

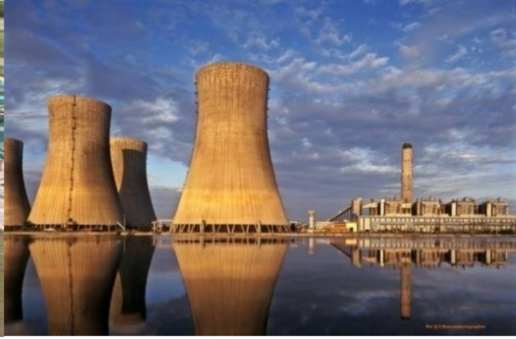

Effects of Flexible Operation on Environment and Chemistry of Sub-critical Coal Based Units

Ashwini K Sinha

Principal Consultant, CWMC

(Ex-Additional General Manager (NETRA), NTPC)

Core Member, CII-Avantha Corrosion Management Committee,

Member NACE International, Life Fellow Member SAEST

ashwiniksinhacwmc@gmail.com

http://cwmcindia.com

National seminar on "Flexible operation of coal fired power plants & Environment, challenges, 1st Nov. 2019, New Delhi

Corrosion and Water Management Consultants

"Improving Plant Performance, Availability & Reliability by Chemical Interventions"

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About Myself

Name: Ashwini K. Sinha (Retired as Addl. GM (NETRA), NTPC in July 2012)

Qualifications: M.Sc (Electrochemistry)
P.G. Dip. In Corrosion Science & Technology, Univ. of Ferrara (Italy)

Affiliations: Member NACE International, Life Fellow Member SAEST, IAAPC
Core Member of CII-Avantha Corrosion Management Committee

Experience: 42 years experience in Corrosion Analysis, Monitoring and Control in Power Plants (5 Years with BHEL (R&D), 30 years with NTPC (R&D) (now “NTPC Energy Technology Research Alliance (NETRA) and balance as Free Lance Consultant in the areas of Corrosion & Water Management).

Specialization: Corrosion Assessment, Failure Investigations, Corrosion Monitoring, Corrosion Audit, Design of Cathodic Protection Systems for Underground Pipelines; Condenser Water Boxes; RCC Structures such as Cooling Towers; etc, Selection of Anticorrosive Coatings, Development & Implementation of Cooling Water Treatments, Waste Water Recycling & Treatment, Chemical Cleaning of Condensers; Boilers; Pipelines; PVC Film Type Fill Packs of Cooling Towers; etc, Material Selection, Water Management, etc. Research Studies on Extraction of Moisture from Flue Gases, Ash Mineralization by Flue Gas, etc.

About Myself

Major Association with: - Consultancy, In-house Training,

1. Adani Power (Mundra, Tiroda, Kawai, Udupi, New Projects)
2. NOMAC – USC Plant, Dubai; CCPP, Salalah, Oman; Tanger Wind Farms, Morocco, Boujdour PV, Layoune PV, NOOR 1 CSP, Morocco, Sohar 3, IBRI IPP; Oman; Vin Hao PV, Vietnam
3. Sembcorp IWPP, Salalah, Oman and Nellore
4. Failure of SS Tubes at Oman Food Products, Salalah, Oman
5. NTPC (almost all stations)
6. Rajasthan RVUNL - Kalisindh , Dholpur, Kota Thermal, Chhabra
7. Mahagenco Chandrapur, Koradi (SC), Bhusawal
8. CLP Paguthan and Jhajjar
9. Haldia Energy Limited, Haldia, Dhariwal Infrastructure Ltd., Chandrapur
10. Vedanta Limited, Jharsuguda and Bhatinda
11. GSECL Sikka TPS, Jamnagar
12. Essar Sallaya Project, Jamnagar
13. IOCL Dibrugarh, Guwahati, Panipat
14. Lanco Kondapally, Gurugram, Udupi (now with Adani Power)
15. Nabha Power Plant, Punjab
16. HMEL Bhatinda, Punjab
17. Sri Mega Power Beawar, Rajasthan
18. Jindal Power, Raigarh; JSL, Odisha
19. Reliance Power - Rosa Power, Shajahanpur, Sasan UMPP
20. NLC and NTPL, Neyveli

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CONTENT

1. Introduction, Installed Capacity and Environmental Norms
2. Flexible Operation Effects
3. Oxidation and Exfoliation of Super-Heater and Re-heater Tubes
4. Acid Dew Point Corrosion
5. Waste Heat Recovery from Flue Gas
6. Conclusions

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Introduction, Installed Capacity & Environmental Norms

Environmental Norms

After consultation with the power ministry, the environment ministry set in place improved pollution norms for the thermal power industry in 2015. Credit: Reuters

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Cycling Units

Cycling

Cycling is a load following operation. The unit load fluctuates with system demand, with the unit synchronized at very low loads during low-demand periods. A typical load variation for cycling units might range from 30% to 100% of design capacity.

Peaking is a form of cycling in which the unit is operated only during peak power demand periods. At off-peak hours the unit is on hot or cold standby, depending upon the estimated time between restarts. Two-shift operation is typical of peaking units, which generally furnish power for the morning and evening high demand hours.

Ref.: Cycling, Startup, Shutdown, and, Layup Fossil Plant Cycle Chemistry Guidelines for Operators and Chemists – TR 107754, EPRI

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Flexible Operation

Flexibility: The term was first introduced in IEA (2008) as: "…The ability to operate reliably with significant shares of variable renewable electricity." A more specific definition was put forward in IEA (2011): "**Flexibility expresses the extent to which a power system can modify electricity production or consumption in response to variability, expected or otherwise**." IEA (2014) introduced a distinction between a broader concept of flexibility and a narrower concept of ramping flexibility: "**In a narrower sense, the flexibility of a power system refers to the extent to which generation or demand can be increased or reduced over a timescale ranging from a few minutes to several hours**."

RES: Unless mentioned otherwise, the term RES or Renewable Energy Sources has been used to represent Solar and Wind power. Biomass and Small Hydro have been mentioned separately whenever required.

Minimum Load: **The minimum load is the lowest possible net load a generating unit can deliver under stable operating conditions**. It is measured as a percentage of normal load or the rated capacity of the unit.

Flexible Operation

Start-up time: **The start-up time is defined as the period from starting plant operation till reaching minimum load**. The start-up time of different generation technologies varies greatly. The other factors influencing the start-up time are, down time (period when the power plant is out of operation) & the cooling rate.

Ramp rate: The ramp rate describes how fast a power plant can change its net power during operation.
Mathematically, it can be described as a change in net power, ΔP, per change in time, Δt. Normally the ramp rate is specified in MW per minute (MW/min), or in the percentage of rated load per minute (% P/min). In general, ramp rates greatly depend on the generation technology.

Minimum Thermal load (MTL): The MTL is the ratio of actual minimum load on the prime mover of a thermal power station and its rated capacity. E.g. if a 200 MW plant runs at minimum load of 120 MW during a day, then the MTL for that plant is 120/200 i.e. 60%.

Source: **FLEXIBLE OPERATION OF THERMAL POWER PLANT FOR INTEGRATION OF RENEWABLE GENERATION, CEA, 2019**

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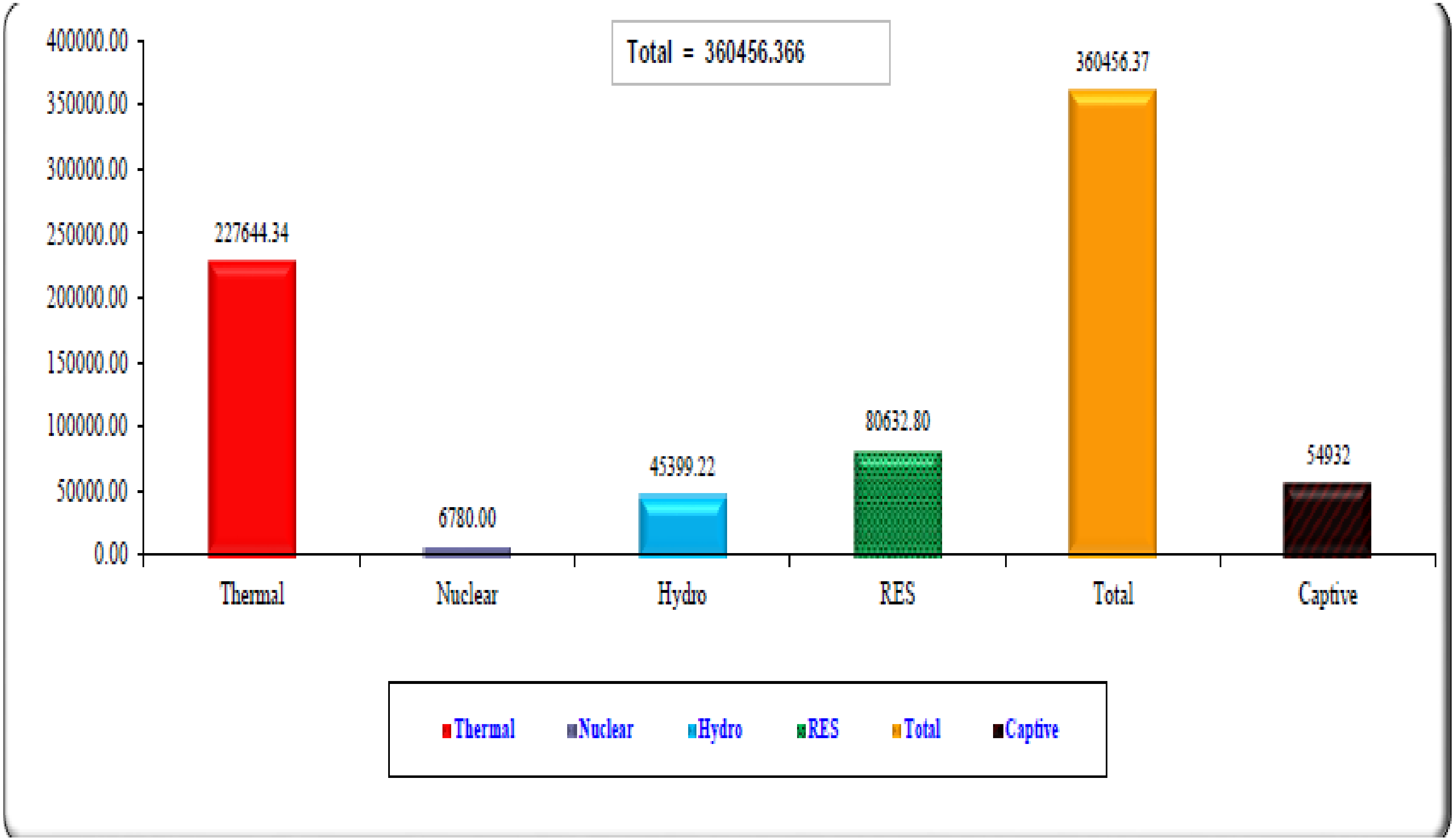
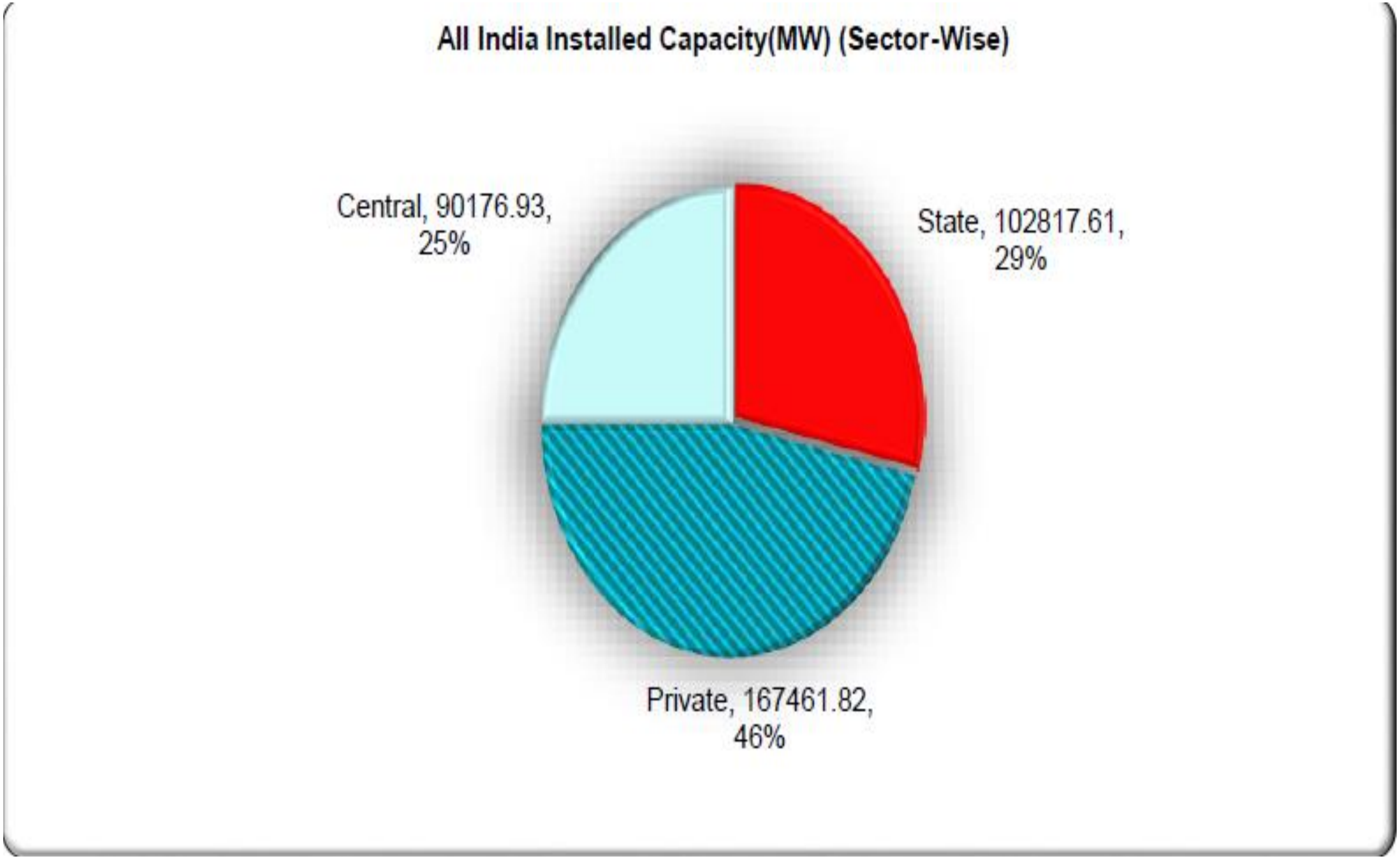
Total Installed Capacity (As on 30.09.2019) - Source : Central Electricity Authority (CEA)



Total Installed Capacity (As on 30.09.2019) - Source : Central Electricity Authority (CEA)



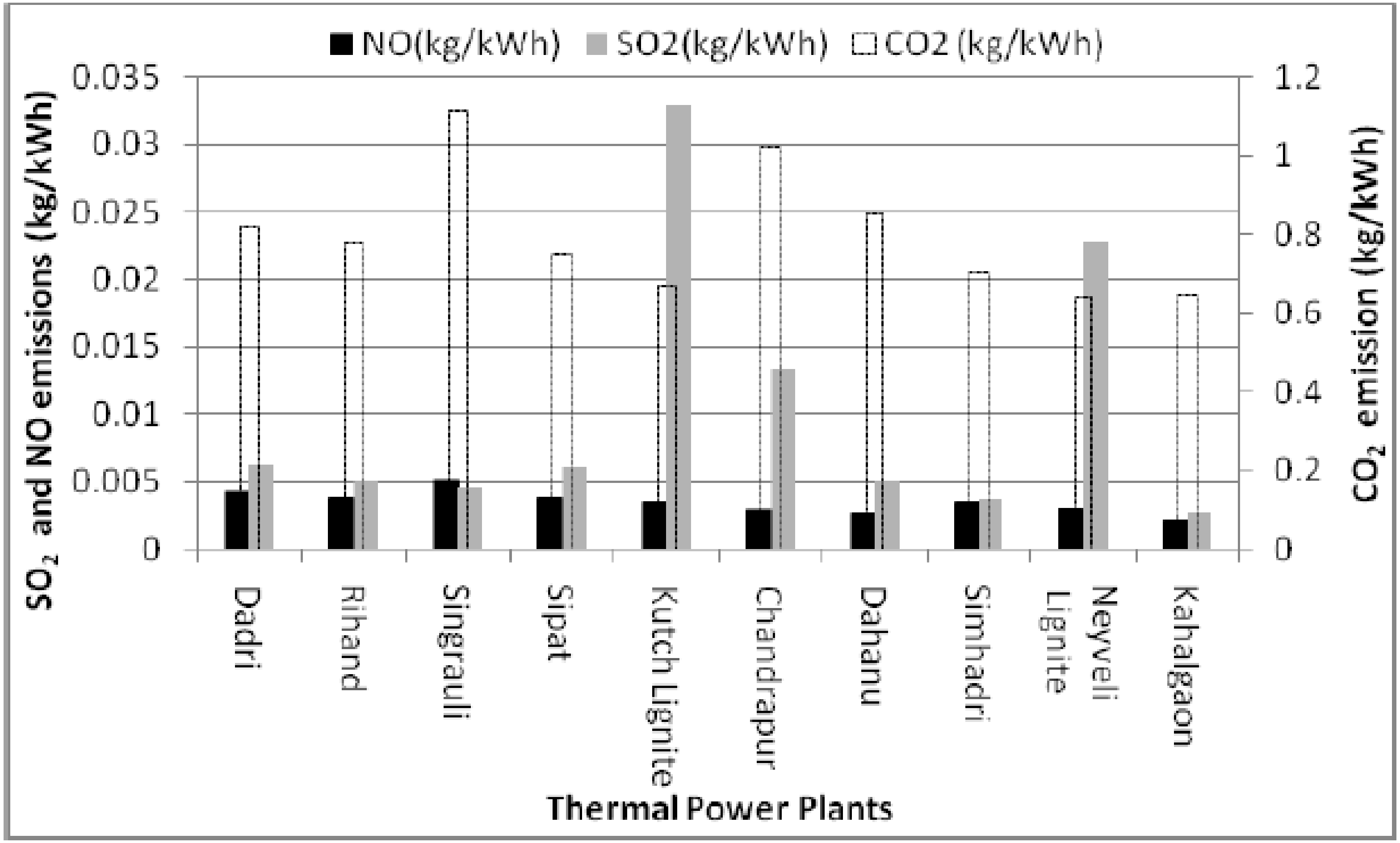
Introduction and Background

Elemental analysis, moisture content, and grades of typical Indian coals

Coal grade	C%	H%	S%	N_2%	O_2%	A%	M%	NCV (Kcal/kg)
D	33.1	2.46	0.44	0.83	NA	25.9	7.2	4999.0
D	30	2.48	0.57	0.69	NA	27.1	2.9	5555.0
D	32.31	2.12	0.4	0.78	NA	25	7.3	5068.0
E	37.9	2.4	0.53	0.8	6%	30.4	7.5	4529.0
F1	41.87	3.33	0.56	0.94	6%	34.07	7.8	4137.0
F2	44.47	3.37	0.35	0.99	6%	36.3	8.4	3833.0
Average of E and F2	41.19	2.89	0.44	0.9	0.06	33.35	7.95	4182.0

Introduction and Background

Elemental analysis, moisture content, and grades of typical Indian coals



EXISTING EMISSION NORMS FOR TPS

Emission parameter	Limiting Values
Suspended Particulate Matter (SPM)	Less than 210 MW (1989) : 350 mg/Nm3 210 MW or more(1989) : 150 mg/Nm3 The above limits were further reduced to 100 mg/Nm3 in 2003 under Corporate Social Responsibilities. Limit of 50 mg/Nm3 is being specified on case to case basis depending on the area
NOx	None for coal based stations
SOx	None, stack provided for dispersion <500 MW - 220 m >=500 MW - 275 m FGD space provision for units size 500 MW and above.

MOEF Notification – 7th Dec. 2015

Pollutants	TPPs (units) installed before 31st December, 2003*	TPPs (units) installed after 1st January,2004, up to 31st December, 2016*	TPPs (units) to be installed from 1st January, 2017**
Particulate Matter (PM)	100 mg/Nm3	50 mg/Nm3	30 mg/Nm3
Sulphur Dioxide (SO2)	600 mg/Nm3 (Units Smaller than 500MW) 200 mg/Nm3 (for units having capacity of 500MW and above)	600 mg/Nm3 (Units Smaller than 500MW) 200 mg/Nm3 (for units having capacity of 500MW and above)	100 mg/Nm3
Oxides of Nitrogen (NOx)	600 mg/Nm3	300 mg/Nm3	100 mg/Nm3
Mercury (Hg)	0.03 mg/Nm3 (for units having capacity of 500MW)	0.03 mg/Nm3	0.03 mg/Nm3
*TPPs (units) shall meet the limits within two years from date of publication of this notification.			
**Includes all the TPPs (units) which have been accorded environmental clearance and are under construction.			

Water Consumption in Thermal Power Plants

S.O. 3305(E).— In exercise of the powers conferred by sections 6 and 25 of the Environment (Protection) Act, 1986 (29 of 1986), the Central Government hereby makes the following rules further to amend the Environment (Protection) Rules, 1986, namely:—

Sr. No.	Industry	Parameter	Standards
"5A.	**Thermal Power Plant (Water consumption limit)**	**Water consumption**	I. All plants with Once Through Cooling (OTC) shall install Cooling Tower (CT) and achieve specific water consumption upto maximum of $3.5 m^3/MWh$ within a period of two years from the date of publication of this notification.
			II. All existing CT-based plants reduce specific water consumption upto maximum of $3.5 m^3/MWh$ within a period of two years from the date of publication of this notification.

Contd.

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Water Consumption in Thermal Power Plants

Sr. No.	Industry	Parameter	Standards
“5A.	**Thermal Power Plant (Water consumption limit)**	**Water consumption**	**III.** New plants to be installed after 1st January, 2017 shall have to meet specific water consumption upto maximum of 2.5 m^3/MWh and achieve zero waste water discharged”;

MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE

NOTIFICATION

New Delhi, the 7th December, 2015

Flexible Operation Effects

Mitigating the Effects of Flexible Operation on Coal-Fired Power Plants (Power Magazine 2011)

Most of the Sub-critical units were designed for base load operation.

New duty cycles force baseload plants and equipment to operate closer to—or beyond—nominal design limits and through more thermal cycles than originally anticipated**.**

The operational impacts of flexible operation result in significantly increased occurrences of thermal transients in the material of critical high-temperature boiler and turbine components.

These transients, and other operational factors associated with flexible operation, have the following effects on coal-fired generating assets.

Additional wear on plant components requires increased spending on preventive and corrective maintenance.

Mitigating the Effects of Flexible Operation on Coal-Fired Power Plants (Power Magazine 2011)

- **Increased rate of wear on high-temperature components.**
- **Increased wear-and-tear on balance-of-plant components.**
- **Decreased thermal efficiency at low load (high turndown).**
- **Increased fuel costs due to more frequent unit starts.**
- **Difficulties in maintaining optimum steam chemistry.**
- **Potential for catalyst fouling in NO_x control equipment.**
- **Increased risk of human error in plant operations.**

Mitigating the Effects of Flexible Operation on Coal-Fired Power Plants (Power Magazine 2011)

Major Damage Mechanisms are:

- Thermal Fatigue
- Thermal Expansion
- Corrosion-Related Issues
- Fireside Corrosion
- Rotor Bore Cracking

Mitigating the Effects of Flexible Operation on Coal-Fired Power Plants (Power Magazine 2011)

Impacts on Environmental Control Equipment

- **Performance and reliability of flue gas desulfurization (FGD) equipment and selective catalytic reduction (SCR) systems.**

- Start-ups of FGD systems.

- Low-load operation of FGD systems

- Operation of large coal-fired plants at low load can force **units with SCR systems to operate with lower flue gas temperatures.** Low temperatures create operational problems for SCRs because of the formation of ammonium bisulfate (ABS)

Mitigating the Effects of Flexible Operation on Coal-Fired Power Plants (Power Magazine 2011)

Strategies for Mitigating Flexible Operation Damage

- **Improved operator performance and selected plant controls upgrades**
- **Efficiency Improvements.**
- **Cycle Chemistry Guidelines for Transient Operations**.
- **Mitigating SCR Issues at Low Load.** To avoid problems with SCR units during low-load operation, conventional design practice calls for a flue gas or water-side economizer bypass to elevate the flue gas temperature at low load to a level high enough to allow reagent injection

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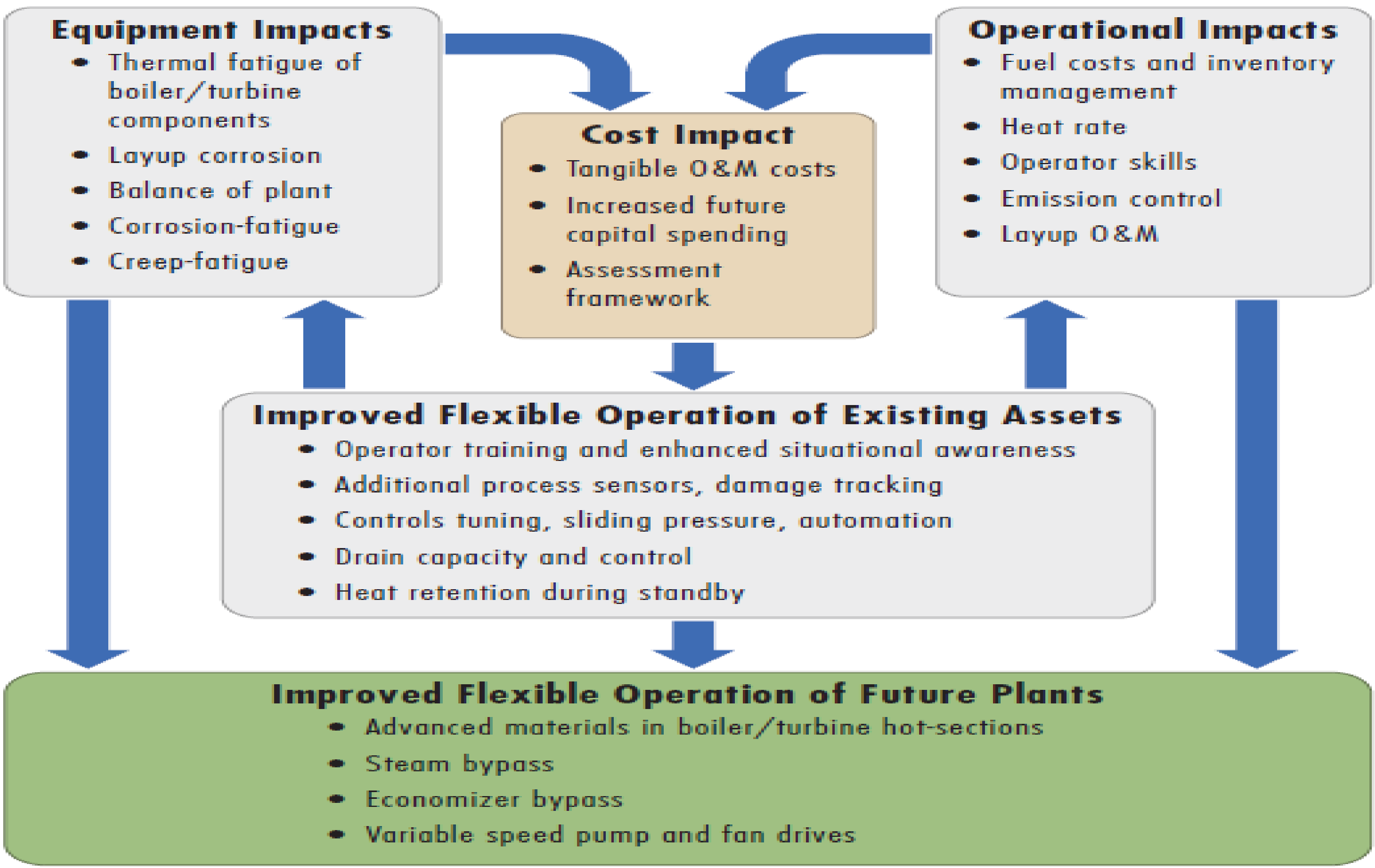
Flexibility Challenges

Key steps to improving coal fleet flexible operation (EPRI

Electric Power System Flexibility CHALLENGES AND OPPORTUNITIES



ENHANCING FLEXIBILITY: ENVIRONMENTAL IMPACTS

- The need to operate the power grid in a flexible manner can increase generation cycling, which can impact air, water, and solid waste emissions.
- As non- or lower-emitting sources displace higher-emitting generation, overall emissions could be substantially reduced.
- **Transient increases in fossil-fueled plants' emissions rates during startup, shutdown, and other ramping periods, as well as during low load, relative to steady-state operations at full load**.
- Temporary increases in emissions rates can be due in part to incomplete combustion and incomplete warm-up of emissions control devices.
- **Biological treatment for FGD wastewater may not be able to sustain performance during cycling operation or shutdowns**.
- Fossil fuel plants on hot standby for lengths of time may increase costs and/or emissions by keeping cooling water circulators, fans, and other devices running despite the lack of power generation.
- Technical challenges in **accurately measuring emissions of chemicals during startup and shutdown, uncertainty may exist in these emissions estimates.**

Ref. **Electric Power System Flexibility** Challenges and Opportunities, EPRI

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Specific components typically affected by cycling (Power Plant Cycling Costs NREL 2012)

Unit Type	Plant Equipment with Most Significant Adverse Impacts from Cycling	Primary Damage Mechanism
Small and Large Sub-Critical Coal	Boiler Waterwalls	Fatigue Corrosion fatigue due to outages oxygen and high starts up oxygen Chemical deposits
	Boiler Superheaters	High temperature differential and hot spots from low steam flows during startup, long term overheating failures
	Boiler Reheaters	High temperature differential and hot spots from low steam flows during startup, long term overheating failures, tube exfoliation damages IP turbines

Specific components typically affected by cycling (Power Plant Cycling Costs NREL 2012)

Unit Type	Plant Equipment with Most Significant Adverse Impacts from Cycling	Primary Damage Mechanism
Small and Large Sub-Critical Coal	Boiler Economizer	Temperature transient during startups
	Boiler Headers	Fatigue due to temperature ranges and rates, thermal differentials tube to headers
	LP Turbine	Blade erosion
	Turbine shell and rotor clearances	Non uniform temperatures result in rotor bow and loss of desired clearance and possible rotor rubs with resulting steam seal damages

Specific components typically affected by cycling (Power Plant Cycling Costs NREL 2012)

Unit Type	Plant Equipment with Most Significant Adverse Impacts from Cycling	Primary Damage Mechanism
Small and Large Sub-Critical Coal	Feedwater Heaters	High ramp rates during starts, not designed for rapid thermal changes
	Air Heaters	Cold end basket corrosion when at low loads and start up, acid dew point
	Water/Chemistry Water Treatment Chemistry	Cycling results in peak demands on condensate supply and oxygen controls
	Fuel System/ Pulverizers	Cycling of the mills occurs from even load following operation as iron wear rates increase from low coal flow during turn down to minimum

Specific components typically affected by cycling (Power Plant Cycling Costs NREL 2012)

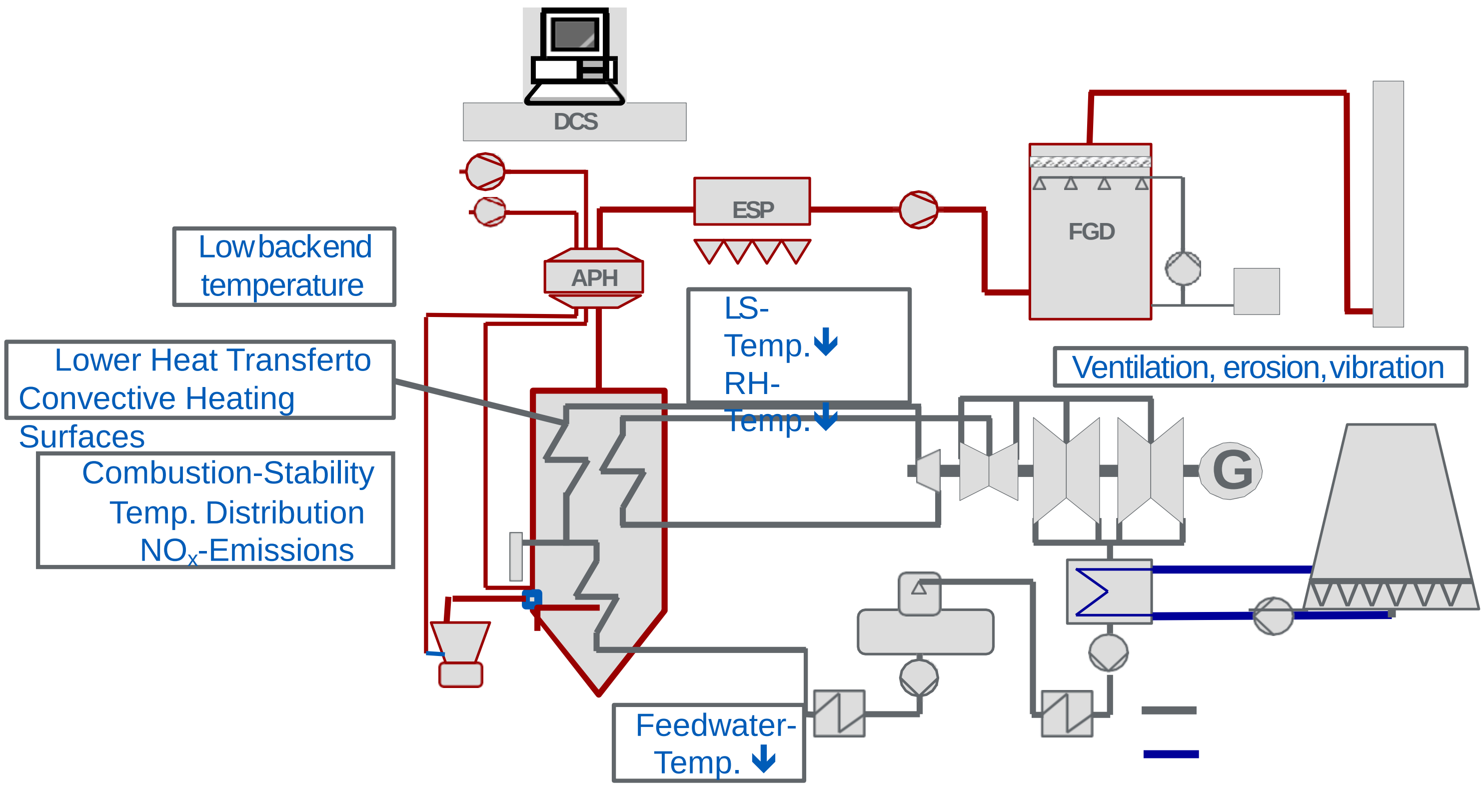
Unit Type	Plant Equipment with Most Significant Adverse Impacts from Cycling	Primary Damage Mechanism
Supercritical Coal (600-700 MW)	Same as subcritical coal except added temperatures in furnace tubing	
	Large supercritical furnace subject to uneven temperatures and distortion	Fatigue due to temperature ranges and rates, thermal differentials tube to headers

Water chemistry issues

Operating Mode	Chemistry Issues	
Load Following	• Feedwater chemistry control • Dissolved oxygen in condensate • Sampling issues	• Phosphate Hideout • Carryover (level control) • Corrosion Product Monitoring
Cycling (weekend off)	• Reheater pitting • Chemistry on startup	• General Steam Path pitting • Carryover (swell)
Cycling (two-shifting)	• Boiler chemistry control • Carryover Issues	• **Feedwater chemistry control** • Carbon dioxide ingress
Extended Layup	• **Turbine Pitting (leading to Stress Corrosion Cracking or Corrosion Fatigue)** • Chemistry System return to service	• Oxygen pitting boiler tubing • Water Treatment Layup • Instrumentation layup
Sustained Minimum Load	• **Increased steam path deposition** • FAC in economizers / IP Evaporator • FAC in BFP recirculation lines • Steaming in Economizer (two-phase FAC)	• DNB and Hydrogen Damage • High level of attemperatoring sprays • Sampling / Monitoring • Air-inleakage control

Source:EPRI

Limitations to be addressed



Ramp Rates-Limitations

- Stresses in thick walled components
- Fuel quality
- Controls and time lag between coal milling and turbine response

Minimum load limitations

- Combustion stability
- Boiler circulation
- DNB
- Minimum feed water flow & BFP
- Last stage blade flutter
- FG Exit Temp./Acid due point
- Vibration issues

Ref. Operational Strategies for Flexing in Thermal Plants, Anjan K Sinha, Indo-USAID

Increasing the flexibility of coal-fired power plants

Water treatment

- Poor water quality causes corrosion, and the likelihood of water quality deterioration is increased as a result of frequent load changes.
- For once-through boiler systems, all-volatile treatment and oxygenated treatment are used.
- **Boilers operating in a cycling mode are best provided with all-volatile treatment together with full-flow condensate polishing. All-volatile treatment with oxygenating is preferable for ferrous-only based systems.**
- The dissolved oxygen concentration is controlled by mechanical means, while chemicals such as ammonium hydroxide and hydrazine or other substances can be used as the pH adjuster.
- Condensate polishers remove dissolved contaminants, such as sodium and silica, and filter suspended particulates that become detached from heat exchanger internal surfaces during load transitions.

Ref: Colin Henderson, September 2014, IEA Clean Coal Centre

Increasing the flexibility of coal-fired power plants

- Operation of makeup water or wastewater clarifiers can be improved by the addition of recirculation lines to allow the maintenance of adequate flow through the clarifier at low load, keeping it ready for increased load operations.

(*Many of the 200 or lower capacity units are provided with copper based tubes and no condensate polishing units are provided. Even with 500 MW units CPU is optional and generally only 33% of full flow is passed through CPU*).

Increasing flexibility – other plant areas

On/off and highly variable load operation affects other parts of the plant also.

NOx removal systems

The main potential issue with low load operation of plants with selective catalytic reduction (**SCR**) systems, which are usually placed after the economiser, is the possibility of **lower flue gas temperatures** occurring. SCR units often use ammonia as reagent, and **ammonia control may become difficult during fast load swings**, compounded by variable fuel properties. Excess ammonia can then leave with the exit gas stream. This so-called **ammonia slip can then lead to ammonium bisulphate (ABS) formation as a sticky liquid that fills catalyst pores, reducing reactivity**. ABS may also deposit in the air heater, increasing its pressure drop, and necessitating cleaning. It can even be blown from the air heater into boiler air ducts, where it can influence readings of air flow measurement devices.

Increasing flexibility – other plant areas

To avoid problems with ABS formation (**ABS is highly corrosive in nature**), the conventional solution is for a flue gas or water-side economiser bypass to be installed to enable the flue gas temperature at low load to be kept at design value.

Such an arrangement can avoid plugging without sacrificing NOx removal performance. **Where units are not, or cannot be, equipped with economiser bypass capabilities, other options are available. One is to monitor continuously the inlet NH_3 and SO_3 concentrations and temperature distribution in the SCR, and to compare these with design conditions**.

Other possibilities may be to change the fuel sulphur content or, if allowed, the NOx reduction levels at low load, or to modify the inlet temperature distribution using a static mixer (baffle). Adding a heating facility for hot gas carrying components can also be used to give shorter start-up times. **Whatever means is used, provided the correct temperature can be maintained, rapid rates of load change can generally be accommodated.**

Increasing the flexibility of coal-fired power plants

FGD Systems

The chemical processes involved in conventional wet flue gas desulphurisation (FGD) systems require precise control of the reaction conditions, which are influenced by reagent flow, water flow and flue gas temperature. Operation at varying power output can consequently affect the performance and reliability of these plants. **The number of shut-downs and start-ups of FGD systems should also be minimised because of the need to purge to avoid slurry solidification**. Reducing the number of shut-downs and start-ups is also needed to minimise the accumulation of start-up fuel oil residues on absorber linings, and to avert the lengthy warming up time that is needed by an FGD system.

It can be possible to obtain savings in energy consumption at part load by switching off some circulation pumps. However, at low-load, it will be difficult to maintain optimal performance if the reagent flow is fixed. **Keeping within required emissions limits during rapid load changes requires sophisticated control concepts, and an increased liquid/gas ratio may be needed for sufficient SO2 capture**.

Particulate removal systems

Particulate control systems can usually cope with a plant operating at partial load and rapid load changes without problems. Inlet gas temperatures need however to be watched – they must not fall so low that acidic moisture condenses on particles, causing adherence of solids to fabric filters or a resistivity that is too low for efficient ESP performance.

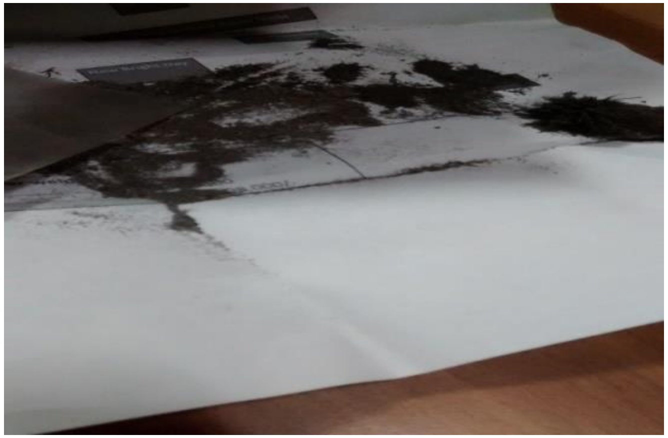
At partial (or full) load, enhanced dust collection may be achieved in electrostatic precipitators by increasing residence time, while energy savings of up to 80% are possible using intelligent control systems for the power supply.

Oxidation and Exfoliation in Super-Heater and Reheater Tubes

Failure of RH/SH Tubes

Failure of RH Tubes – Tube SA 213 T22

Failure of RH/SH Tubes



Failure of RH Tubes