Operational Hazards Associated with Coal Fired Boilers: Design Requirements of Safety Control Systems
Objective

• Highlight some safety areas of concern
• Hazards and mitigation
• Assessment tools
• Flame monitoring concerns and complexity
• Brief comments on SIL’s and IEC 61508
Power Station Safety – Fuel Issues

• Areas of concern:
  – Fuel storage – bulk store and bunkerhouse
  – Conveyors
  – Mills
  – PF systems
  – Burners and furnace
  – Air heaters
  – Draught plant

• Not an exhaustive list – all plants are different

• For this presentation, we will focus on combustion safety issues, principally the boiler
Definitions - Hazard and Risk

• Hazard – anything that can cause harm
• Risk - the chance, high or low, that somebody could be harmed by these hazards, with an indication of how serious the harm could be
• Safety analysis will encompass both of these to develop a suitable protection system
• Evaluation must account for specific site features – fuel, burner design, use of OFA or FGR
Combustion Safety Tools

- Codes and standards – *general guidance and best practice*
- Hazard Identification – *site specific identification of hazards present*
- HAZOP – *established procedure based on nodes and key words* – ‘more flow’, ‘less flow’ etc
- Layers of Protection Analysis – *quantitative assessment of individual risk to compare with numerical risk target (ALARP)*
Standards and Guidance

- A number of Standards and Codes of Practice are available
- Some better than others, not always consistent
- NFPA 85 Boiler and Combustion System Hazards Code
- Following a code does not guarantee safety – site specific factors must be analysed
NFPA 85

- Includes detailed guidance on oil, gas and coal
- Different boiler types (PF boiler, fluidised bed)
- Includes FGD / SNCR / SCR / FGR hazards
- Guidance for different fuels
- Standard P & IDs, interlock lists etc
Coal Fired Boiler Hazard

• Focus on combustion related issue
• Principal boiler hazard is the *ignition of accumulated unburnt fuel, leading to a pressure rise that is sufficient to breach containment of the boiler casing*, resulting in the expulsion of hot gases, materials and structural components
• Combustion safety system is intended to prevent this
Reignition Event – Coal Fired Boiler

- MFT initiates on furnace high pressure trip
- 16 mbarg trip setting

Indicative loss of ignition at 11:14:47
Load drops at 11:15:10
Furnace pressure hits high pressure trip at 11:16:09
MFT initiated at 11:16:12
Furnace pressure doesn’t reach low pressure trip
# Boiler Operation – Fuel Hazards

<table>
<thead>
<tr>
<th>Operating Mode</th>
<th>Hazard</th>
<th>Mitigation</th>
</tr>
</thead>
</table>
| Boiler start up | Leaking fuel from gas igniters or oil burners accumulates in furnace | Boiler air purge as part of start sequence  
Master block valve driven closed when boiler shut down |
| Burner start up | Failed ignition on first burner(s) releases fuel into boiler           | Fixed burner start sequence; *flame monitor* detects flame  
Re-purge on failed ignition |
| Mill start      | Lean fuel / air mixture at burner; failed / unsupported ignition releases fuel into furnace  
Greater hazard for first mills | Fixed mill start sequence; *flame monitor* detects flame  
Correct ignition burner design  
Correct ignition burner pattern  
Hazard warning system – remove people from area |
## Boiler Operation – Fuel Hazards

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<tbody>
<tr>
<td>Normal Operation</td>
<td>Coal flame instability caused by restriction or loss of coal feed (bunker hang up)</td>
<td>Only impacts on one mill group Operators can use oil burner support <em>Flame monitors</em> detect loss of flame and trip mill Mill temperature high alarm</td>
</tr>
<tr>
<td>Normal Operation</td>
<td>Coal flame instability caused by wet coal or poor quality coal</td>
<td>Oil burner support <em>Flame monitors</em> detect loss of flame and trip mill(s) or all firing Mill temperature low alarm</td>
</tr>
<tr>
<td>Normal Operation</td>
<td>Coal flame instability caused by control system error – e.g. combustion air incorrectly diverted to overfired air ports</td>
<td><em>Flame monitors</em> detect loss of flame and trip mill(s) or all firing</td>
</tr>
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Flame Detection

• An integral part of a combustion safety system
• Sounds simple, but can be complex to implement
• Flame monitor should detect a flame and take action on loss of flame:
  – burner
  – mill
  – ‘significant loss of flame (partial loss of ignition)
  – furnace (total loss of ignition)
Flame Monitor Requirements

A flame monitor must:
• Detect the presence and absence of the flame on it’s burner
• Not detect flames on nearby burners (flame discrimination)
• Not respond to hot / glowing refractory
• Be reliable (self checking capability)
• Work in a cold and hot boiler

Modern units are becoming increasingly complex
Flame Monitor Adjustment

- To enable tuning, many adjustments are possible
- Frequency response
- Gain
- Threshold settings
- Multiple settings for different boiler conditions
Flame Monitoring

- Using flame flicker enables monitor to see near flame and ignore flame further away
- Higher frequency of main part of flame is detected whilst lower frequency would be ignored
- This design feature is intended to differentiate flames. The ability to adjust the orientation of the flame monitor is important here.
- The instrument is only one part of the system – how should the output be used?
Flame Stability
Flame Detection In Practice – multi burner boiler

- 48 burners
- 6 burners per mill
- 36 required for full load (6 mills)
- Individual burners cannot be shut down, only mill groups (6 at a time)
Flame Detection In Practice – multi burner boiler

- For a significant accumulation of unburnt fuel, sufficient time must be provided before ignition
- Spatial spread of burners is important
Flame Detection In Practice – multi burner boiler

6 burners on mill
1 – how many flame losses to trip a mill
• 1 flame?
• 2 flames, one LHS, one RHS?
• 4 flames, 2 per side?
• 2 flames, both on same side?
Flame Detection In Practice – multi burner boiler

6 burners on mill
1 – how many flame losses to trip a mill
• 1 flame?
• 2 flames?
• 4 flames?
• Same number irrespective of mills in service?
Flame Detection Logic

• Flame detection logic is a complex area
  – Risk of fuel accumulation is higher during start up with fewer mills in service
  – Not as many sources of ignition in boiler
  – Different boilers have different mill configurations, which have different requirements
  – Little guidance for this

• Over conservative – unnecessary mill trips
• Under conservative – safety risk
Control System Design – IEC 61508

• IEC 61508 is a standard applicable to safety related programmable systems
• Based on a quantified risk analysis, it determines the reliability requirements of a control system to act correctly on demand
  – The higher degree of risk reduction required of the system, the more reliable it must be
• Establishes the design, testing and maintenance requirements of a control system
Safety Integrity Levels

- IEC 61508 introduces the concept of Safety Integrity Levels (SIL)
- Based on the probability of ‘dangerous failure on demand’ for a safety function (how likely is the system to work when needed’)
- Ranked 1 – 4:

<table>
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<tr>
<th>SIL</th>
<th>PFD</th>
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<tbody>
<tr>
<td>1</td>
<td>0.1 – 0.01</td>
</tr>
<tr>
<td>2</td>
<td>0.01 – 0.001</td>
</tr>
<tr>
<td>3</td>
<td>0.001 – 0.0001</td>
</tr>
<tr>
<td>4</td>
<td>0.0001 – 0.00001</td>
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- SIL 1 is lowest integrity, 4 is highest
- For furnace protection, SIL 1 – 2 is most applicable
- Assessment generally carried out by layers of protection analysis based on individual risk
Conclusions

• Hopefully, an introduction to combustion safety
  – Highlight complexities of loss of flame protection and flame detection
  – Very brief introduction to SIL

• Suitable and sufficient analysis is required for each scenario