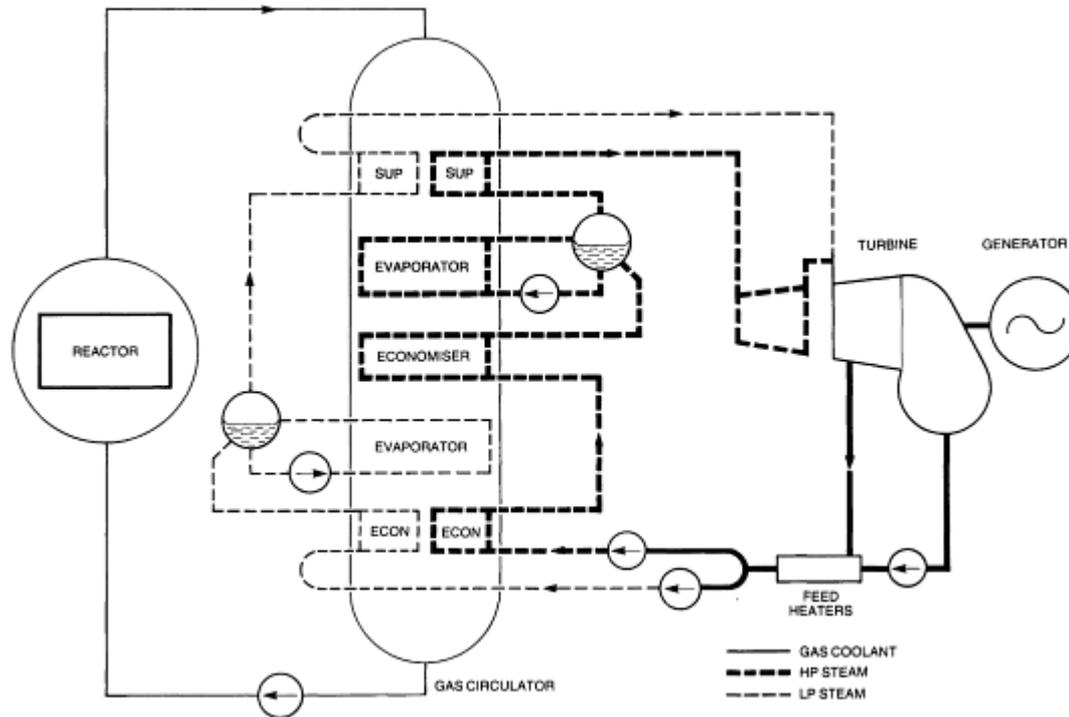


# History of the Wylfa Boilers

An Exercise in Problem Solving

- Four decades of operation:
  - Three major problems
  - Approximately one problem in each of the first three decades
  - Each problem potentially life limiting
  - Each problem solved by the skill and determination of lots of people
- In many ways a metaphor for the whole Magnox programme
- Also a personal journey of a career periodically intersecting the story

- Before Wylfa all the Magnox Reactors had dual pressure steam cycles:

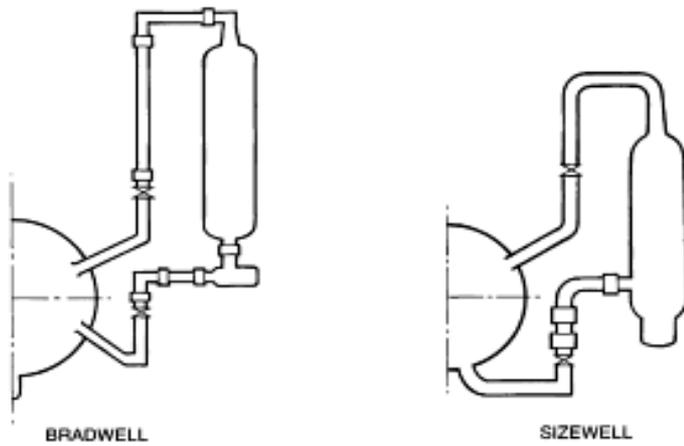
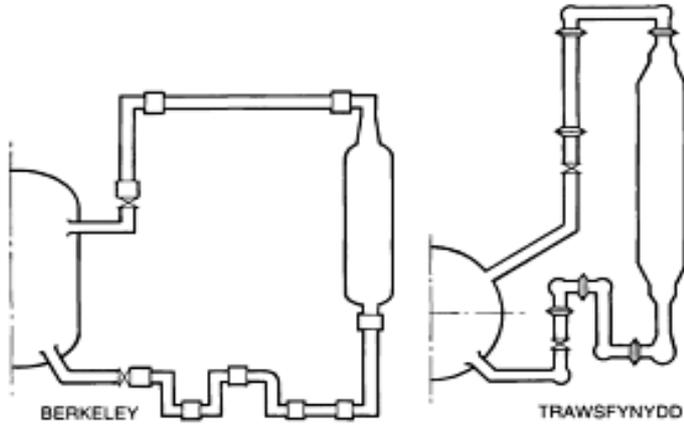


- Effective use of the steam through use of high pressure and low pressure steam systems
- Steam drums for separating steam from water and also for chemical control
- Requires many penetrations through the boilers casings

- Most elemental such design was Calder Hall with four such boilers per reactor:



- Others followed all with six boilers per reactor:

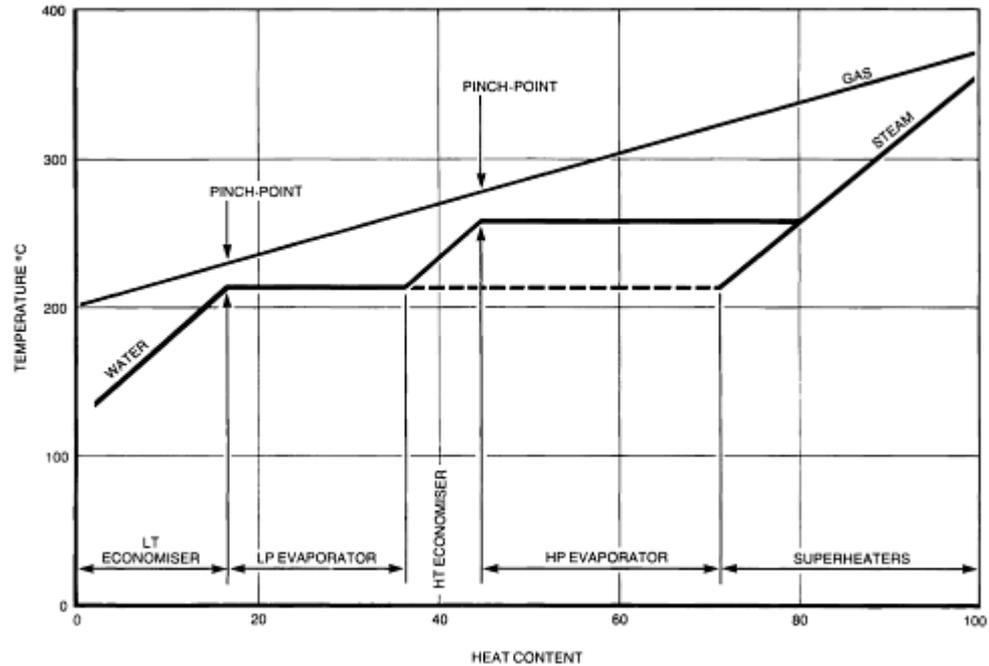


- Single and dual steam cycles:

Dual cycle



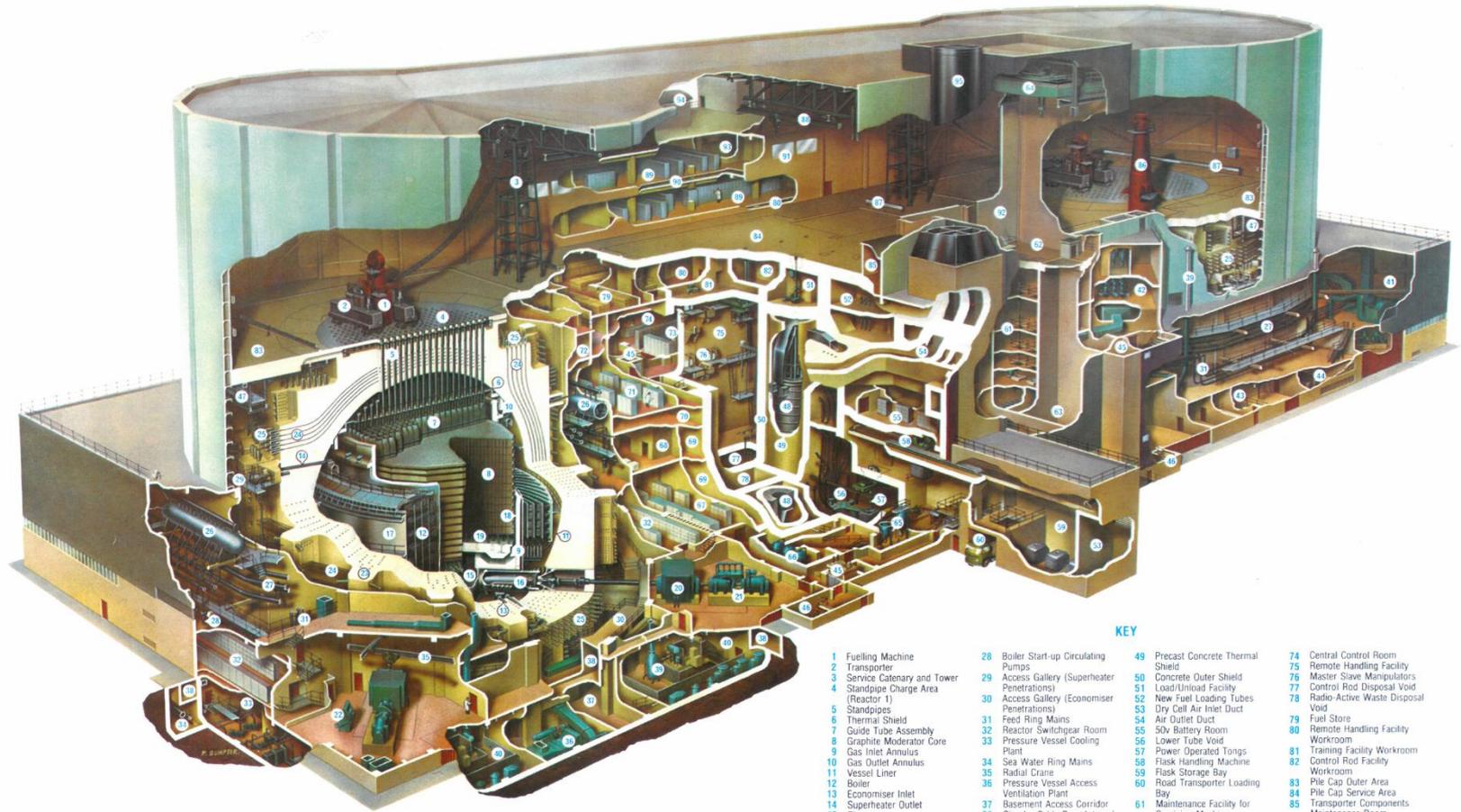
Single cycle



t diagram

- Cycle efficiency is approximately proportional to the area under the water/steam line

- To build a pre-stressed concrete pressure vessel with external boilers would obviate much of the benefit of the design
- The decision to build Wylfa with a spherical pre-stressed concrete pressure vessel led to a design with:
  - an integral boiler
  - a boiler that fits into the “wasted” space between the cylinder of the core and the sphere of the pressure vessel
  - a single cycle boiler (also called “once through boiler”)
- Thus minimum types of boiler penetrations:
  - Water in
  - Steam out
- The reactor can’t start with the boilers in “once through” mode so there is a start-up steam drum
- Because the boiler is inside the pressure vessel there are no boiler pods. This enables an evenly distributed boiler surface

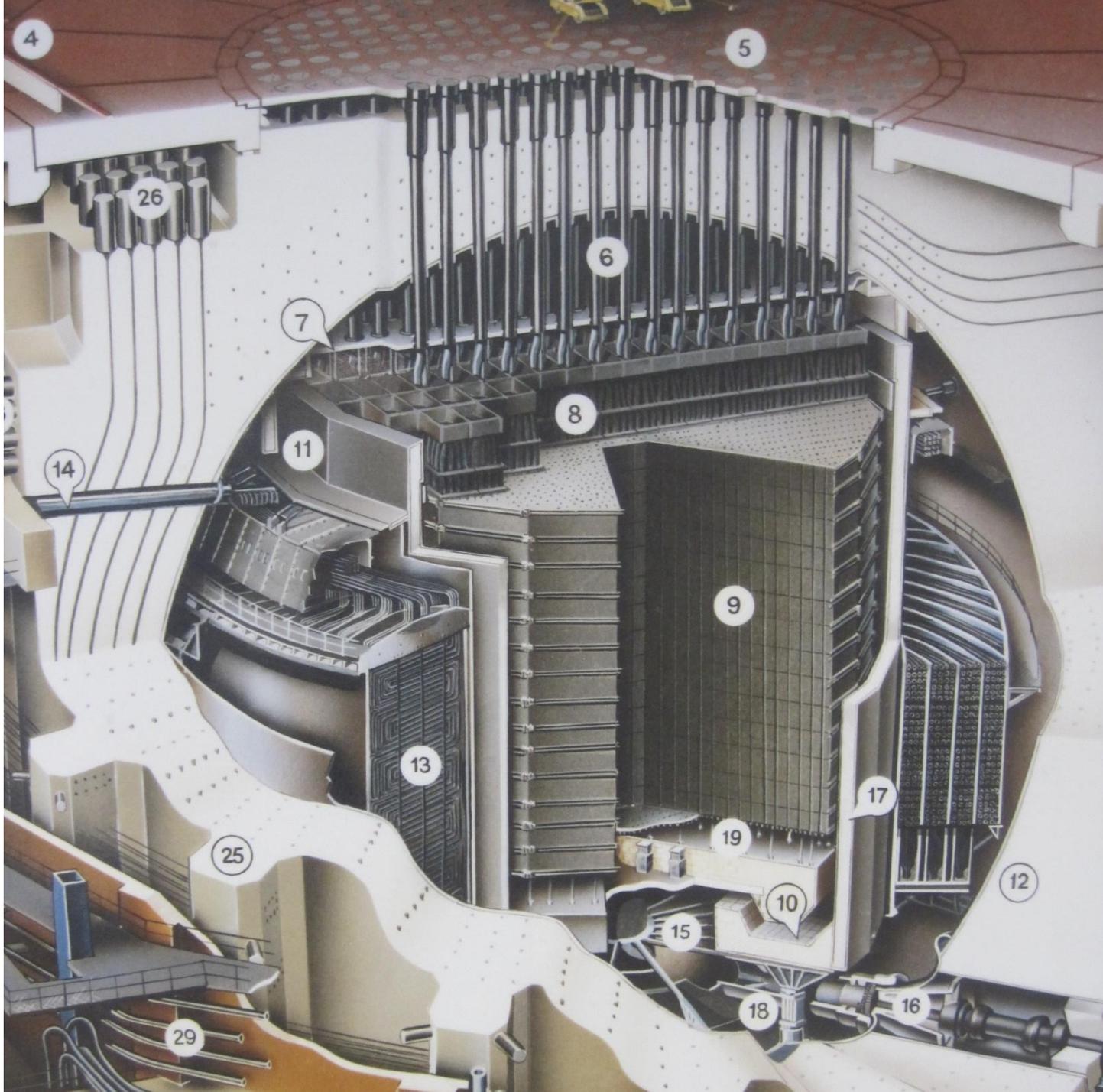


# WYLFA POWER STATION

## KEY

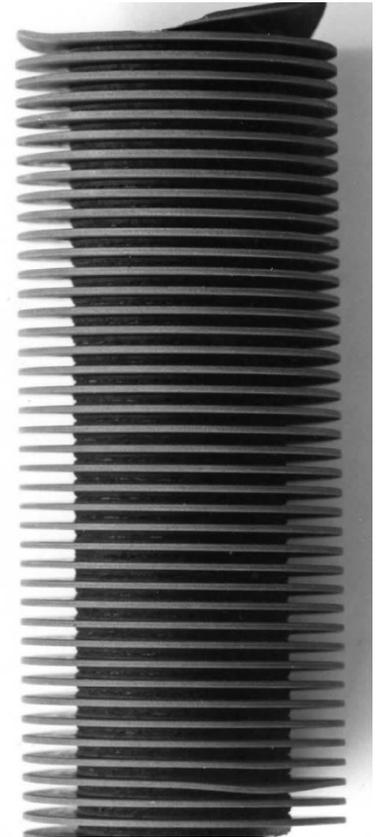
- |    |                                   |    |   |    |  |    |   |
|----|-----------------------------------|----|---|----|--|----|---|
| 1  | Fuelling Machine                  | 28 | Boiler Start-up Circulating Pumps         | 49 | Precast Concrete Thermal Shield            | 74 | Central Control Room                    |
| 2  | Transporter                       | 29 | Access Gallery (Superheater Penetrations) | 50 | Concrete Outer Shield                      | 75 | Remote Handling Facility                |
| 3  | Service Catenary and Tower        | 30 | Access Gallery (Economiser Penetrations)  | 51 | Load/Unload Facility                       | 76 | Master Slave Manipulators               |
| 4  | Standpipe Charge Area (Reactor 1) | 31 | Feed Ring Mains                           | 52 | New Fuel Loading Tubes                     | 77 | Control Rod Disposal Void               |
| 5  | Standpipes                        | 32 | Reactor Switchgear Room                   | 53 | Dry Cell Air Inlet Duct                    | 78 | Radio-Active Waste Disposal Void        |
| 6  | Thermal Shield                    | 33 | Pressure Vessel Cooling Plant             | 54 | Air Outlet Duct                            | 79 | Fuel Store                              |
| 7  | Guide Tube Assembly               | 34 | Sea Water Ring Mains                      | 55 | 50V Battery Room                           | 80 | Remote Handling Facility Workroom       |
| 8  | Graphite Moderator Core           | 35 | Radial Crane                              | 56 | Lower Tube Void                            | 81 | Training Facility Workroom              |
| 9  | Gas Inlet Annulus                 | 36 | Pressure Vessel Access Ventilation Plant  | 57 | Power Operated Tongs                       | 82 | Control Rod Facility Workroom           |
| 10 | Gas Outlet Annulus                | 37 | Basement Access Corridor Plenum           | 58 | Flask Handling Machine                     | 83 | Control Rod Facility Workroom           |
| 11 | Vessel Liner                      | 38 | Circular Cable Race Internal and External | 59 | Flask Storage Bay                          | 84 | Pile Cap Outer Area                     |
| 12 | Boiler                            | 39 | Blowdown Tank and Stack                   | 60 | Road Transporter Loading Bay               | 85 | Pile Cap Service Area                   |
| 13 | Economiser Inlet                  | 40 | Circulator Auxiliary Plant Room           | 61 | Maintenance Facility for Servicing Machine | 86 | Transporter Components Maintenance Room |
| 14 | Superheater Outlet                | 41 | Ventilation Plant Area                    | 62 | Pile Cap Maintenance Shop                  | 87 | Servicing Machine                       |
| 15 | Plenum                            | 42 | Gas Relief Valve and Filter Chamber       | 63 | Decontamination Shop and Loading Bay       | 88 | Transporter Navigation Mirrors          |
| 16 | Gas Circulator                    | 43 | Basement Plant Access Facility            | 64 | 60 Ton Maintenance Crane                   | 89 | Control Rod Equipment Rooms             |
| 17 | Boiler Outer Casing               | 44 | CO2 Fire Extinguishing Equipment          | 65 | Sludge Settling Tanks                      | 90 | Cable Racks                             |
| 18 | Inner Shield                      | 45 | Lifts                                     | 66 | Sand Pressure Filters                      | 91 | Pile Gap Viewing Gallery                |
| 19 | Core Support Structure            | 46 | Access Staircases                         | 67 | Switchgear Rooms                           | 92 | Maintenance Shop Door                   |
| 20 | Gas Circulator Motor              | 47 | Cable Race and Walkway                    | 68 | Non-Active Laundry                         | 93 | Water Tank Room                         |
| 21 | Gas Circulator Auxiliary Motors   | 48 | Dry Storage Cell                          | 69 | Corridors                                  | 94 | Demineralised Water Tank Room           |
| 22 | Auxiliary Motor Liquid Controller |    |   | 70 | Cable Race                                 | 95 | Air Outlet Stack                        |
| 23 | Vessel Ribs                       |    |   | 71 | Ancillary Electrical Equipment             |    |   |
| 24 | Prestraining Tendons              |    |   | 72 | Burst Cartridge Detection Equipment Room   |    |   |
| 25 | Prestraining Cable Anchorages     |    |   | 73 | Fuelling Machinery Control Room            |    |   |

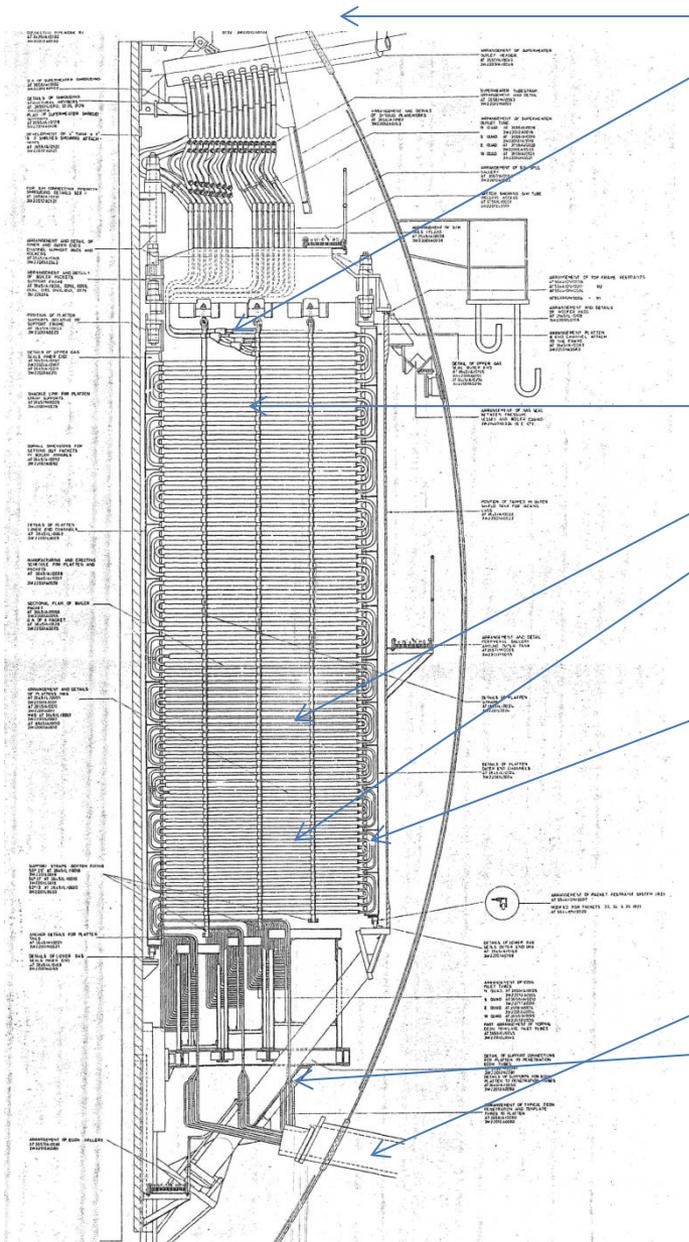
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- Top of superheater boiler tubes during construction to illustrate the density of finned tubing





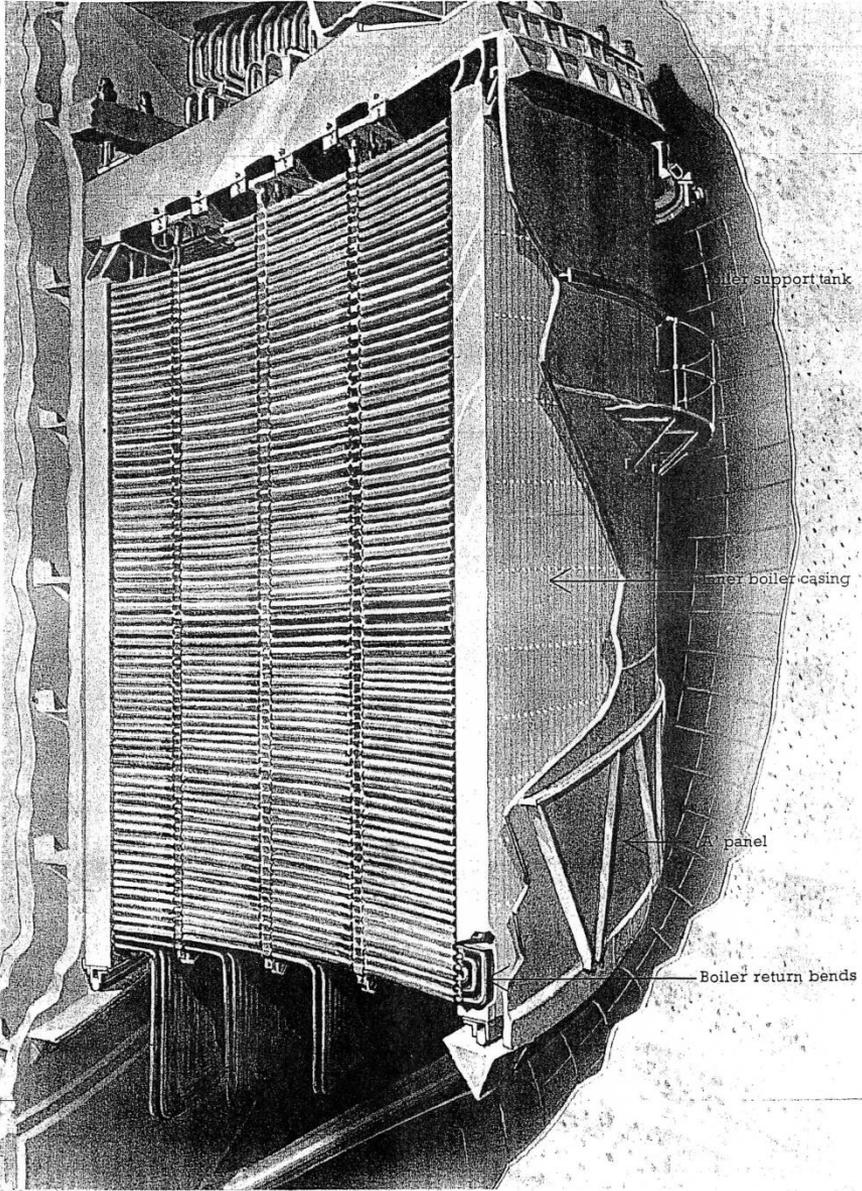
- The three tubes are joined at the top of the platen through two bifurcations before connecting to a superheater header

- Each tube is 240 ft long fabricated from mild steel finned tube in three sections:
  - 1.5" OD superheater (30mm ID)
  - 1.25" OD evaporator (24mm ID)
  - 1" OD economiser (18mm ID)

- Unfinned return bends are baffled in end-channel sections so no heat input at bends

- Each tube fed separately at the bottom from an economiser waterbox via 18' of 0.3" NB restrictor tube

- A platen consists of three boiler tubes interleaved in three serpentines from bottom to top



- A platen of the three continuous interleaved tubes is involute in plan

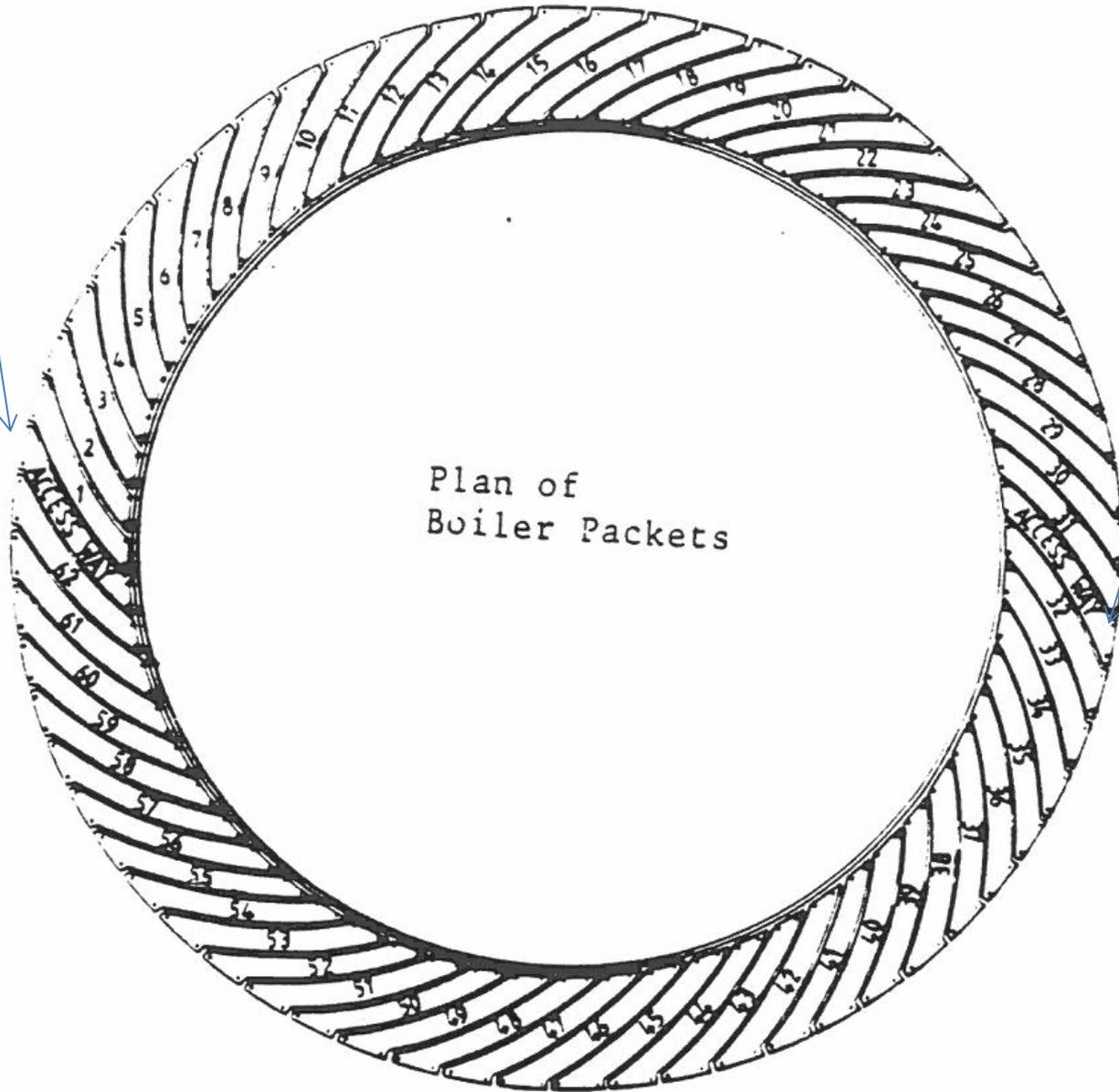
- 16 platens are secured together to form a packet

- 62 packets are suspended from a support frame above the boiler tank

- 32 feed-water penetrations

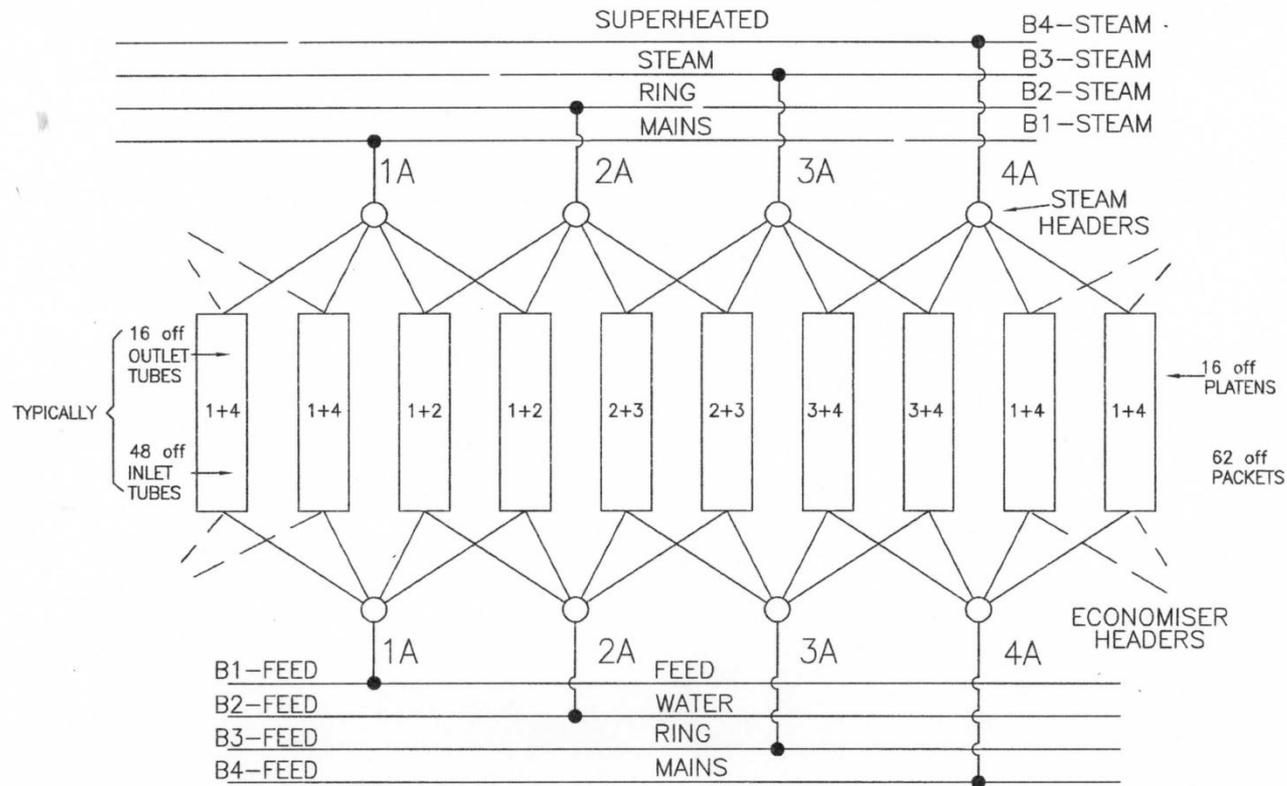
- 32 superheater outlet penetrations

- 2 “missing” packets provide man-access ways to the top of the boiler and reactor



- Note that the packet boundaries are virtual not actual, except at access ways

- Nominally Wylfa has 4 “Boilers”

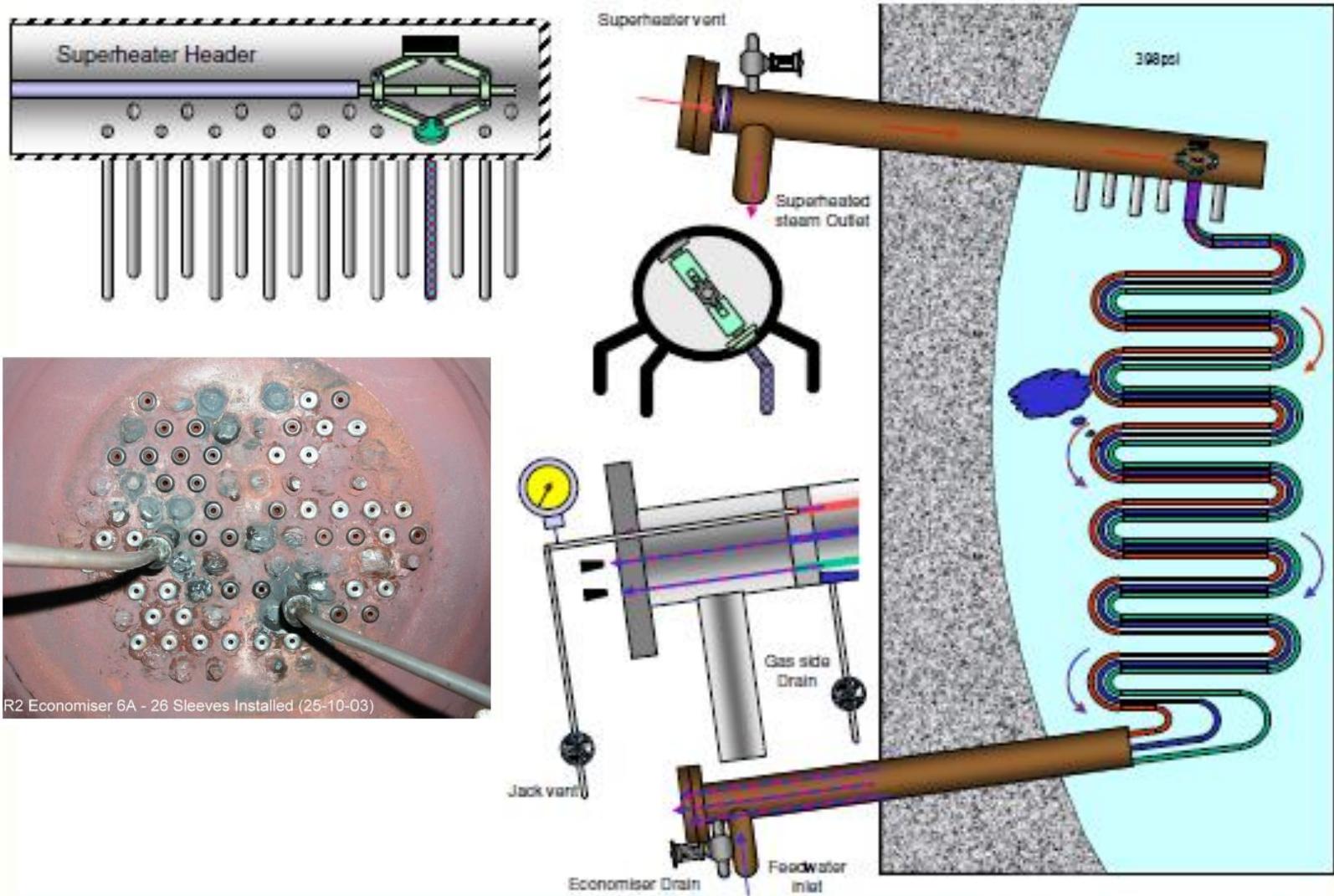


BOILERS  
DISTRIBUTION OF BOILER SECTIONS  
AND PACKETS

- Alternate platens are fed as odd and even boilers, so if boilers 1 and 3 are isolated then every alternate tube is fed by either boiler 2 or boiler 4. Thus running at half power into one turbine alternator still provides circumferentially uniform heat removal.

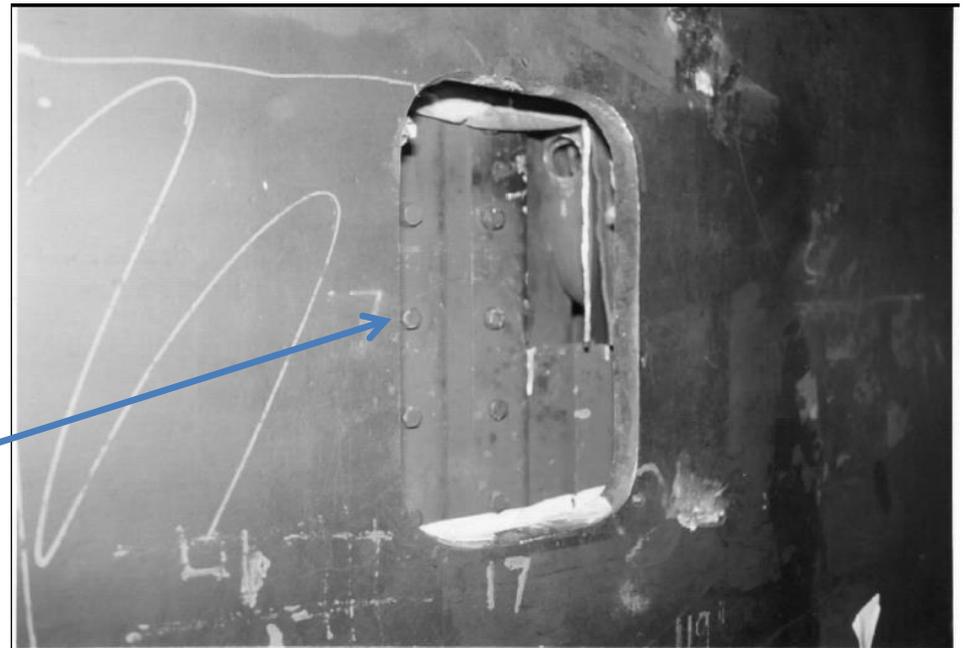
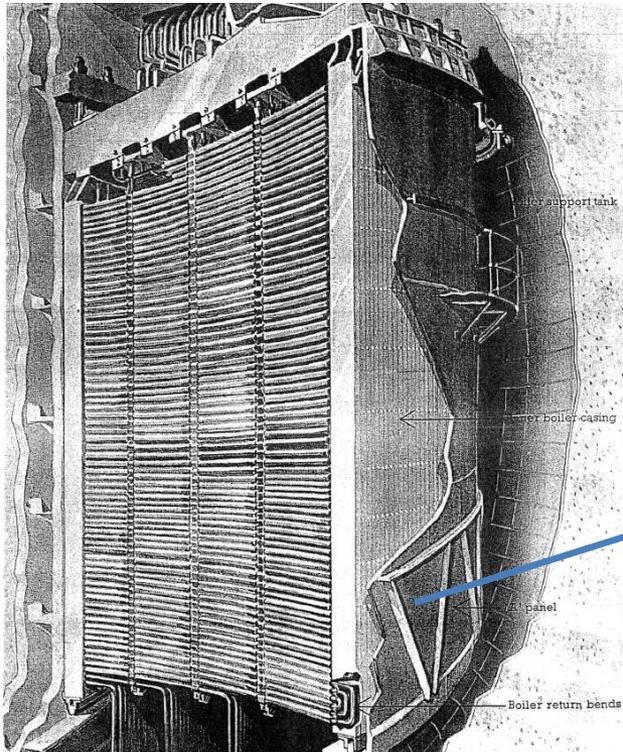
- Steam pressure is 550psig, thus higher than the 385psig CO<sub>2</sub> pressure.
- First sign of a leak is an increase in reactor gas moisture
- A boiler leak will therefore:
  - result in increased moisture in the reactor gas (normally <2ppm) potentially increasing steel oxidation and magnox fuel can corrosion
  - threaten increased reactor pressure for larger (guillotine) boiler tube failures
- Thus boiler leaks aren't tolerable for any length of time
- ~10% over-surfaced to allow for leaks but when T<sub>2</sub> reduced to 360 °C the excess was lost so each failed platen represents a loss of output
- Reactor 1 commenced operation in January 1971 and reactor 2 in June 1971
- In late 1972 boilers tube leaks began to impact reactor 2 but not reactor 1

- Finding and repairing leaks is very time consuming



- Leaks cause loss of generation during repair and permanent loss of boiler tube surface

- Reactor 2 leak incidence increased and by mid 1974 leaks were occurring every few days, mostly initially on platen 16 in a packet, with some later leaks on platen 1
- Reactor 2 was shut down for investigation
- Leak heights were found by manometric and /or acoustic means and an access hole was cut in the outer wall of the boiler tank to inspect a leak site



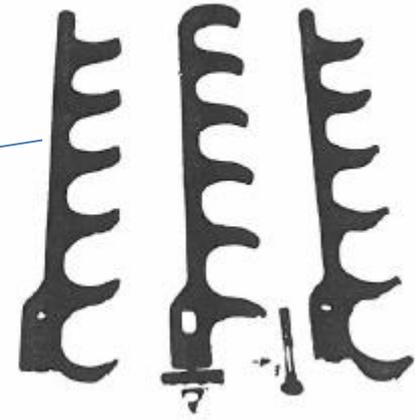
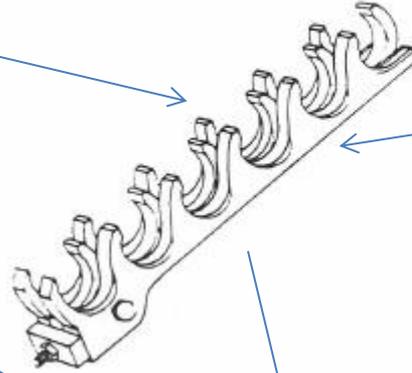
- Problem revealed to be due to fretting between the unfinned section of the boiler tube and the “seagull” clip



- Fibre-optic inspection showed that only end-of-packet tubes in the economiser were damaged where boiler packets had moved relative to each other and opened ~1" gaps
- Extensive instrumentation was fitted and gas circulator runs revealed vertical resonance of the tubes at the vortex shedding frequency of the gas travelling up the larger inter-packet gaps

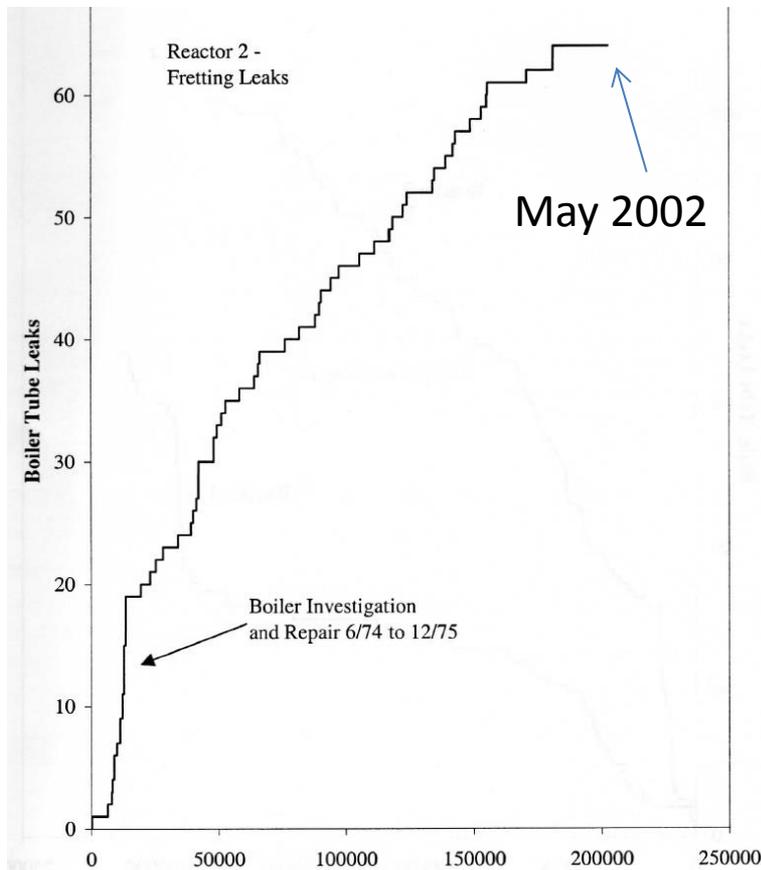
- Repairs were effected by Routley Clamps,

- By jacking back into position and then fitting restraints



- Physical work on the boilers inside the reactors is cramped, uncomfortable, hot, claustrophobic and arduous. The engineers, fitters, HP monitors and others who, outage after outage, have worked there deserve massive praise.

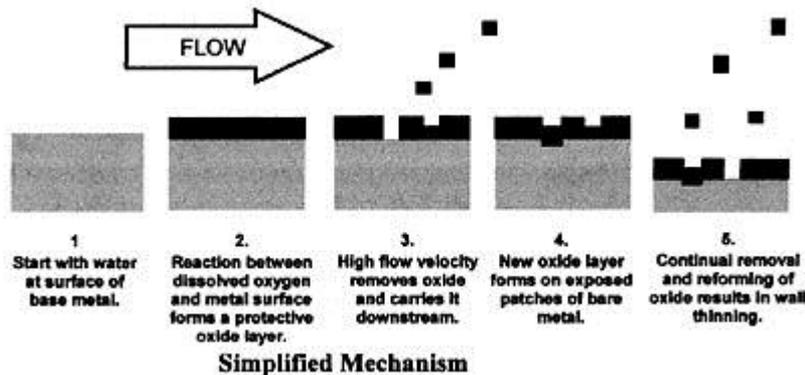
- Reactor 2 returned to power in January 1976, after an outage of 19 months
- After 70 days running and an internal inspection it received final clearance in the late summer of 1976.
- Failure rate much reduced, but occasional failures in platens 1, 16 and 2, 15



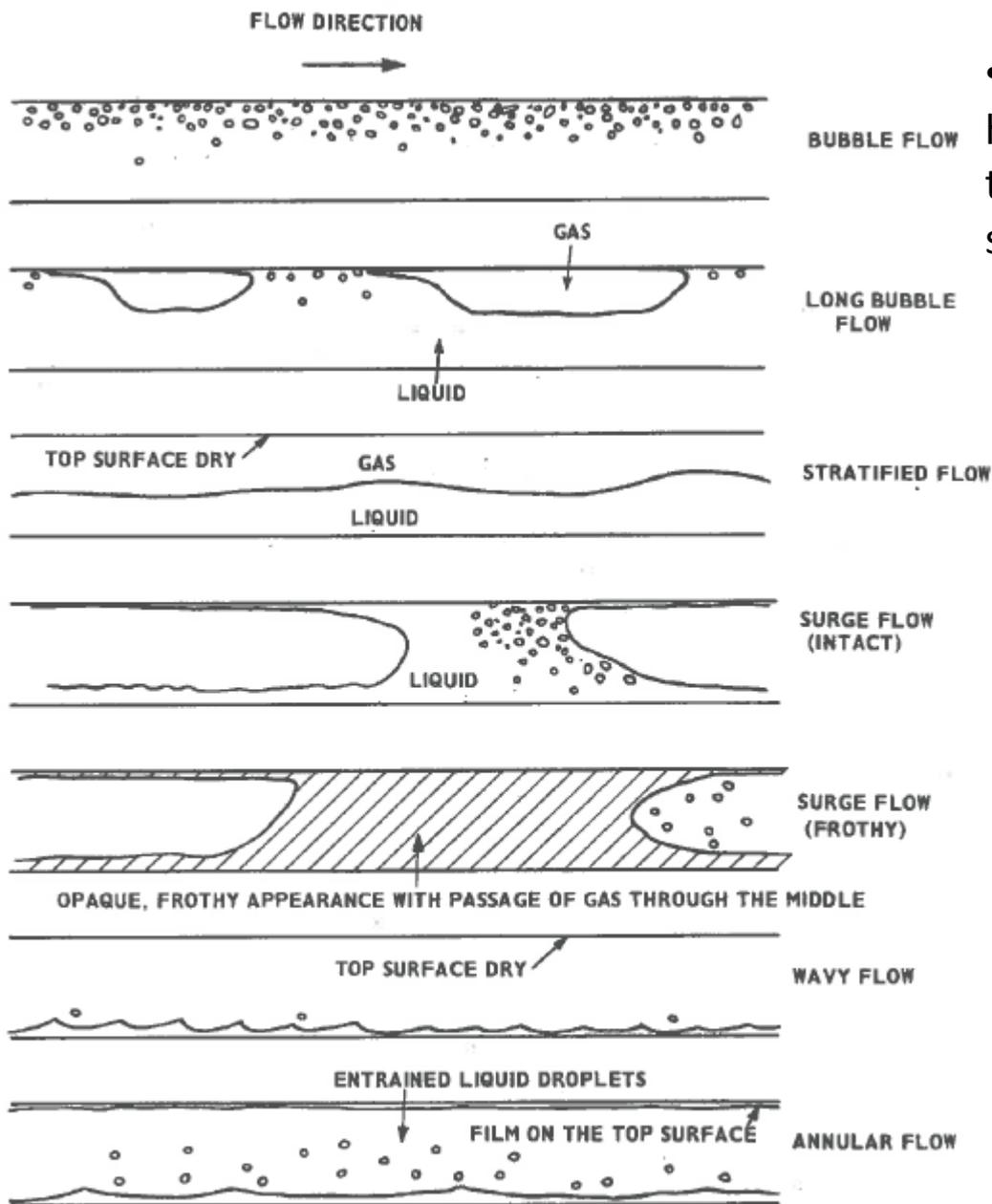
• No R1 fretting leaks!

• R2 fretting leaks were made manageable by many engineers and scientists at Wylfa and other CEBG scientific and engineering support and research facilities

- A different population of leaks started in Reactor 1 in 1975
- Initial investigations showed these were caused by two-phase erosion-corrosion in the 1" OD economiser tube bends on the platens nearest the access ways (packets 1,31,32,62)



- Tubes here ran hotter causing boiling to occur lower with the steam-water mixture increasing the flow resistance further driving the boiling point lower. Thus boiling was occurring in the small bore economiser at higher velocity rather than the larger bore evaporator at lower velocity
- Once an access way platen has been plugged the problem transfers to the next platen
- In Reactor 1 the first 10 platens in packet 31 have been lost

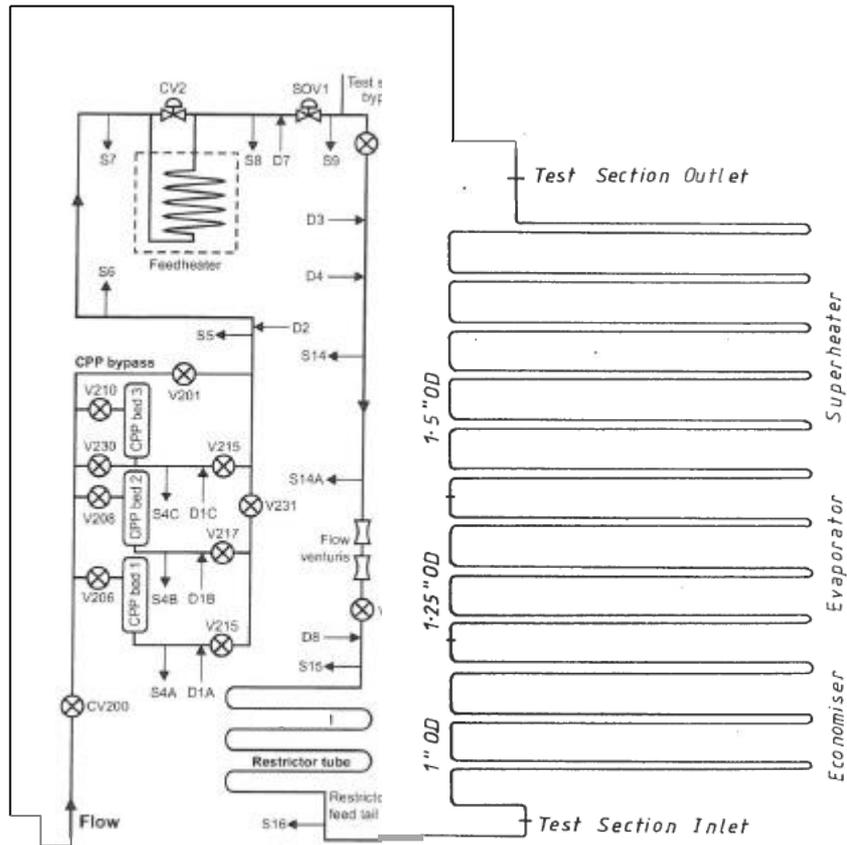


- Understanding exactly what happens at and around the transition from liquid water to steam is not trivial!

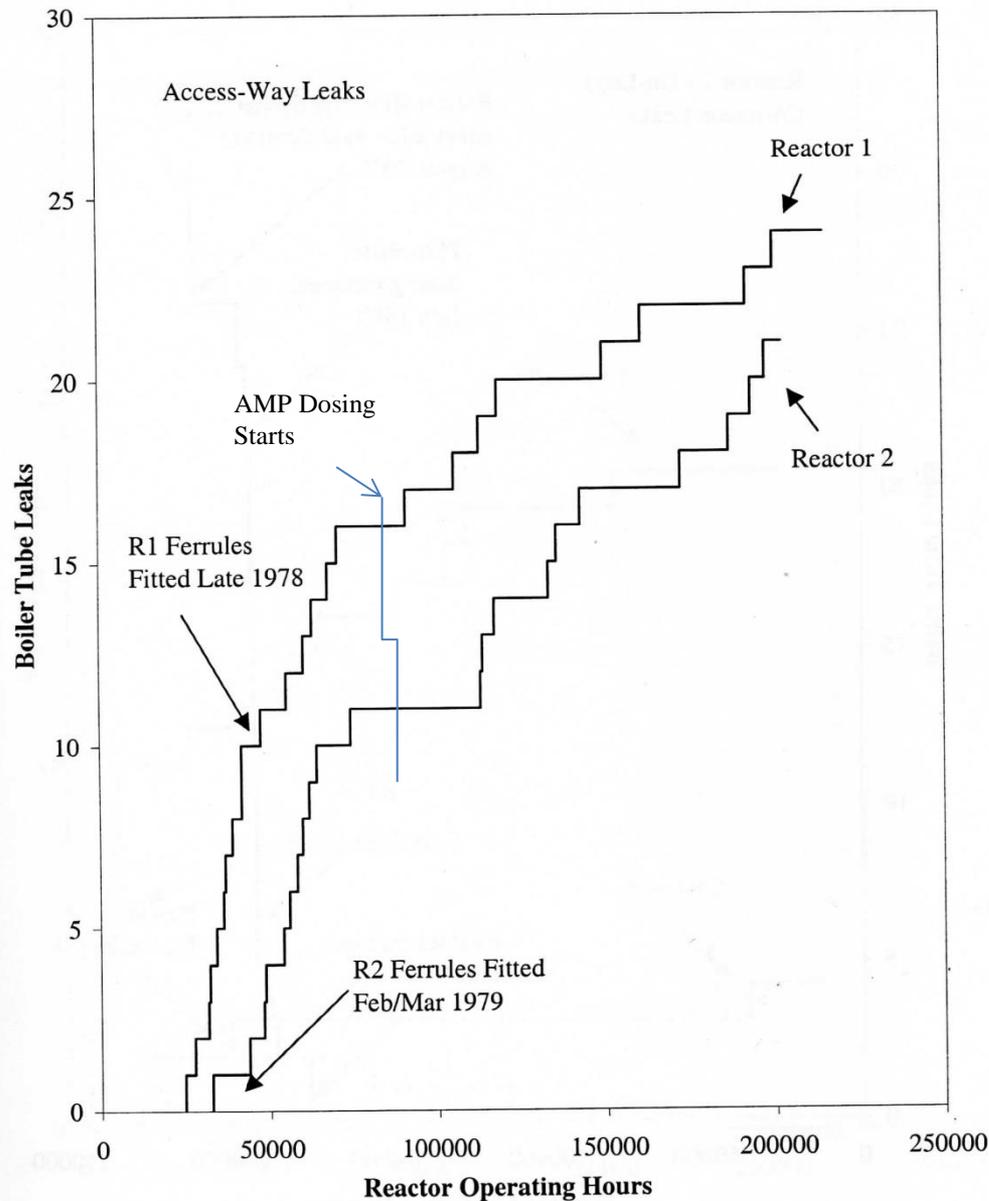
FROTHY SURGES MAY ALSO OCCUR IN ANNULAR FLOW, BUT THE FILM ON THE TOP SURFACE IS MAINTAINED, WHETHER THEY ARE PRESENT OR NOT, BY OTHER MECHANISMS (SEE CONEY, 1971)

- Two basic approaches were followed to counter the problem:
- Firstly the pressures in the penetrations feeding access way platens were increased to increase flows in these platens with the other platens fed from the penetration ferruled to bring their flows back to design
- Secondly the liquid phase pH was increased to reduce the two-phase erosion-corrosion in all platens
- Reactor 2 started to suffer from the problem in 1979, catching up after its fretting shutdown
- Failures slowed to just manageable numbers but considerable trial-and-error experimentation was required in such aspects as ferrule design and feed water pressure
- In 1979 the Central Electricity Generating Board commissioned a steaming test loop at its NW Region Scientific and Technical Services Department site at Wythenshawe, Manchester
- Here, boiler tubes from Wylfa, Heysham 1 AGR, Heysham 2 AGR and others could be run in almost exact reactor conditions.

- It celebrated 30 years of operation in 2010
- Full length of a chosen boiler tube could be exposed to the thermohydraulic and chemical conditions experienced in the reactor

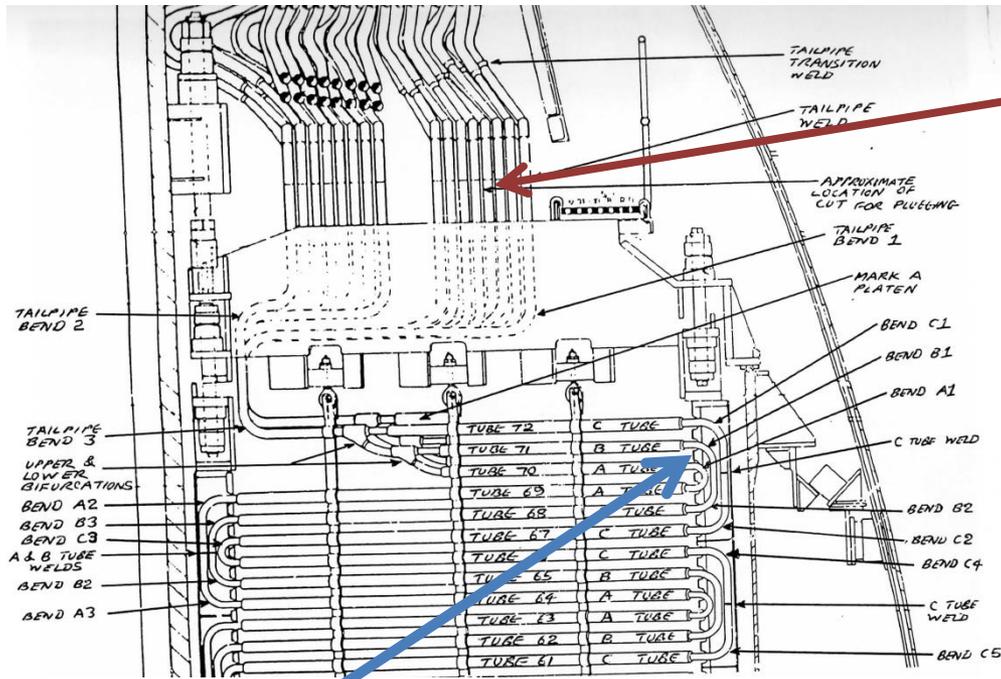


- Tube heated by passing current through it
- ~0.5 MW of electrical heating
- Removable bends for testing
- Test bends subject to proton beam irradiation to produce a layer of  $^{56}\text{Co}$  to an ~80 $\mu\text{m}$  depth to enable a metal loss measurement sensitivity of  $\pm 0.1\mu\text{m}$
- Outcome was change from ammonia dosing to Amino Methyl Propanol (AMP) in 1983 and to 5-aminopentanol (5AP) in 1992, mainly to protect the 30mm ID superheater tubes



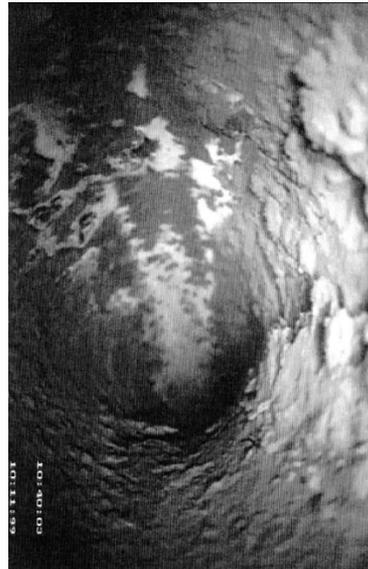
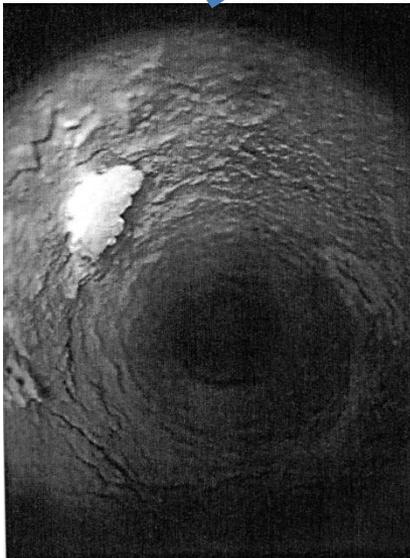
- Access-Way (Erosion-Corrosion) leaks brought under control
  - Still occur but at a manageable rate
  - No erosion-corrosion failures of 30mm ID superheater tubes
- The CEGB developed some of the country's leading hydrodynamicists in the 1980s**

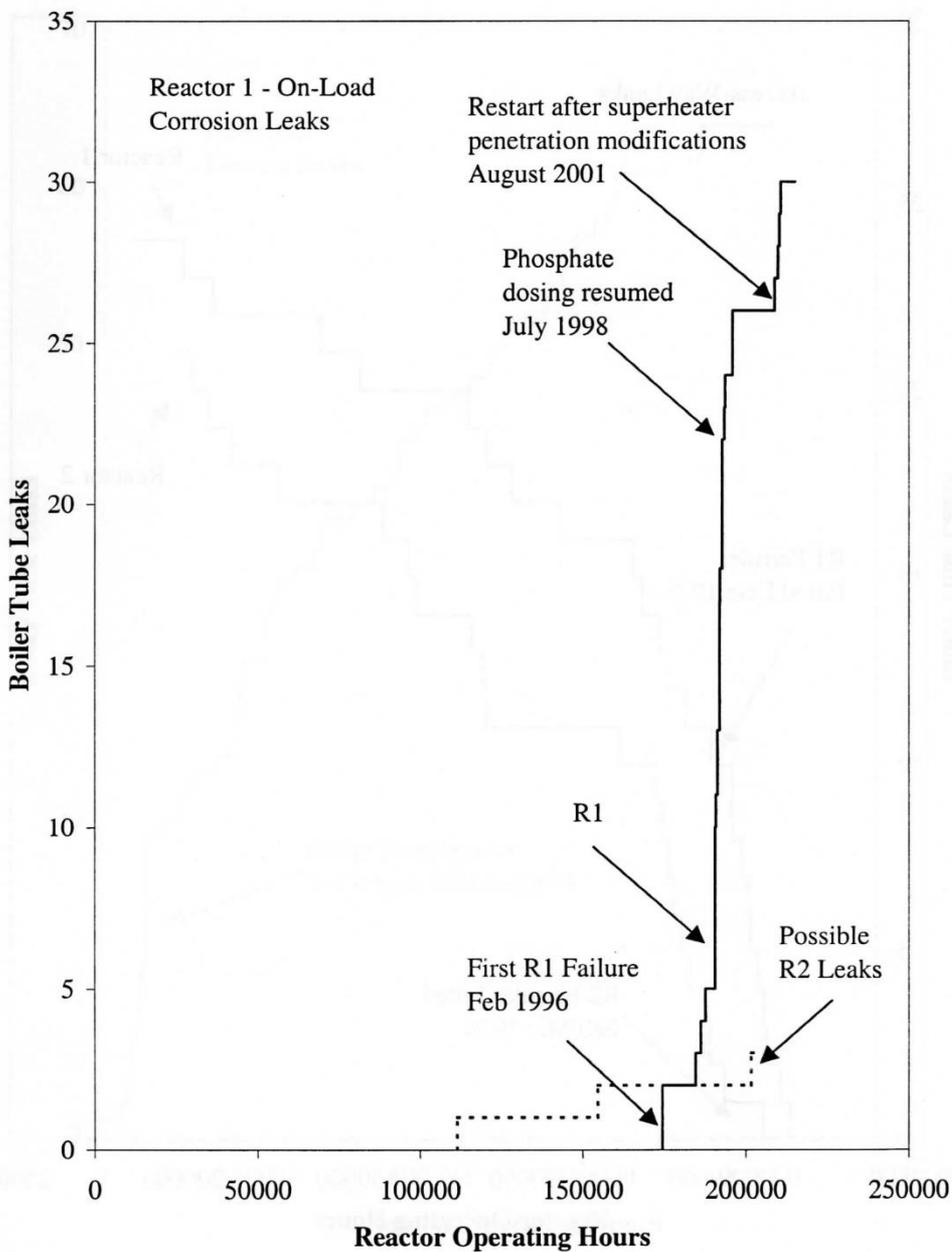
- The third leak-producing mechanism to afflict the Wylfa boilers started in Reactor 1 early 1996 and escalated rapidly in 1998 when the rate of boiler leak occurrence was worse than the fretting period of 1973/1974
- Based on experience of conventional stations the cause was thought likely to be on-load corrosion where the normally protective magnetite coating of the inside of the boiler tube becomes pitted and scabbed until the scab breaks away often to produce a leak
- This occurs high in the boiler around the point of final dry-out
- Phosphate dosing had stopped in 1994 when 5AP was introduced on the mistaken belief that 5AP would raise the pH sufficiently to protect the dry-out zone
- As an immediate countermeasure phosphate dosing resumed in July 1998 to ensure that corrosive acidic conditions could not exist under corrosion scabs



- Waterside video inspections were possible by vessel entry and cutting superheater tailpipes to provide access for specially designed cameras

- Inspections in the April 1999 R1 outage confirmed the presence of on-load corrosion scabs

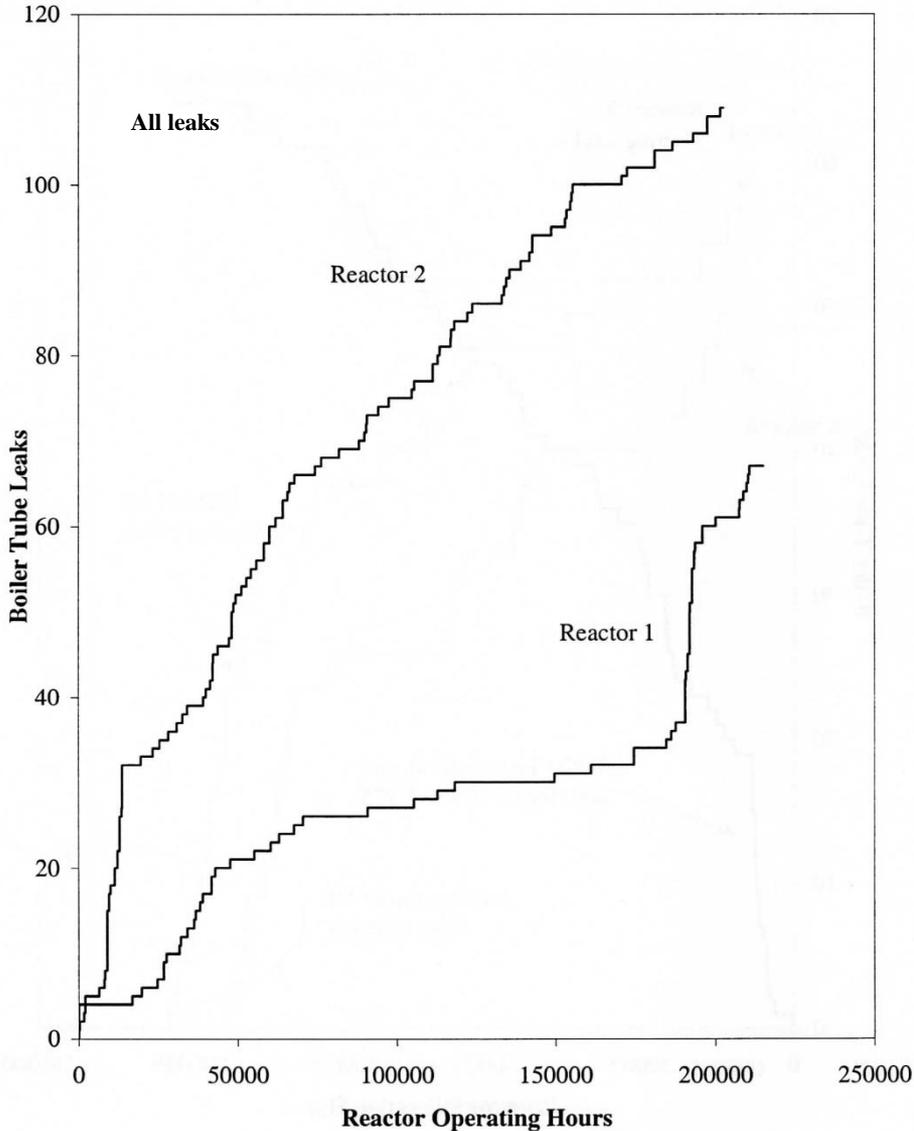




•Leak occurrence rate reduced but residual damage took time to work through:

2003: 4  
 2004: 1  
 2005: 3  
 2006: 2  
 2007: 4  
 2008: 1  
 2009: 2  
 2010: 1  
 2011: 0  
 2012: 0  
 2013: 1  
 2014: 0  
 2015: 0

•The heirs of the CEBG inherited some of the country's leading boiler chemists in the 1990s



- Three distinct boiler water-side problems: fretting, erosion corrosion and on-load corrosion

- To date R1 has lost 86 platens, R2 has lost 133

- Each problem potentially threatened to shorten drastically the generating life of Wylfa

- **That none of them did is a testament to an enormous amount of very hard work by many dedicated and clever teams in many locations and by incredible teamwork between those teams**