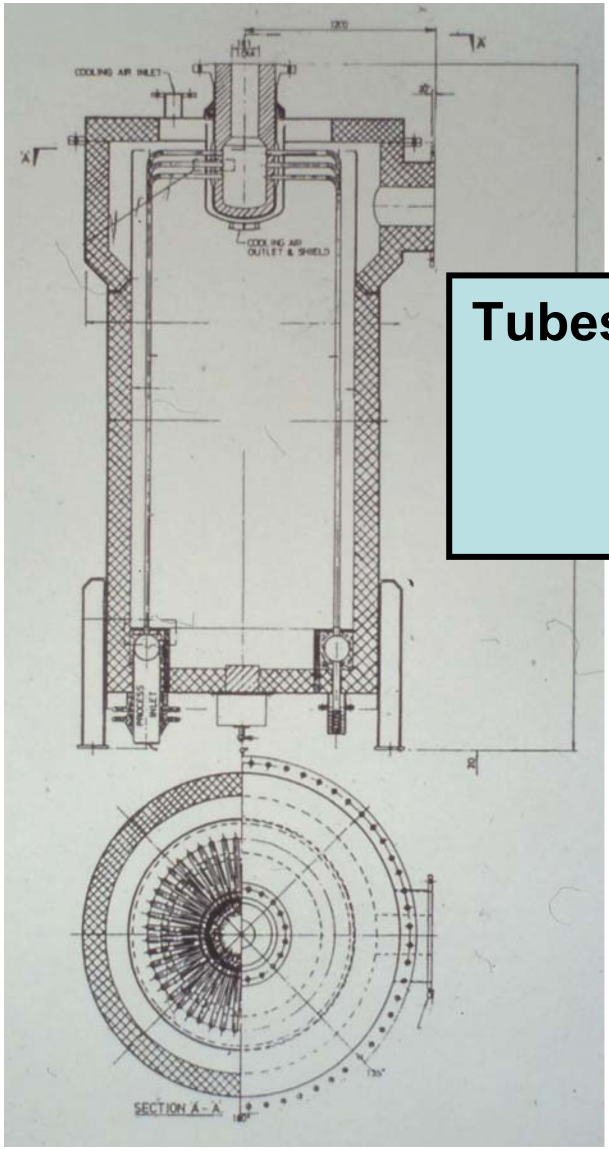
System Layout for Demonstrator



The Closed Cycle Part of the Demonstrator

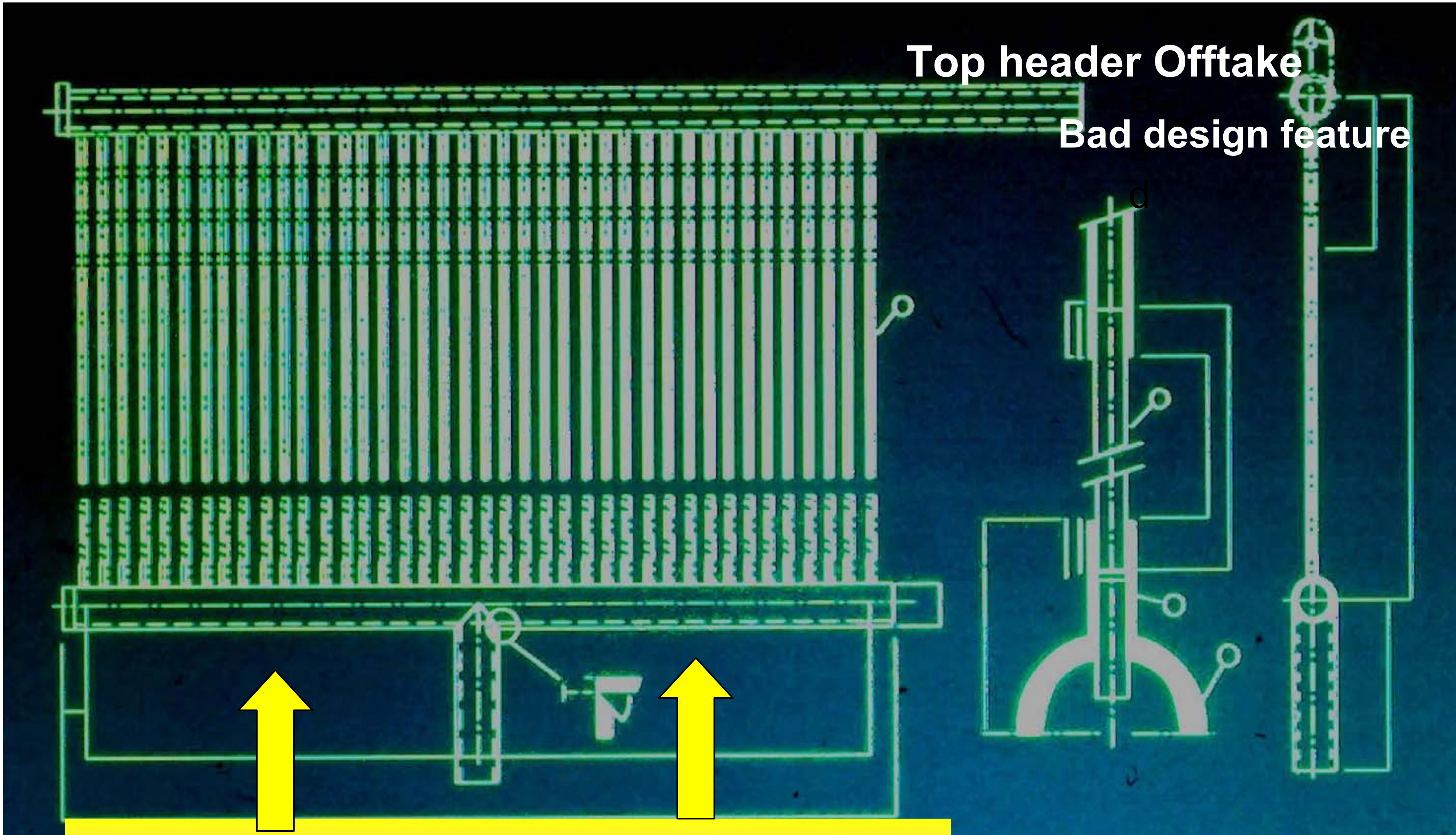


Original Idea for Heater : Cage Type



Tubes symmetrically arranged round burner

Late Design Change to Harp Type



Location of the Two Floor Burners

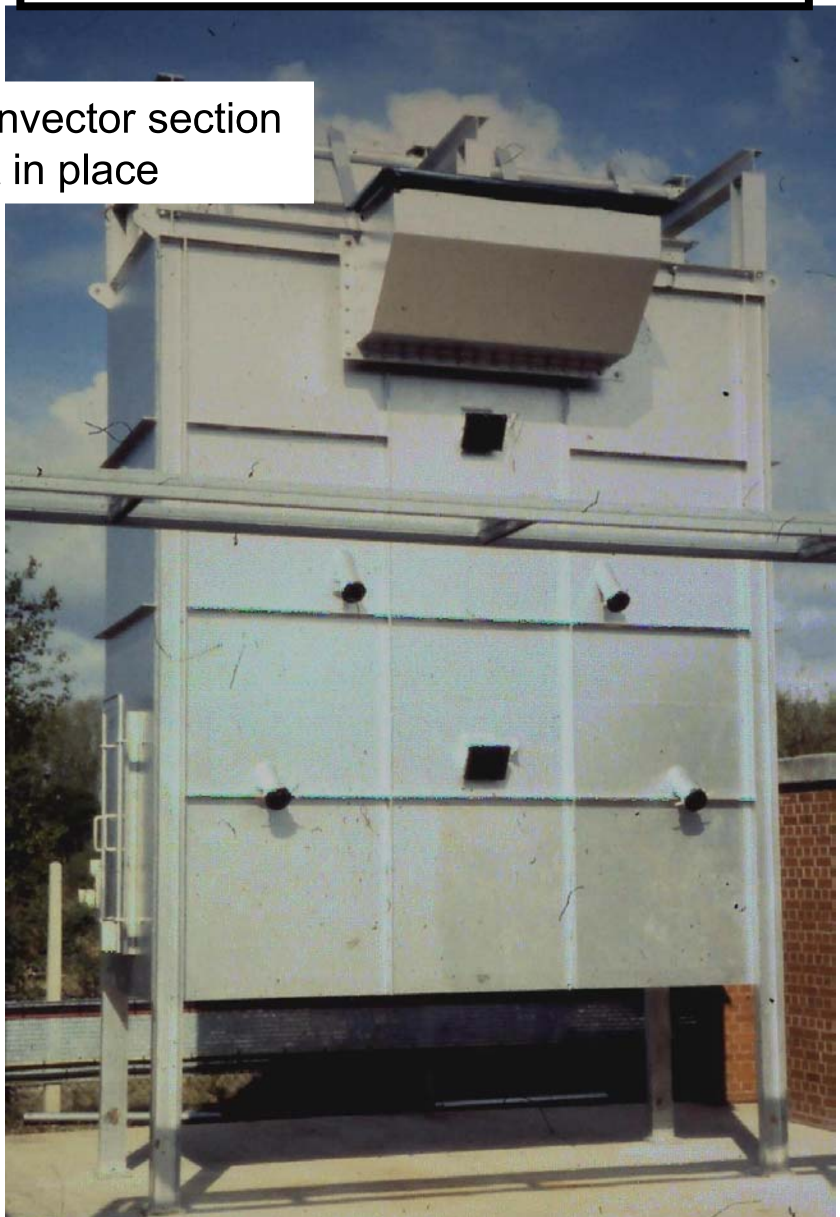
<u>A very bad design feature</u>

Dr Quentin Mabbut : Responsible for getting the Demonstrator built

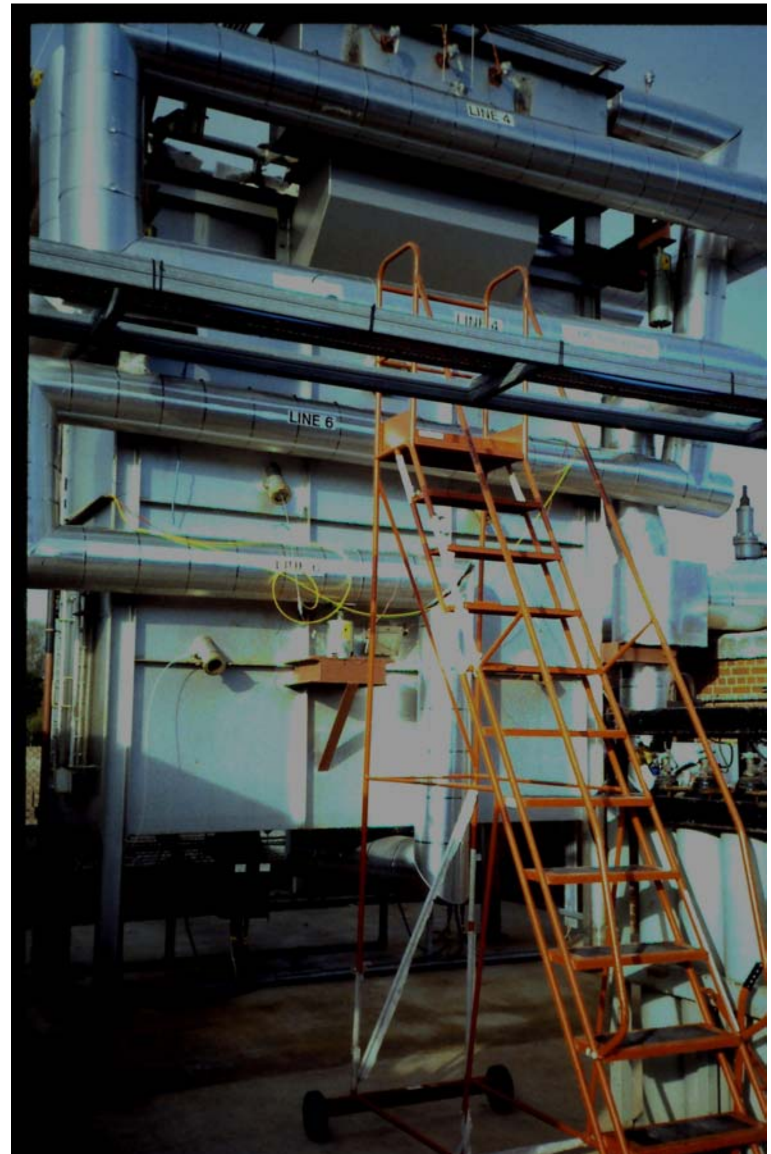
And for making the tubes in Belgium!

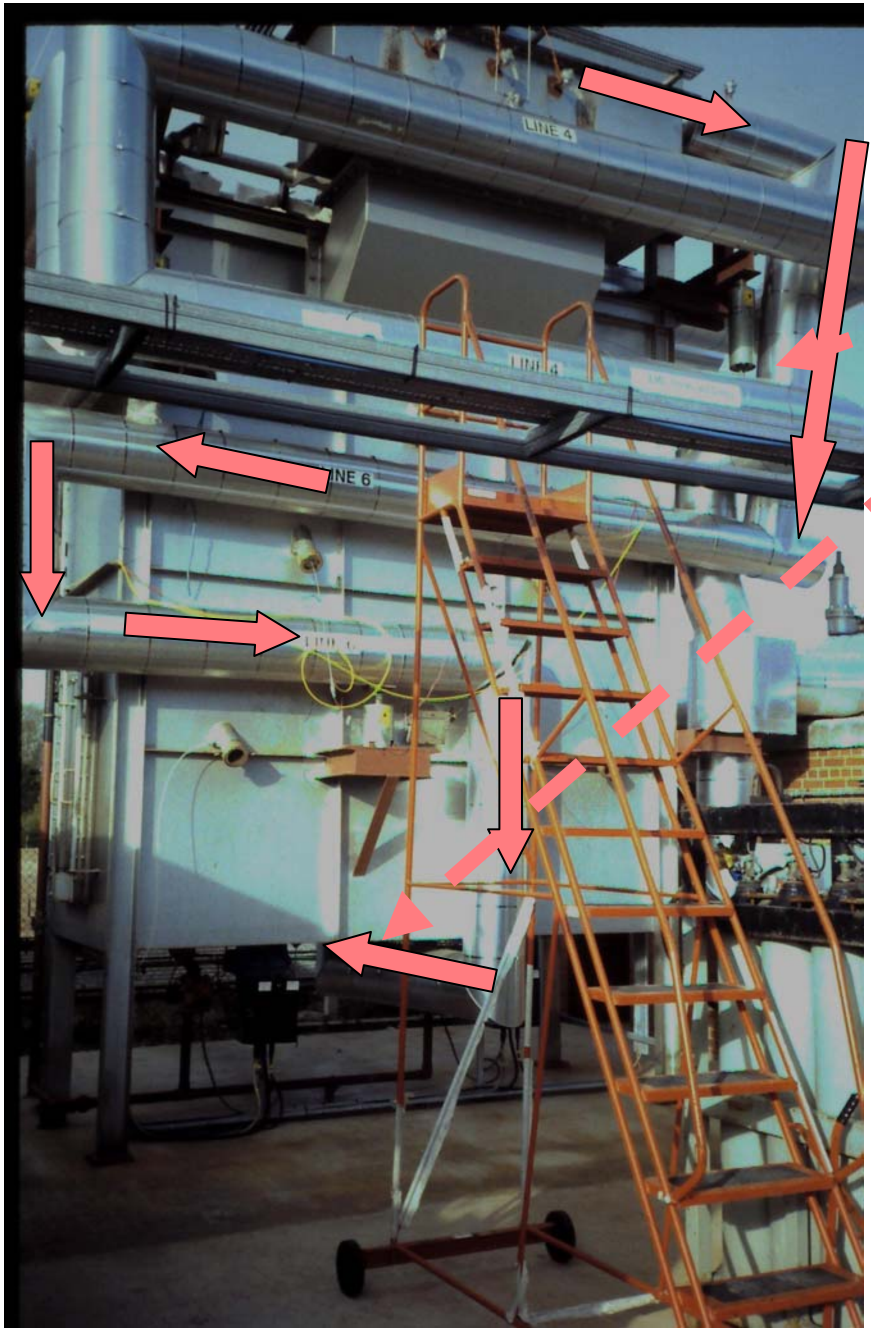
Heater Box Before Piping Up

Convector section
not in place



Heater When Operating





800ºC Flow from Convector to ODS Heater

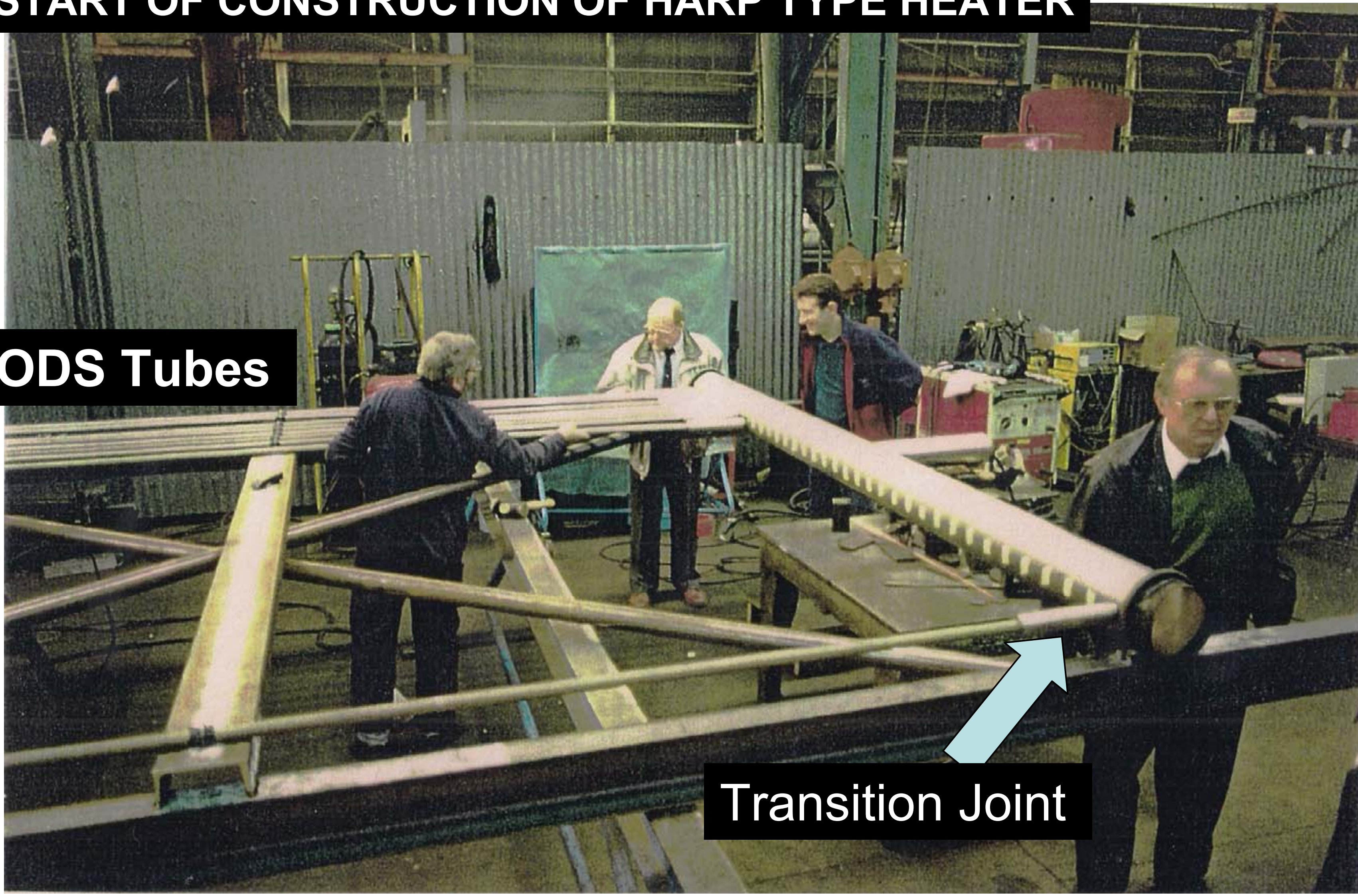
Piping system was extremely complex because of ;

Bypass systems to reduce inlet temperature to turbocharger

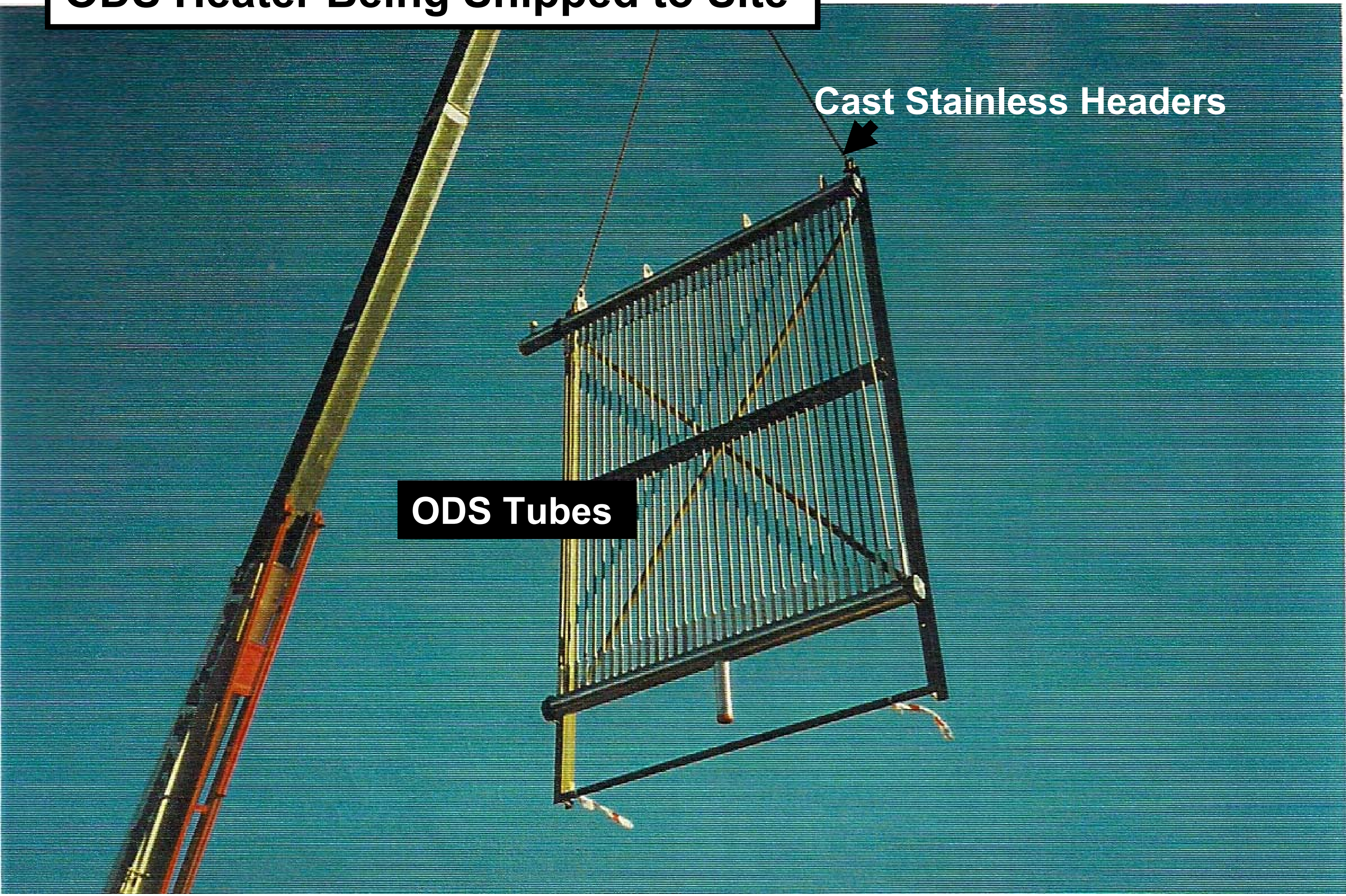
Cocurrent flow design of heater

Pipe to Turbocharger

START OF CONSTRUCTION OF HARP TYPE HEATER



ODS Heater Being Shipped to Site



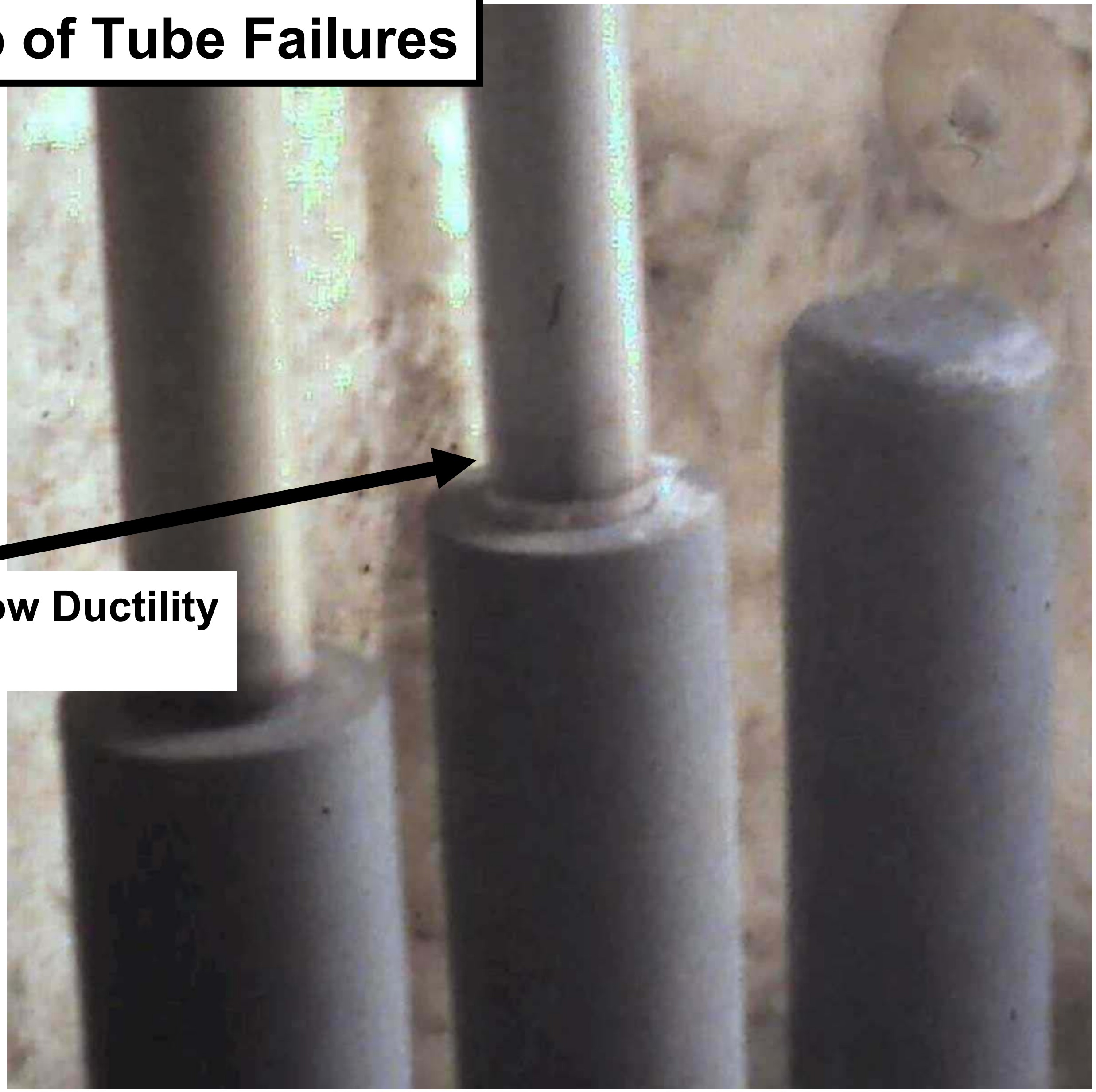
Inside of Furnace Box

End Tube had to be Capped off Because of Tube Failure

Failure occurred very rapidly in end ODS tubes:

- **Poor temperature and heat distribution**
- **Tubes did not have bends to compensate for thermal expansion**
- **Very limited short term tensile and creep ductility**

Close Up of Tube Failures

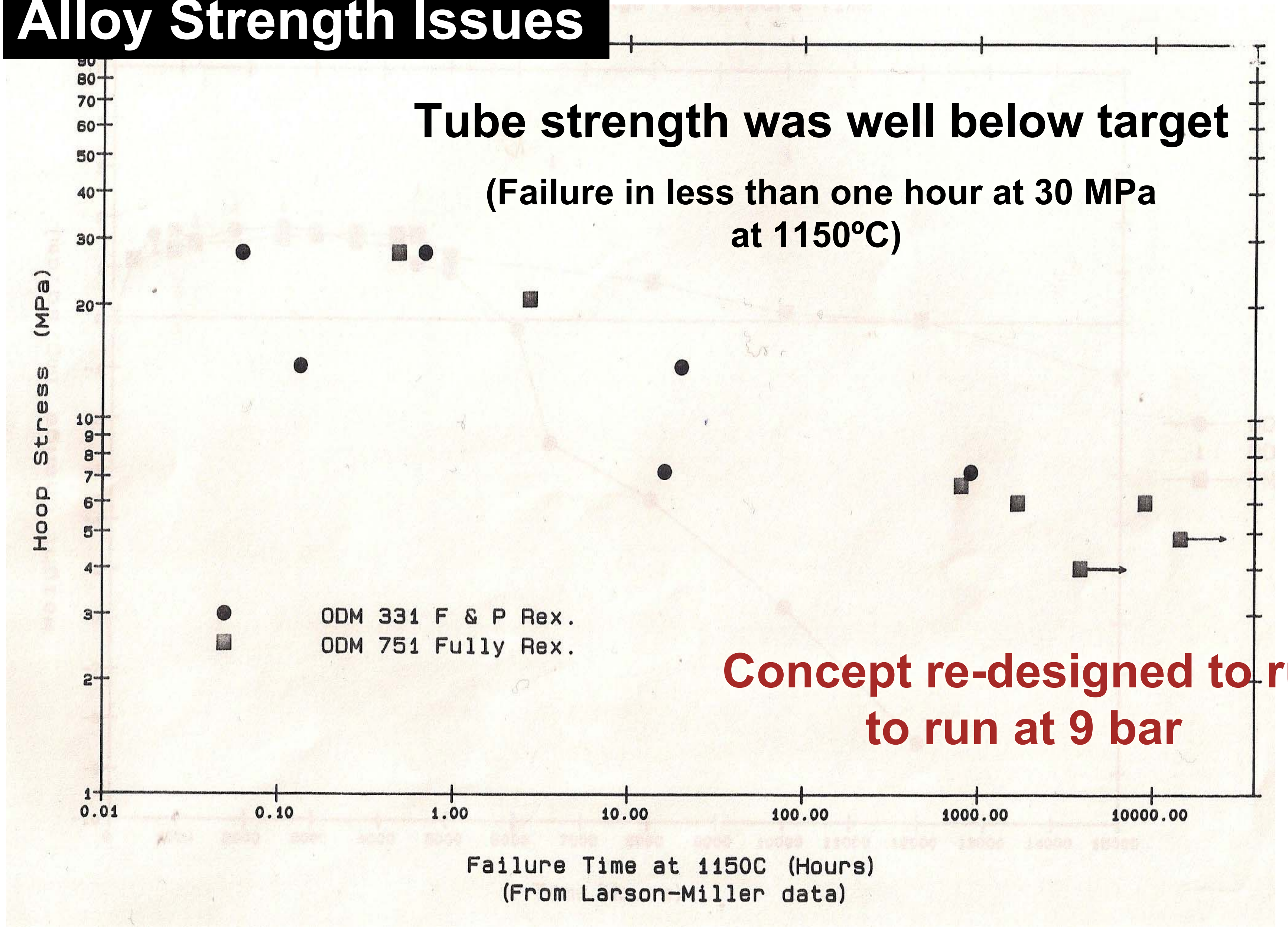


Alloy Strength Issues

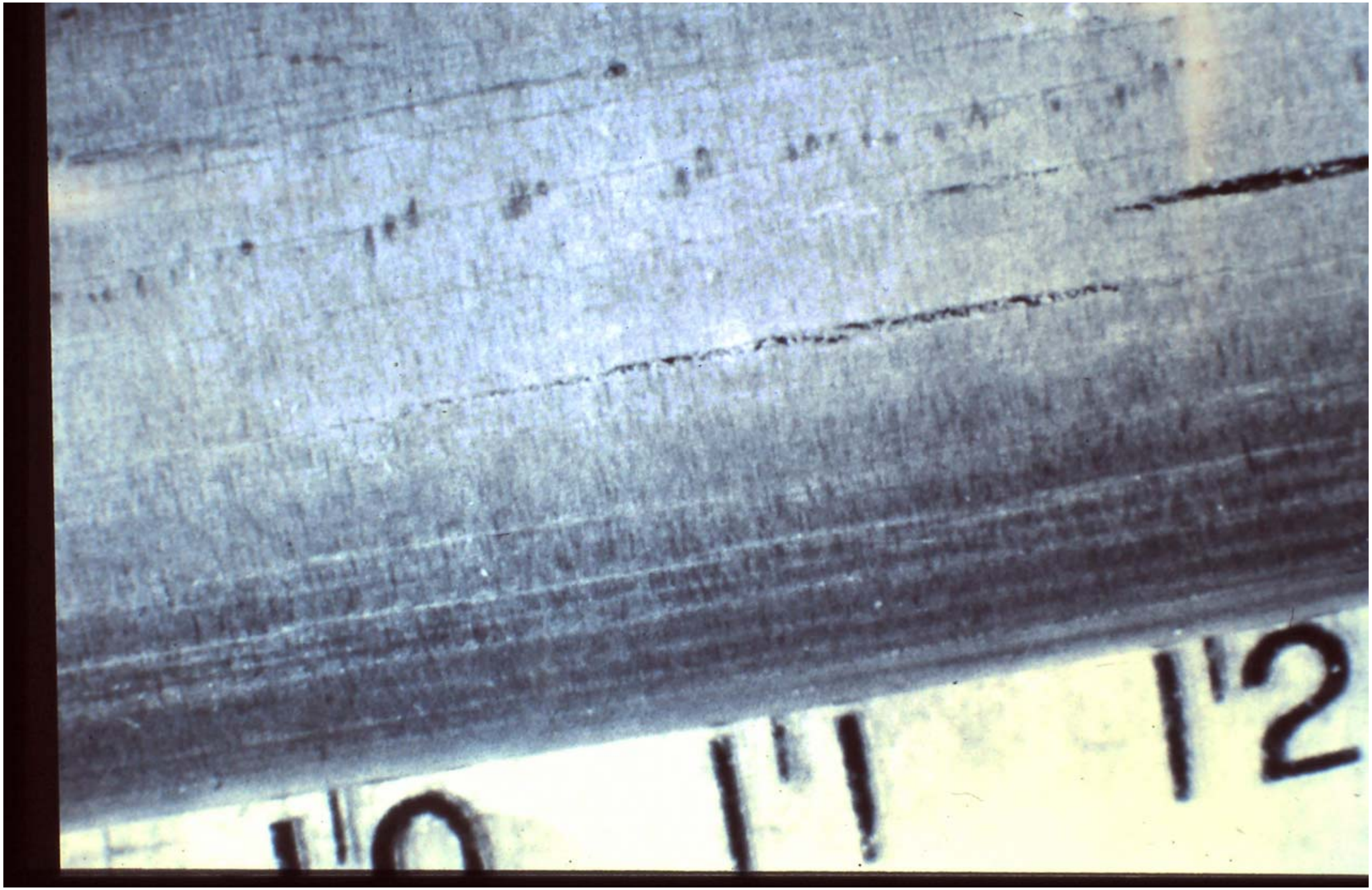
Tube strength was well below target

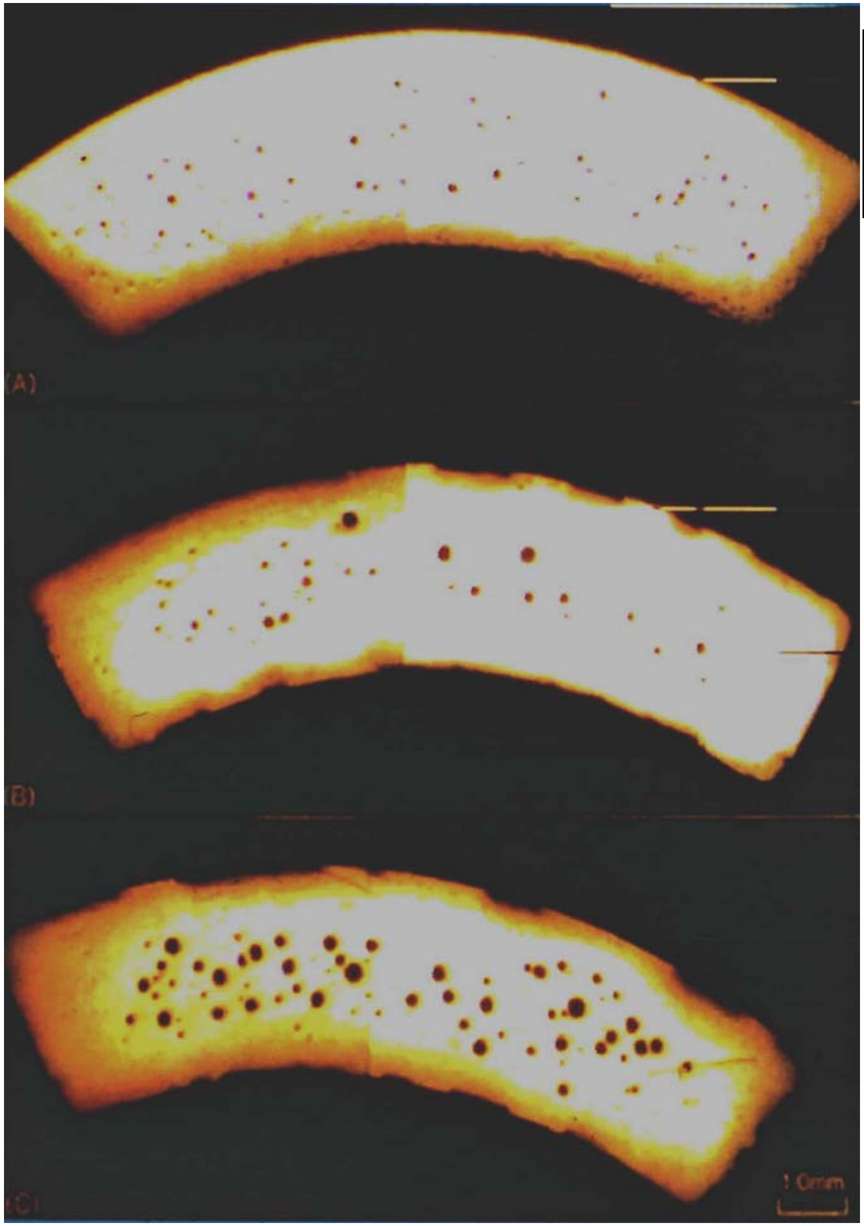
(Failure in less than one hour at 30 MPa at 1150ºC)

Concept re-designed to run to run at 9 bar



Limited creep ductility





Long term exposure leads to growth of porosity

In this case porosity may be nucleated by Kirkendall Vacancies from Oxidation

However any disruption of the microstructure which leads to increases in sites for nucleation results in porosity formation

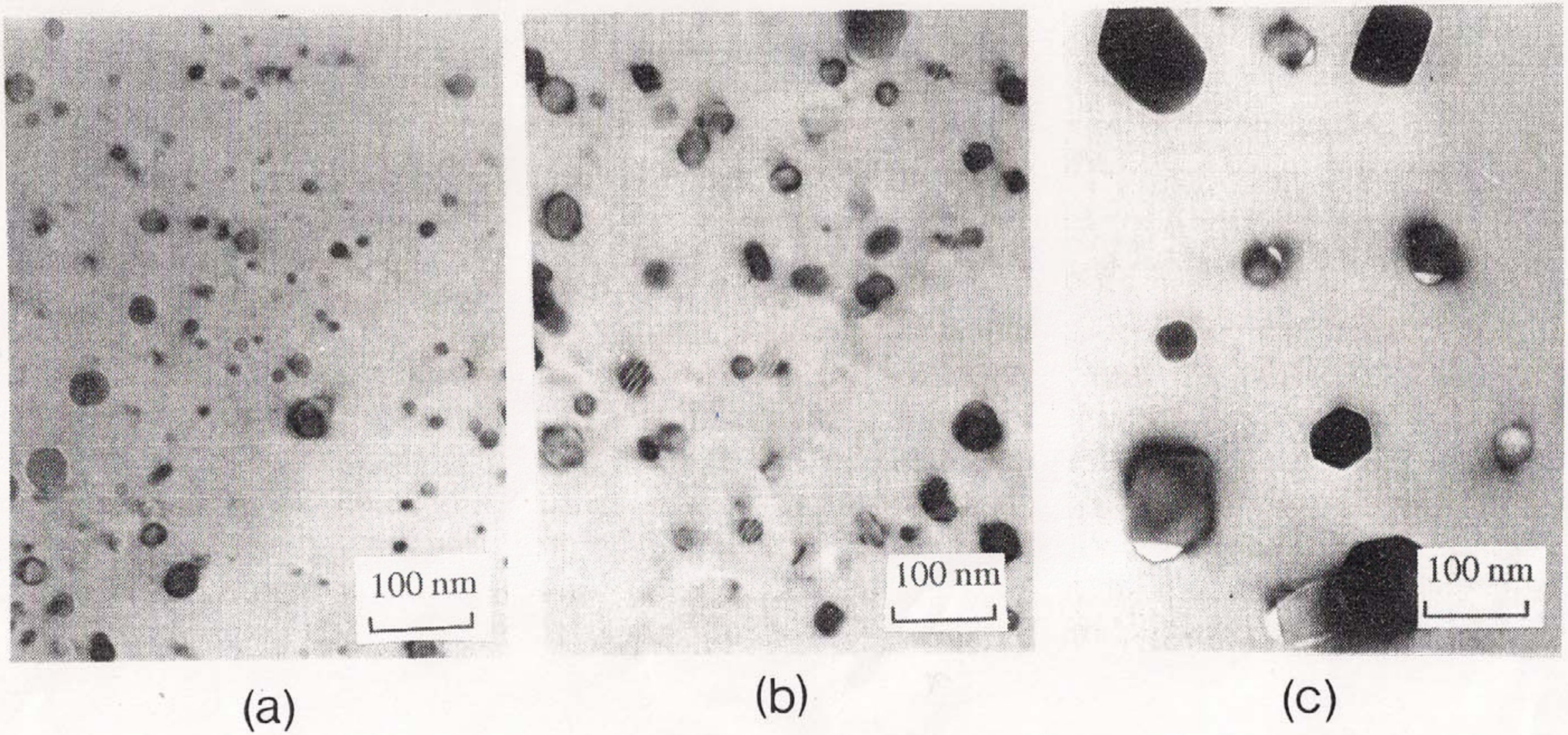
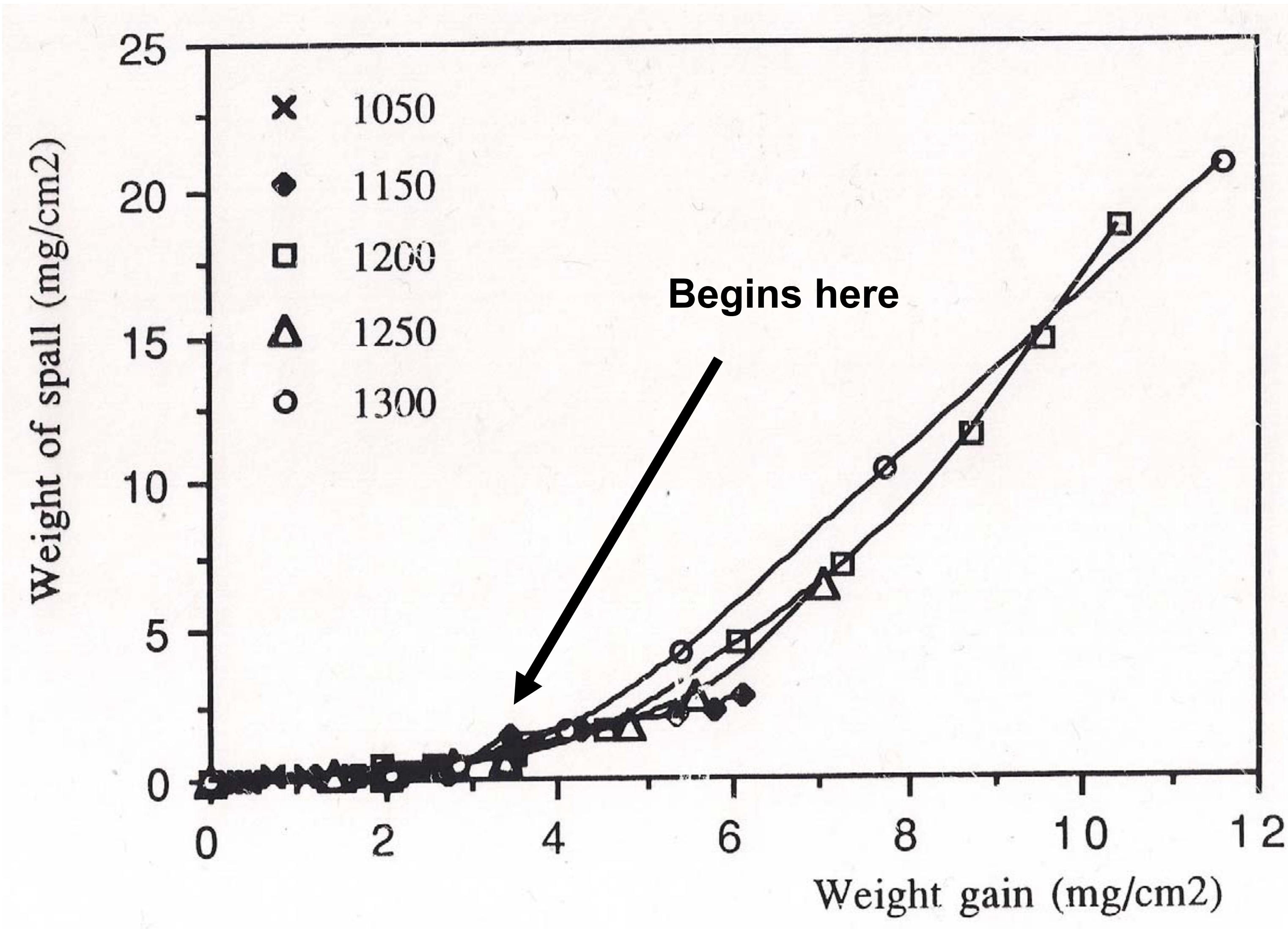


Figure 4: Typical micrographs showing particle sizes and shapes in MA 956 bar (a) in the as-received condition and after exposure in air for (b) 50 hours and (c) 1000 hours at 1300 °C.

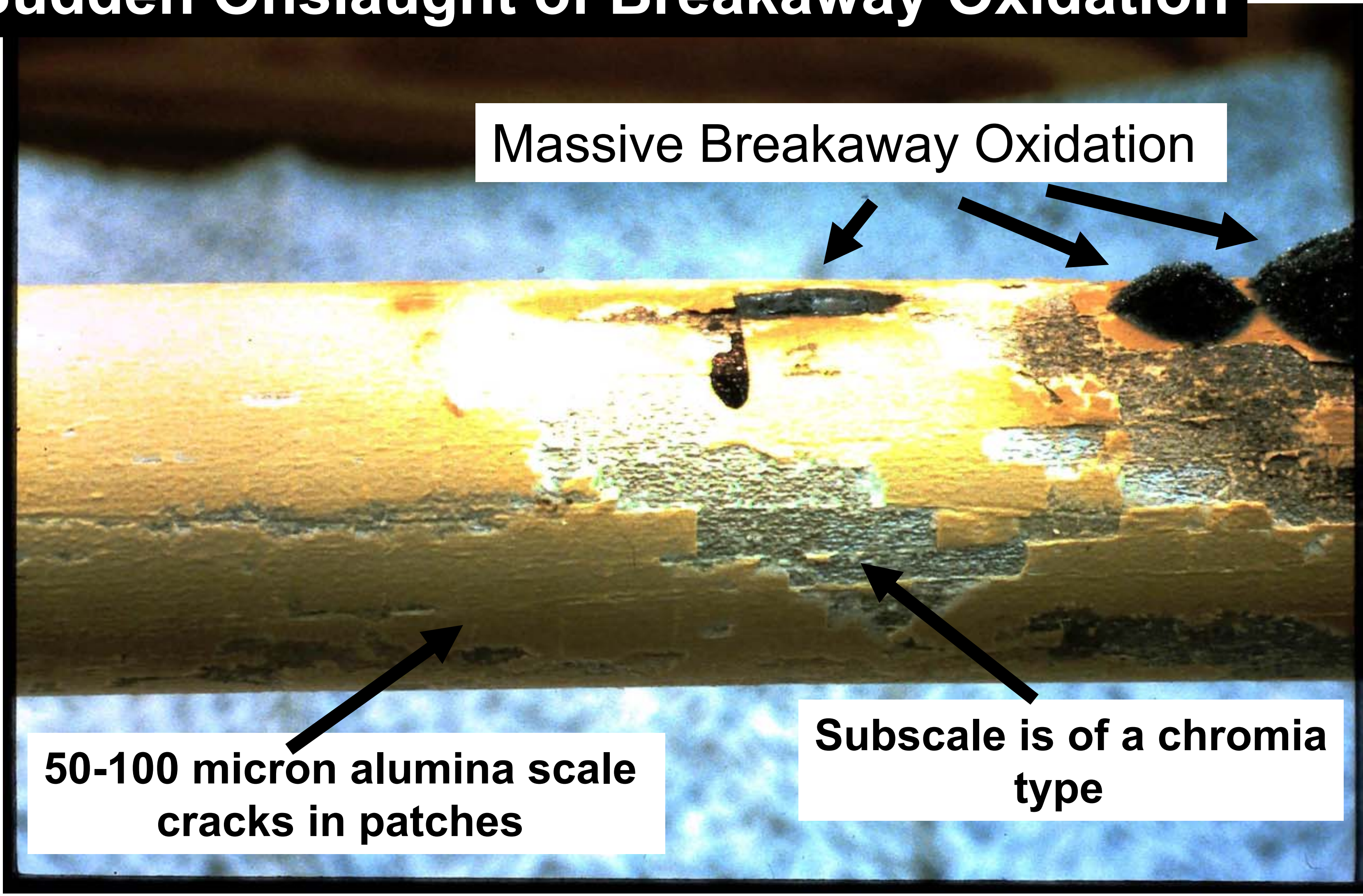
Initial Concern about Oxidation was Spalling



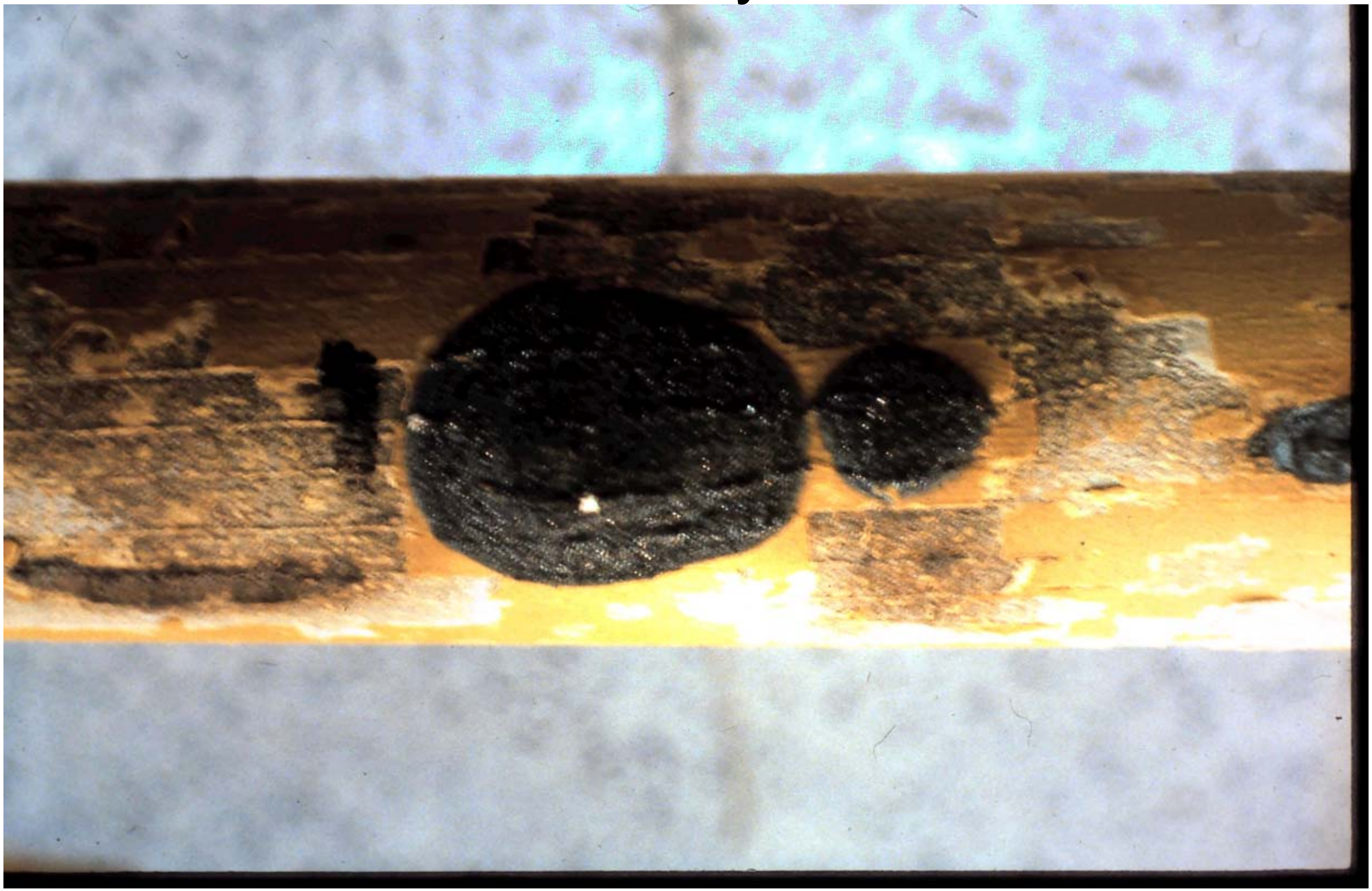
Generally good oxide adherence after 6000 Hours at 1150-1200ºC

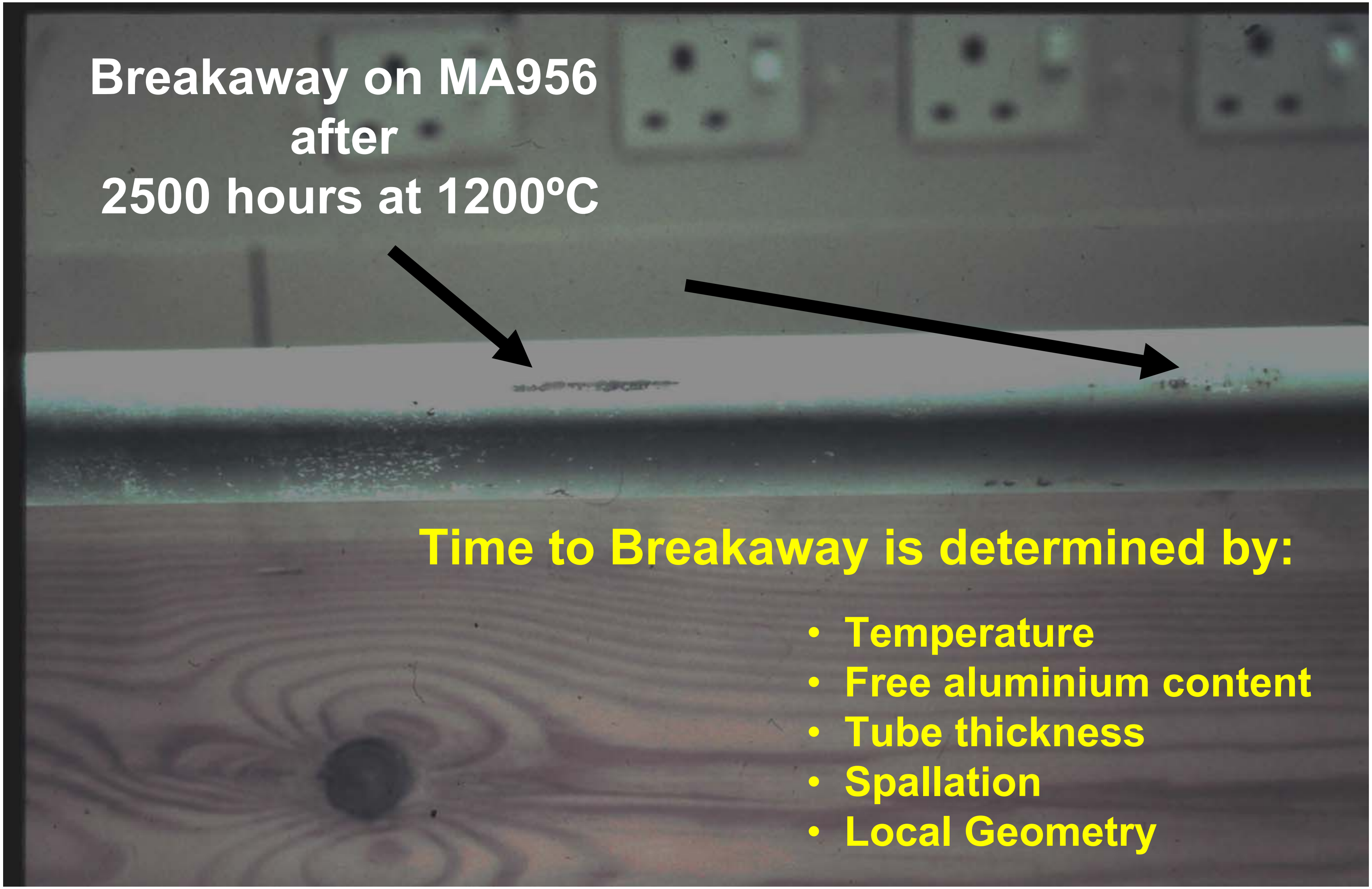
Bright spots are where local spalling has occurred

Sudden Onslaught of Breakaway Oxidation

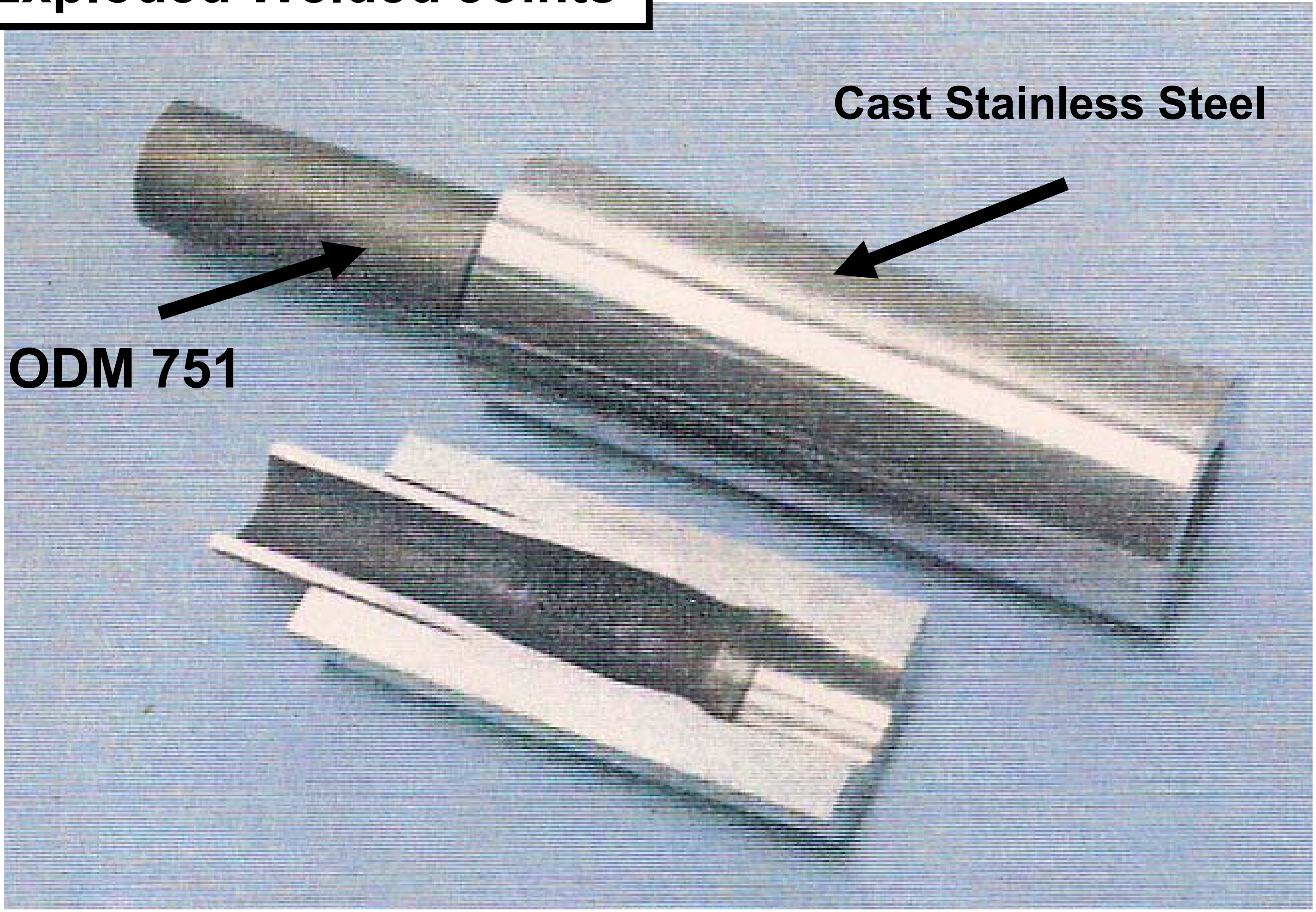


Another View of Breakaway

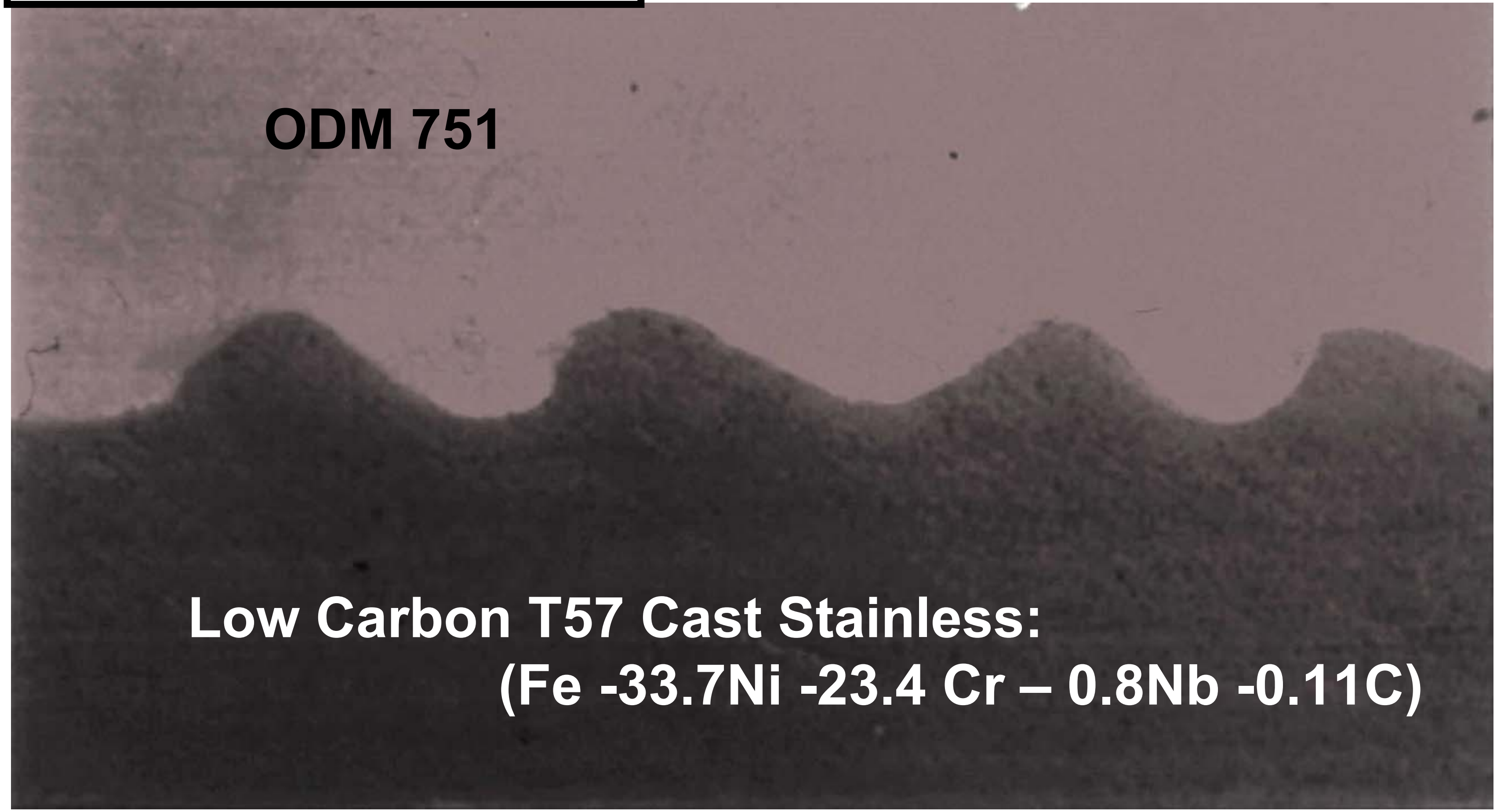



Breakaway on MA956
after
2500 hours at 1200ºC
Time to Breakaway is determined by:
• Temperature
• Free aluminium content
• Tube thickness
• Spallation
• Local Geometry

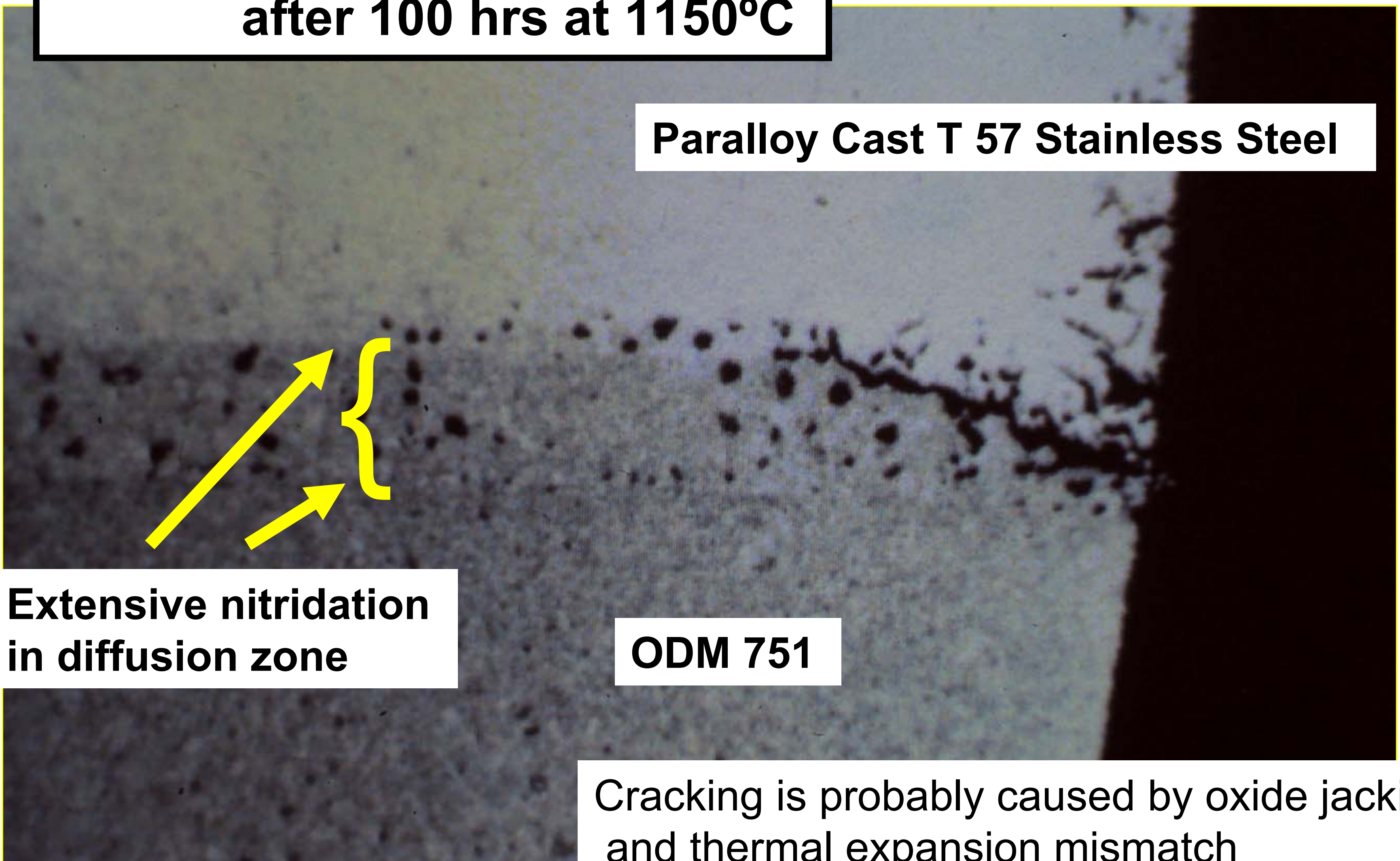
Exploded Welded Joints



Type of Joint Bonding

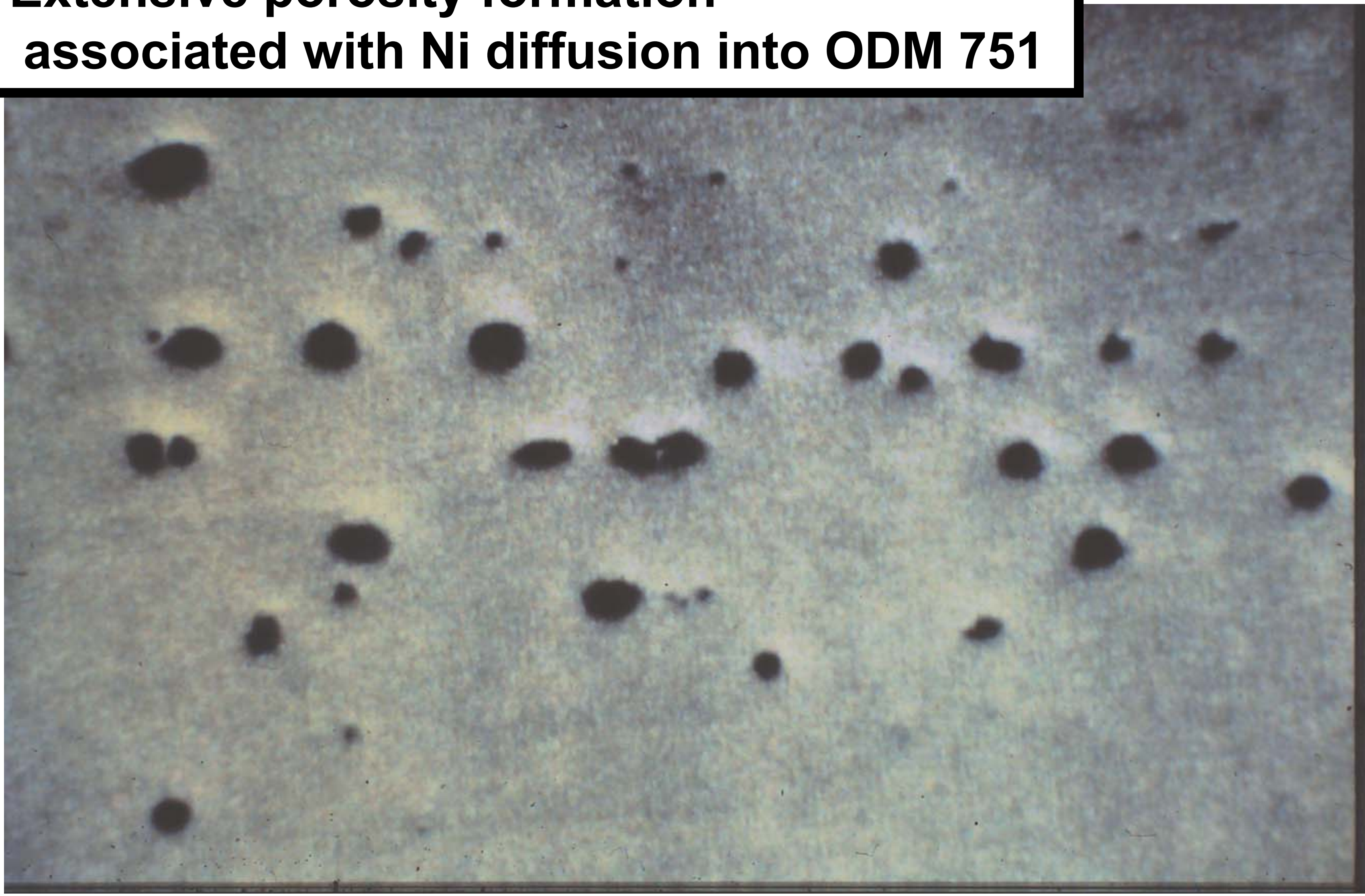


Formation of Diffusion Zone after 100 hrs at 1150ºC

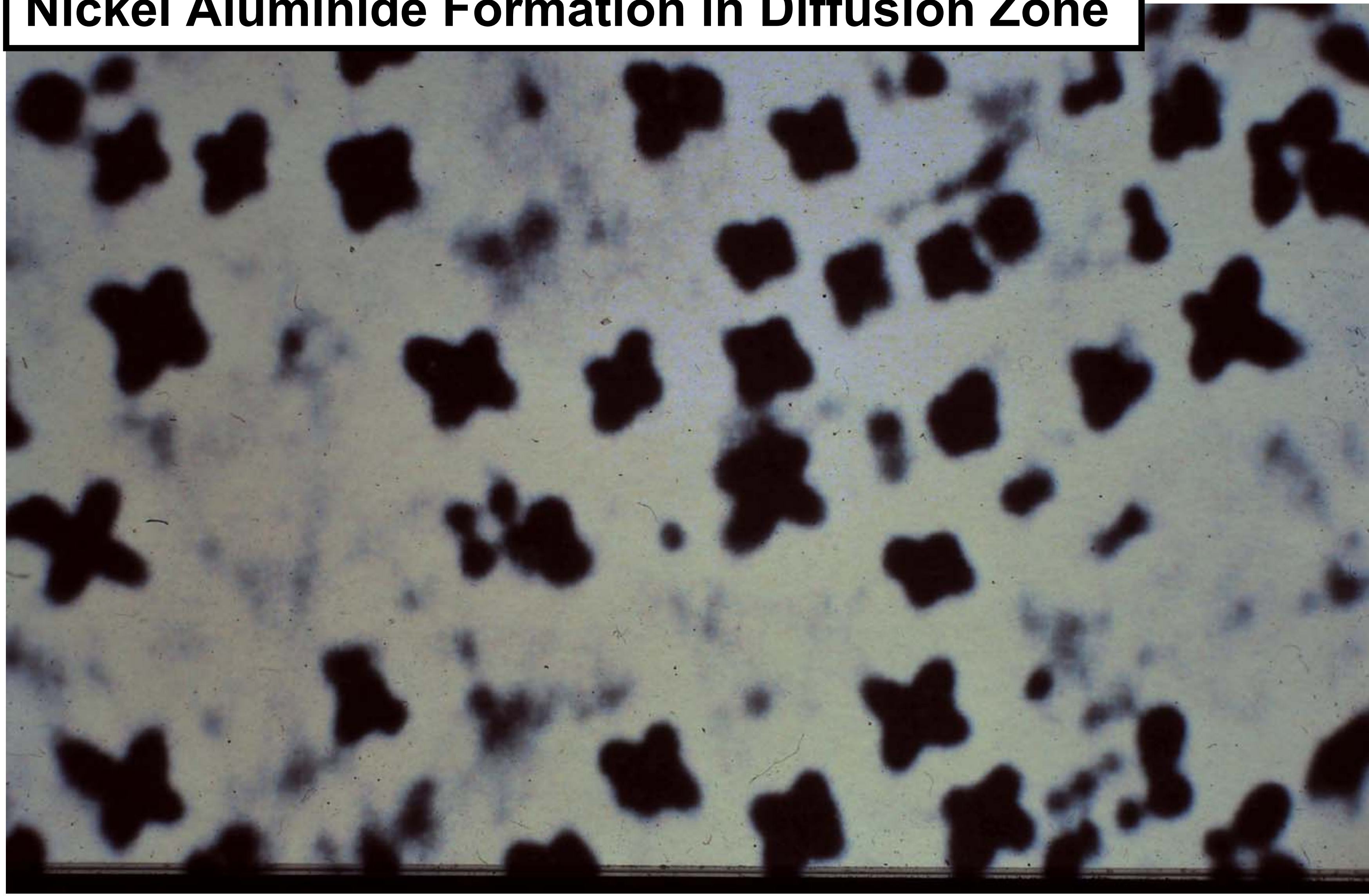


Cracking is probably caused by oxide jacking and thermal expansion mismatch

Extensive porosity formation associated with Ni diffusion into ODM 751



Nickel Aluminide Formation in Diffusion Zone



Three Manufacturing Routes: What Did We Learn?

H. Wiggins MA956

Fine grain size is completely useless
The transition weld problem

Dourmetal : ODM 331 and 751

Coarse onion skin grains needed for tubing
Stress sensitivity is high
Breakaway corrosion

Plansee 2000

Uniform working process to ensure uniform recrystallisaton
Oxidation and nitridation and porosity formation

ODS Alumina Formers Development Targets and Commercial Prospects

"Clean" Environments Only

Welding, Joining and Safety Factors

Plus 1100ºC

Tubing a Priority

- Reduce Directionality
- Reduce Spalling
- Lengthen Time to Breakaway

"Topping" and "CCS"
Power Generation
Cycles

Below 1050º

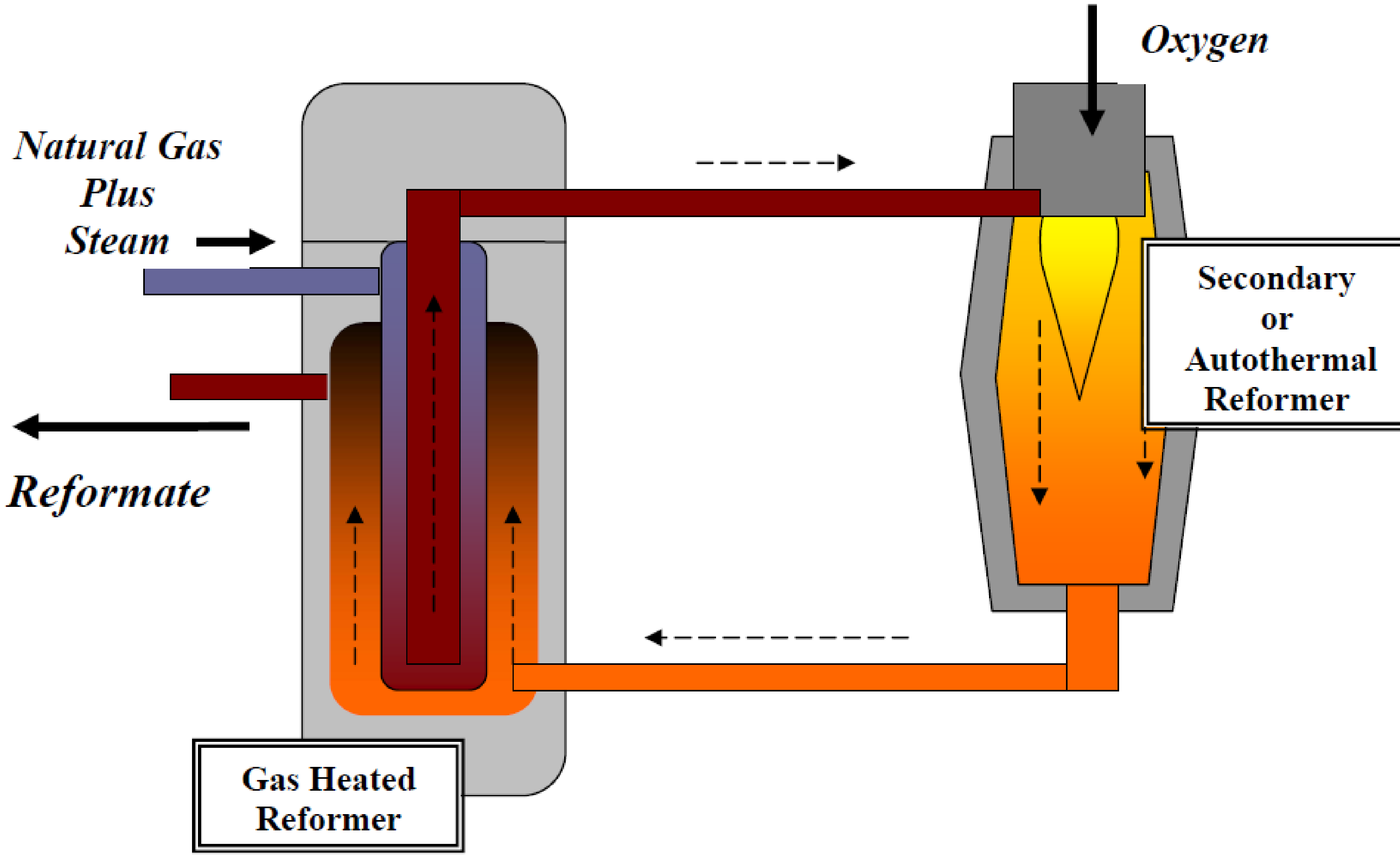
Pipe, Tubing, Sheet

- Reduce Directionality
- Improve Strength

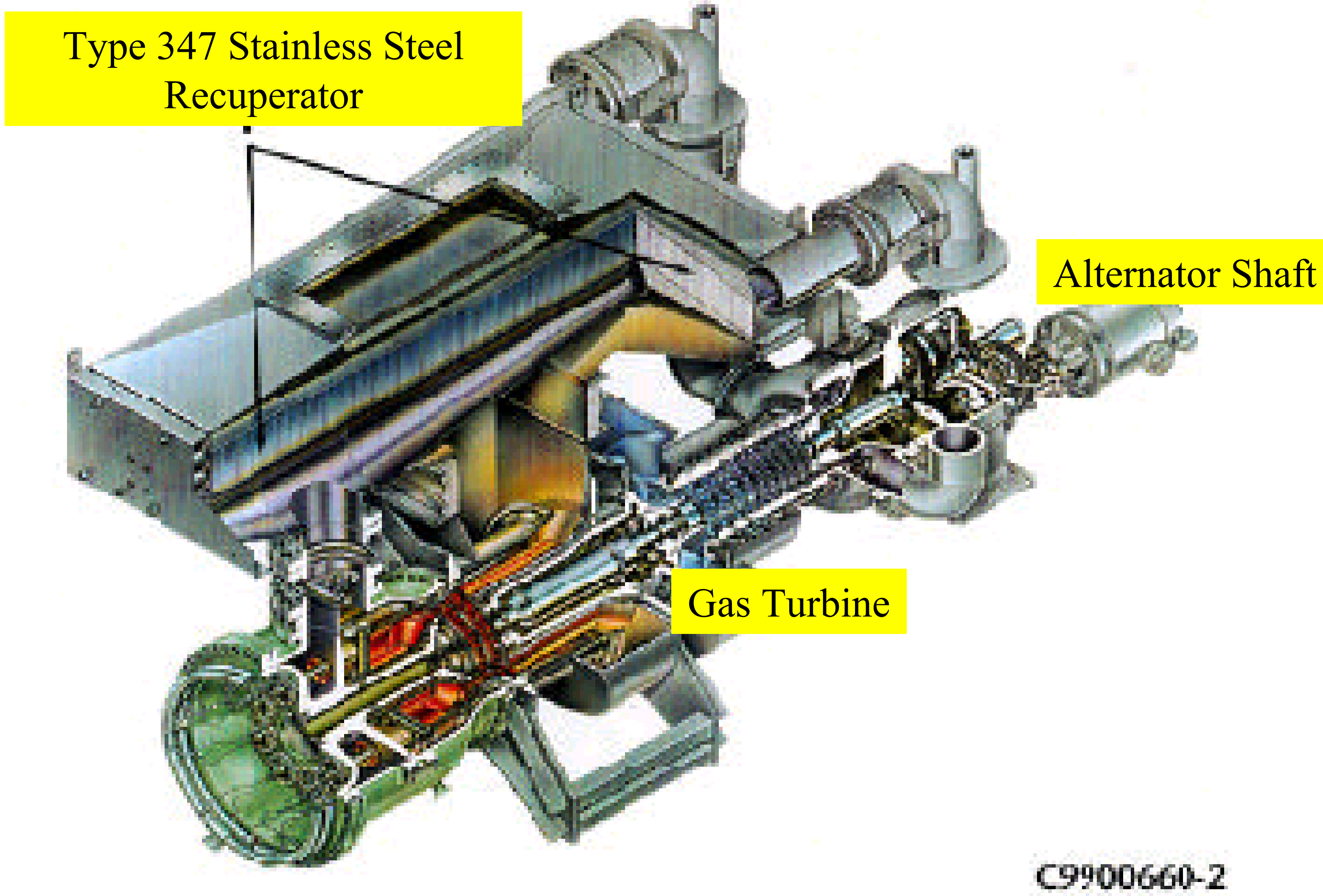
Gas Heated Reformer
Recuperative Gas Turbines
Radial Microturbines
Exhaust Valves

COSTS AND COST EFFECTIVENESS

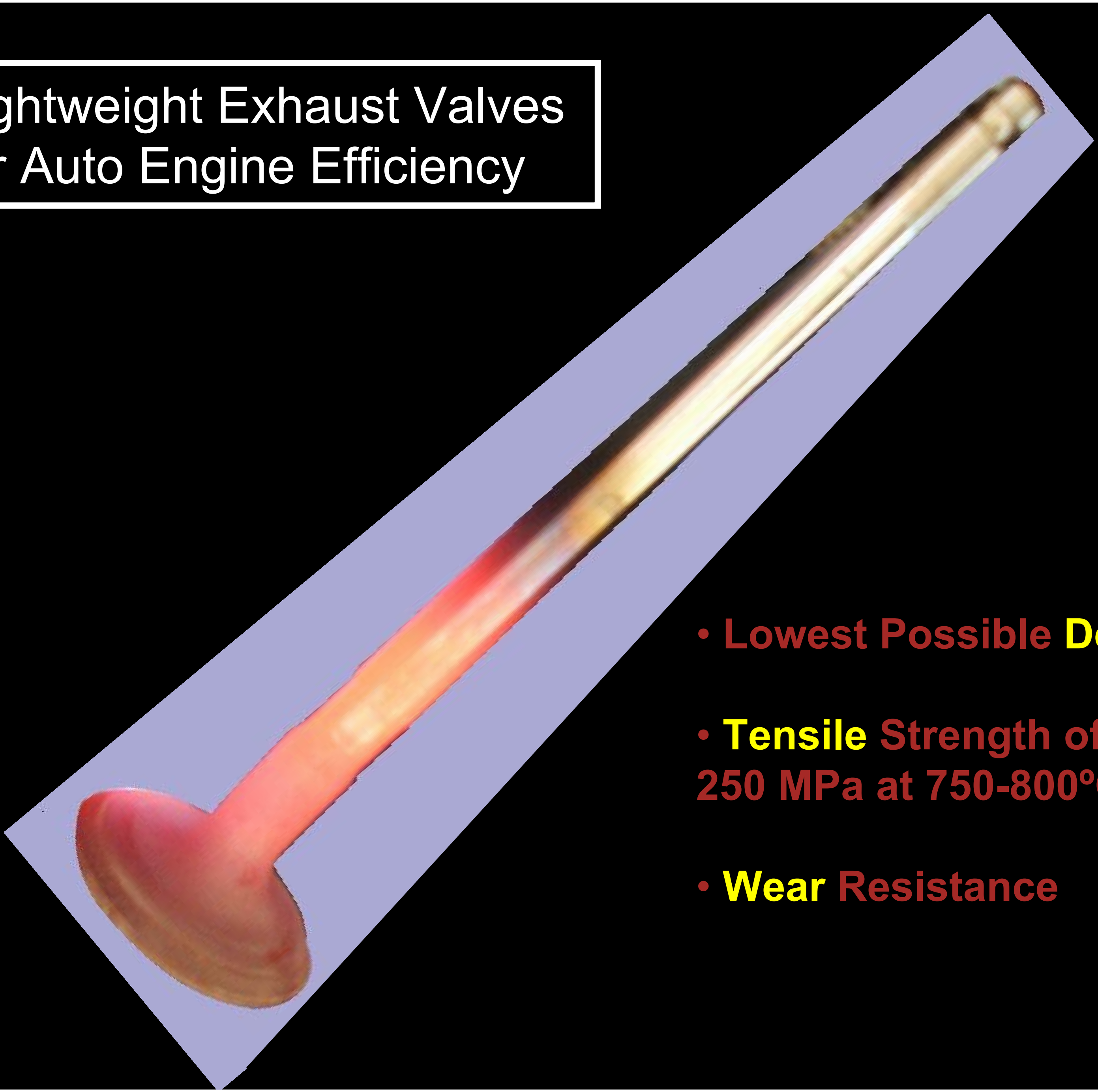
Gas Heated Reformer for Hydrogen Production and Natural Gas CCS



Solar Mercury 50 Recuperative Gas Turbine



Lightweight Exhaust Valves for Auto Engine Efficiency



- Lowest Possible **Density** .
- **Tensile** Strength of 250 MPa at 750-800ºC
- **Wear** Resistance

Closed Cycle Developments?

Improvements in CCGTs undermine prospects for simple closed cycle

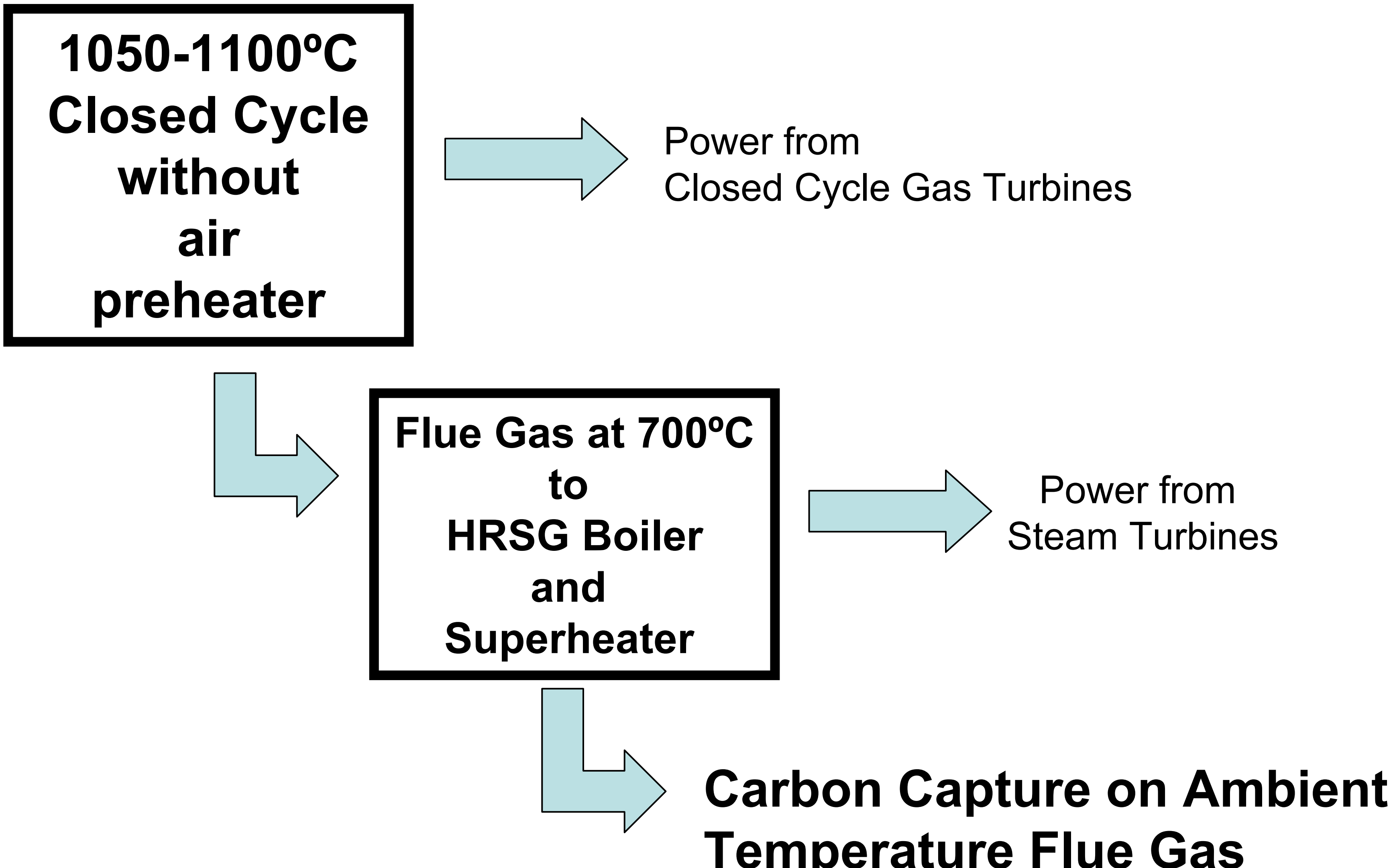
But CO_2 capture is a problem for CCGTs

High excess air 200-300% results in dilution of CO_2

Excess air in closed cycle heater is 20%

But probably best to use closed cycle as part of an advanced steam cycle

CCS Closed Cycle Concept



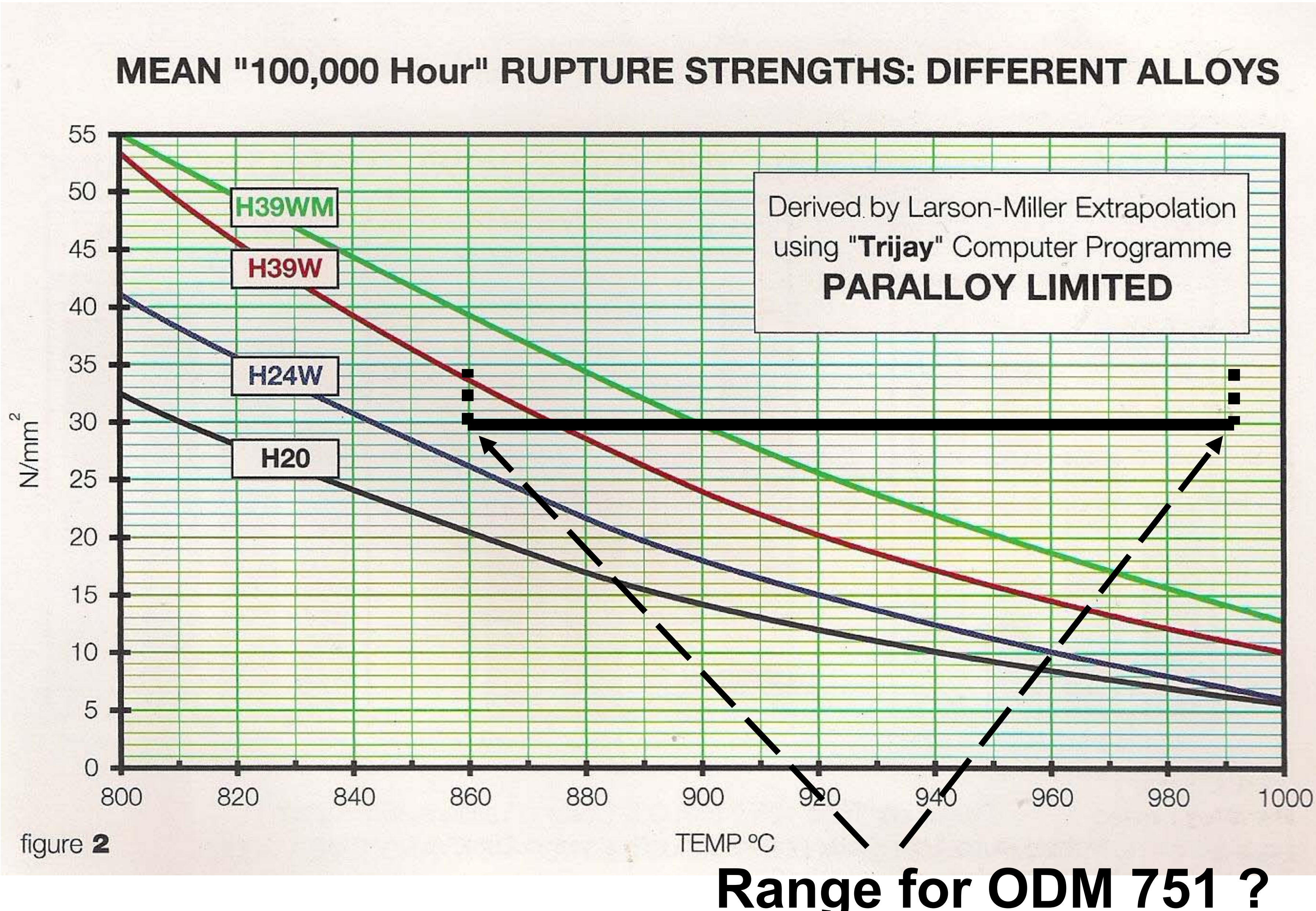
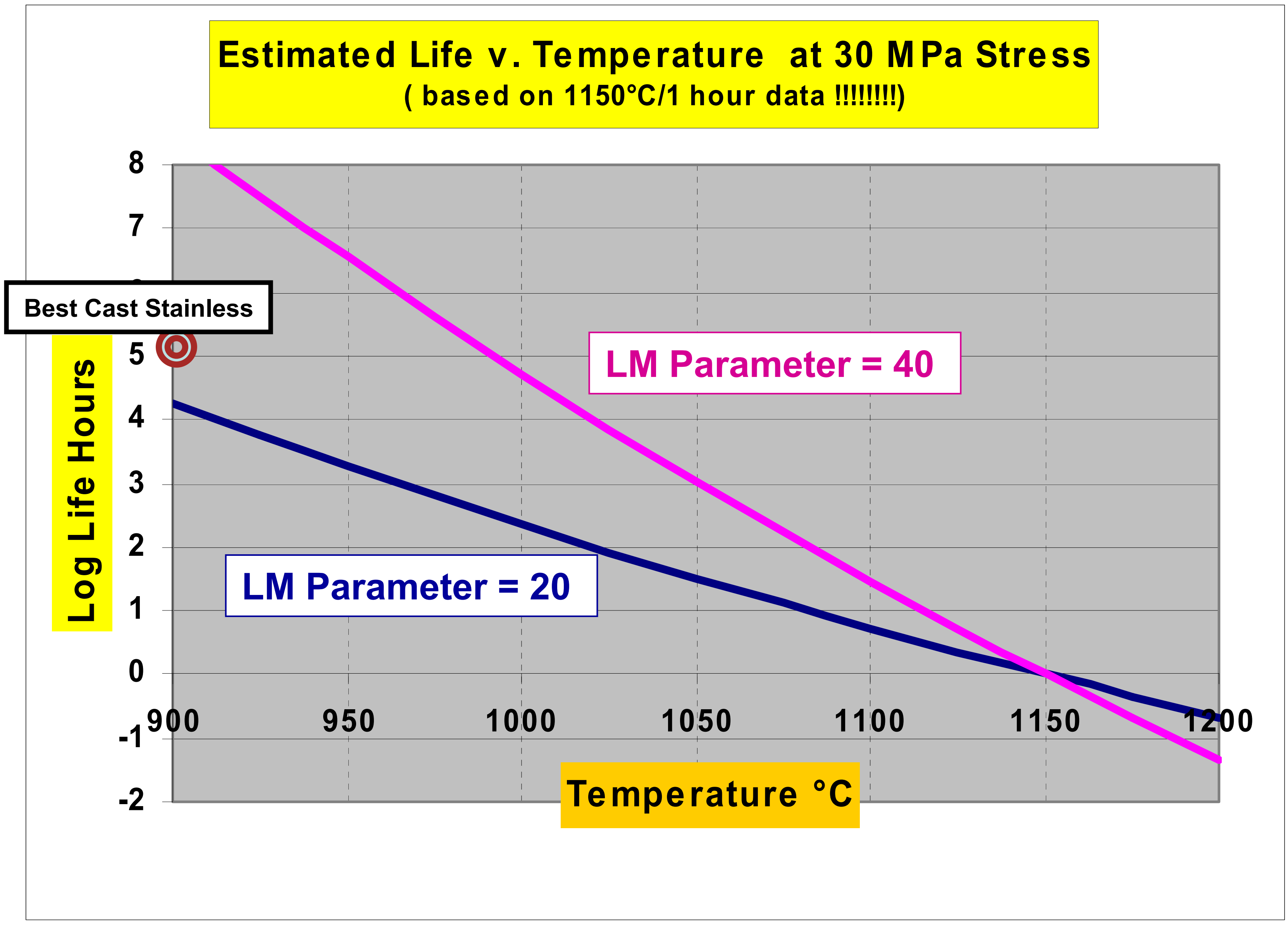

MEAN "100,000 Hour" RUPTURE STRENGTHS: DIFFERENT ALLOYS
Derived by Larson-Miller Extrapolation
using "Trijay" Computer Programme
PARALLOY LIMITED
H39WM
H39W
H24W
H20
N/mm²
TEMP ºC
55
50
45
40
35
30
25
20
15
10
5
0
800
820
840
860
880
900
920
940
960
980
1000
Range for ODM 751 ?

figure 2



Estimated Life v. Temperature at 30 MPa Stress
(based on 1150°C/1 hour data !!!!!!!!)
Best Cast Stainless
LM Parameter = 40
LM Parameter = 20
Log Life Hours
8
7
5
4
3
2
1
0
-1
-2
900
950
1000
1050
1100
1150
1200
Temperature °C

Conclusions

By building a heat exchanger we took ODS alloys right to the borderline

In so doing, we put "numbers" to the academic issues of:

- The effect of directionality on strength
- Oxidation rates and breakaway
- Porosity

Highlighted the need for long term testing of joining techniques

What Now? (As Barack Obama is saying)

Better and less costly materials, more data, better joining methods

- Better ductility, at room temperature, and in creep
- Effect of bending and cold working on properties
- **Safety factors of directional materials with a high stress sensitivity**

Thank You

Especially to :

Bimal Kad

Peter Torterelli