Demonstrating Compliance with Moderator Content Limits in UO_2 Powder upon Leaving a Furnace Environment

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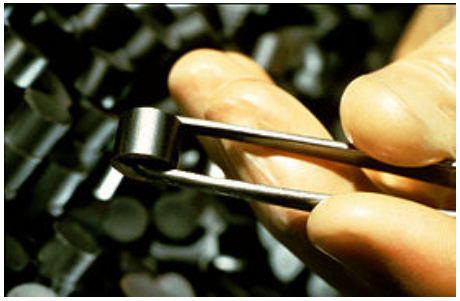
Introduction

This presentation covers:

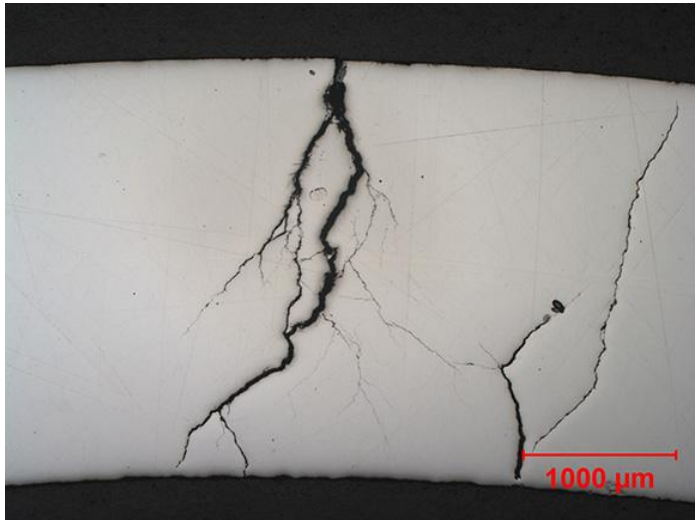
- An overview of defluorination in LEU fuel manufacture
- Criticality safety considerations in a typical defluorination furnace
- Methods of ensuring compliance with moderation limits
- A Case Study reviewing an existing facility

Defluorination Process

UF_6 cylinders used in transport

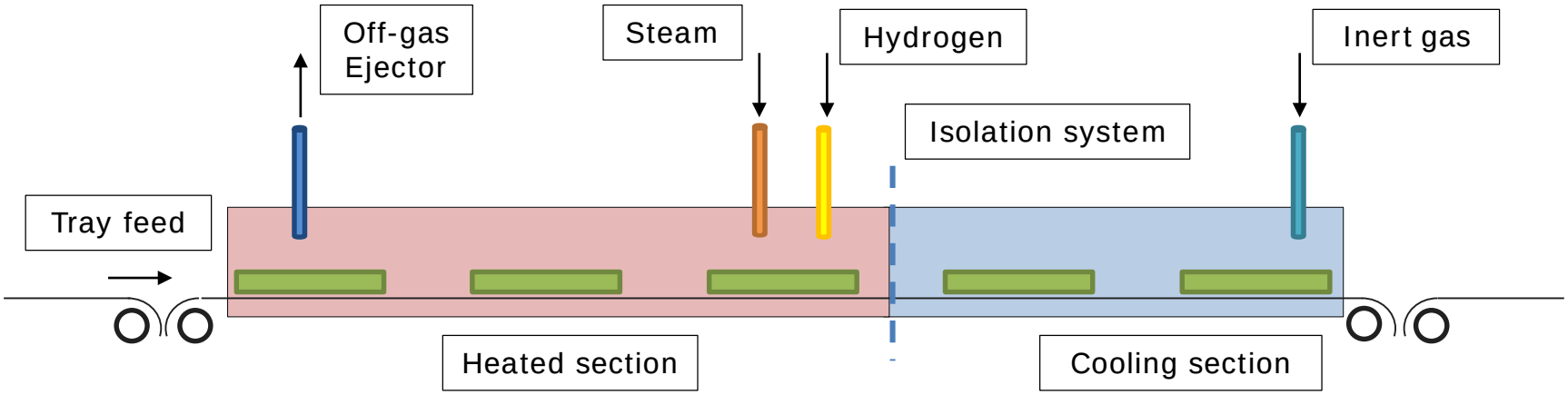


Pure UO_2 fuel pellets



Example of stress corrosion cracking in steel
(note image not from a nuclear application)

Typical Defluorination Furnace

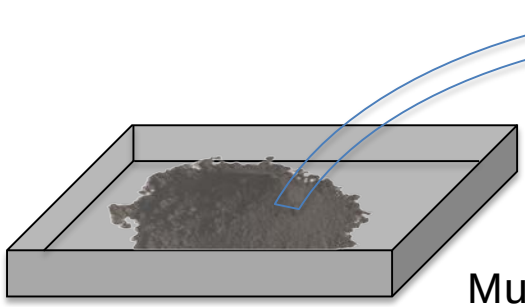


$$UF_6 + 2H_2O \rightarrow UO_2F_2 + 4HF \quad (1)$$

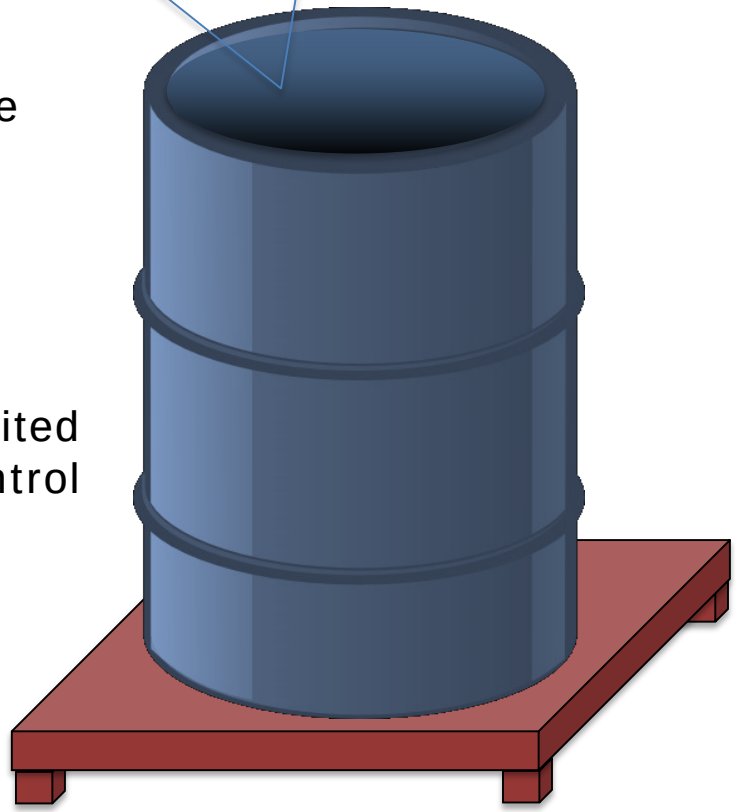
$$6UO_2F_2 + 6H_2O \leftrightarrows 2U_3O_8 + 12HF + O_2 \quad (2)$$

$$U_3O_8 + 2H_2 \leftrightarrows 3UO_2 + 2H_2O \quad (3)$$

Criticality Safety in Defluorination



Much less than infinite critical slab height



Meets limited moderation control

Under normal operations, criticality safety is ensured by the high temperature of the furnace heated section, the balance of gas flows and the isolation between the heated and cooled sections

Fault Identification (1)

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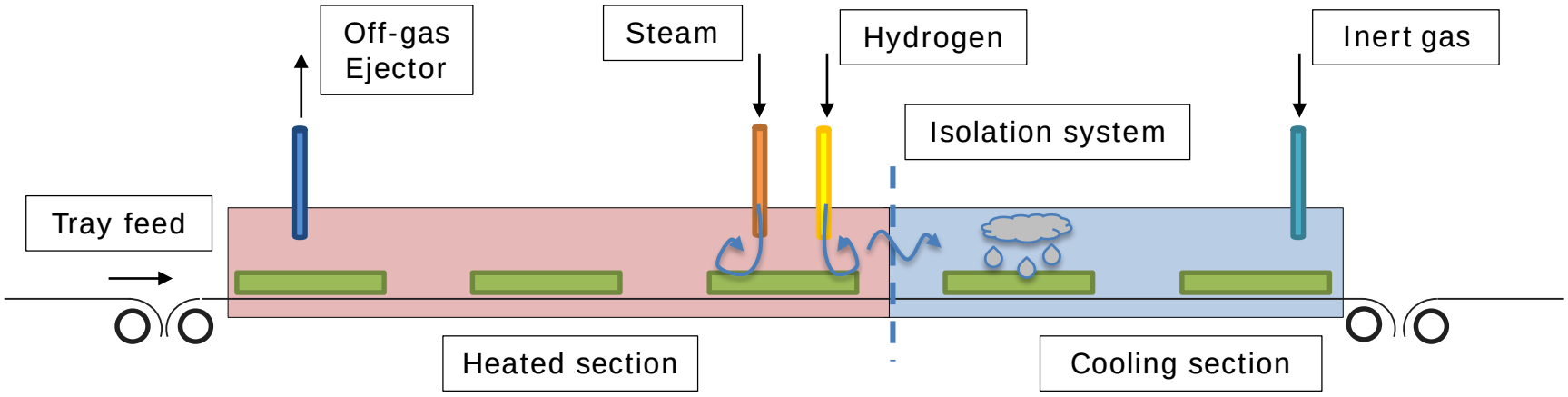
High Steam / Hydrogen Flow



Fault Identification (2)

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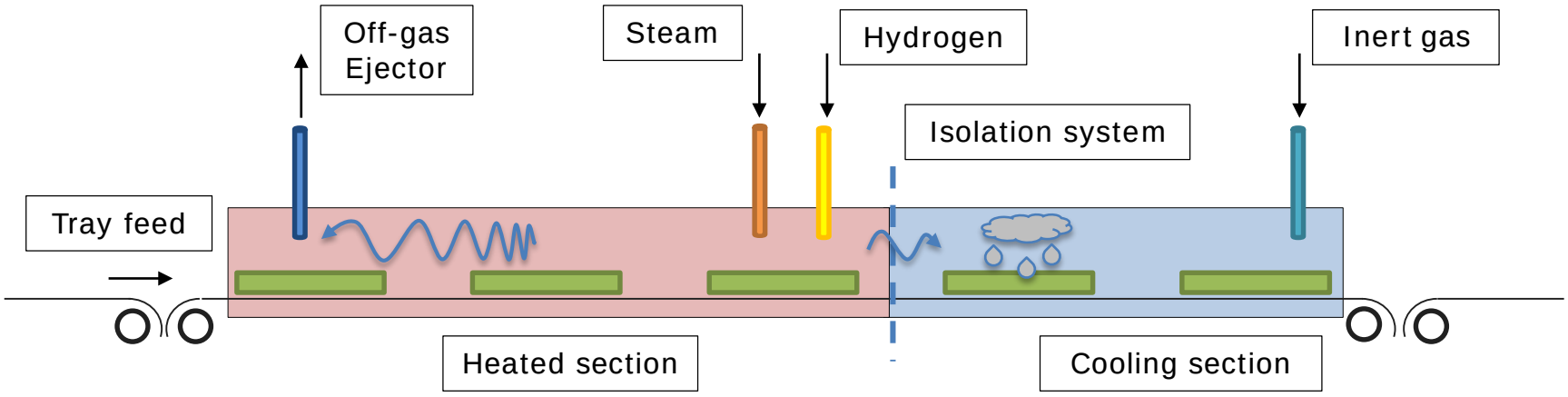
Total / Partial Failure of Heated Section Extract



Fault Identification (3)

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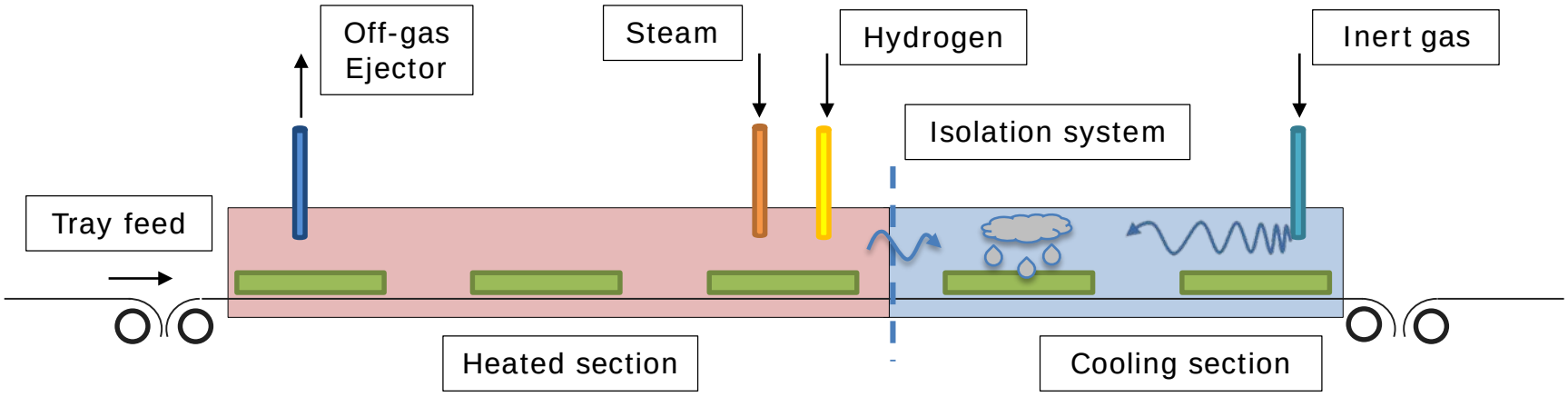
Total / Partial Loss of Inert Gas Flow to Cooling Section



Fault Identification (4)

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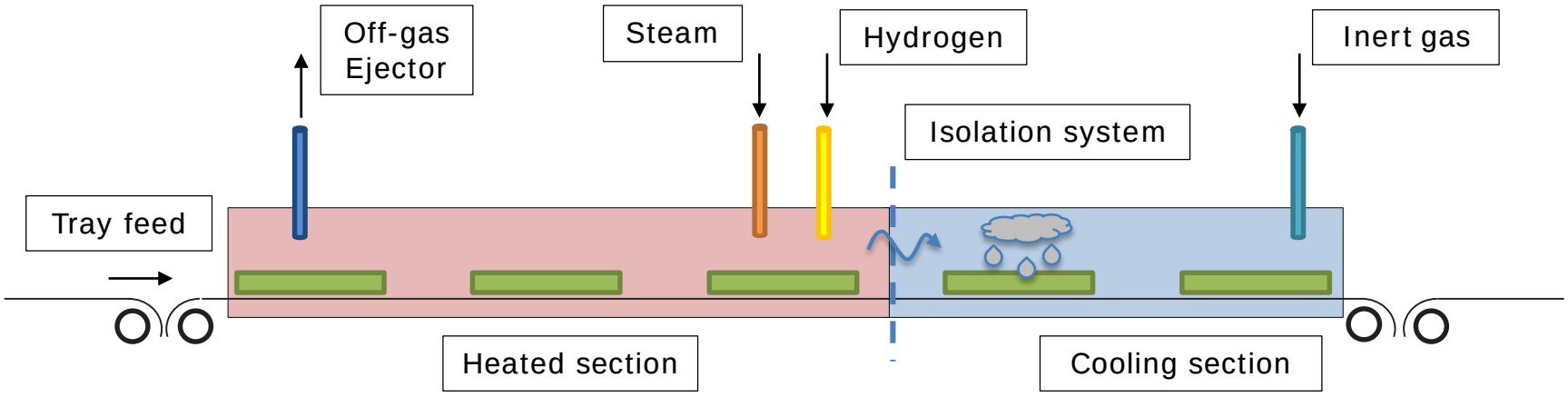
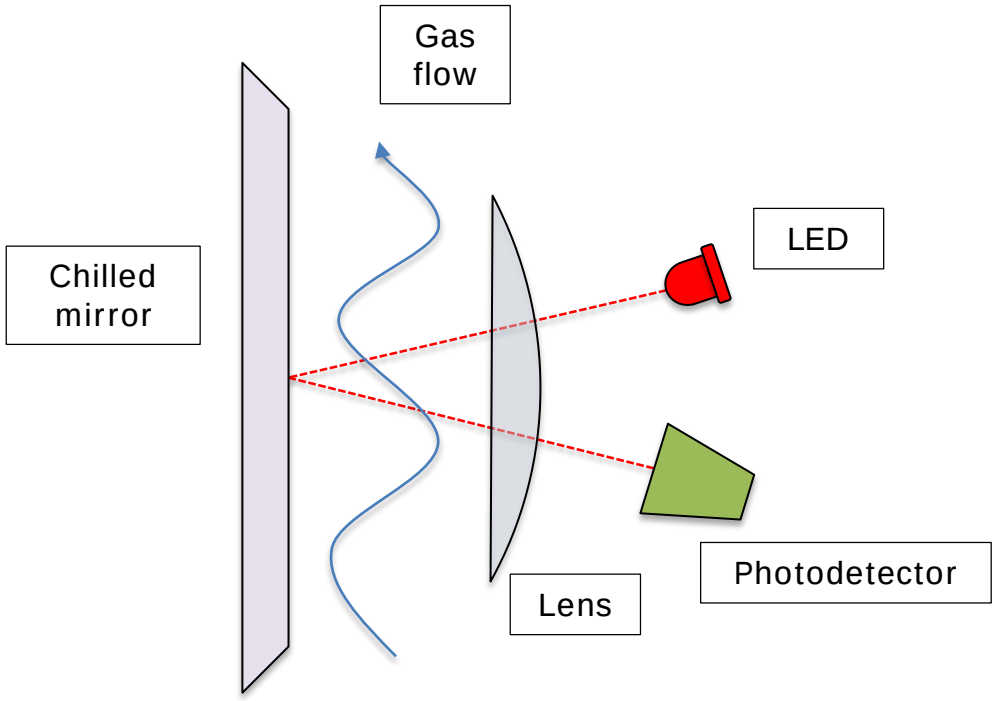
Failure of Isolation between Heated & Cooling Sections



Protective Measures (1)

Direct Detection – Chilled Mirror Hygrometer

- Mirror is chilled until moisture condenses
- Held at the temperature where the rate of condensation equals the rate of evaporation
- Dewpoint temperature ∝ relative humidity
- By comparing the relative humidity in the general atmosphere and close to the powder, an indication of whether the powder is wet or dry can be gained



Protective Measures (2)

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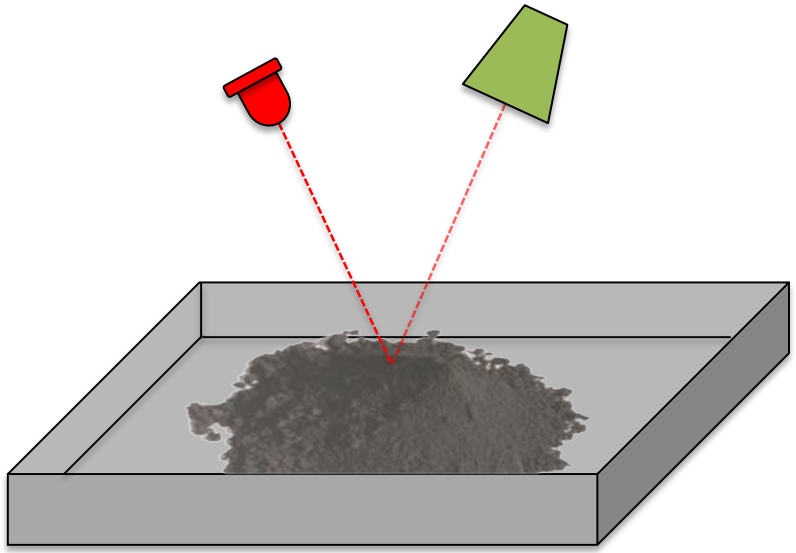
Direct Detection – Infra-Red Moisture Meter

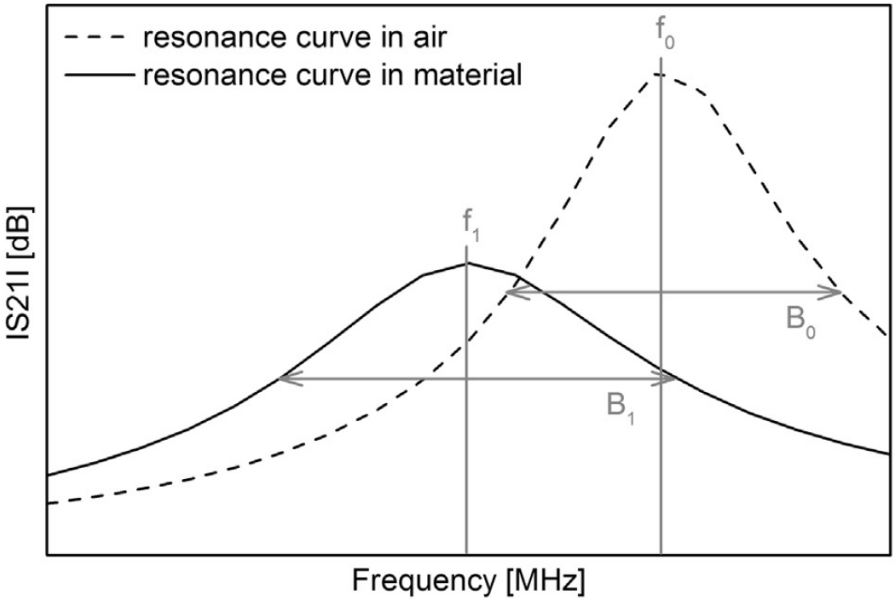
- Infra-red light shone onto powder
- Water is strong absorber of infra-red so intensity of reflected light inversely proportional to the moisture content
- Requires agitation or raking of powder to avoid only sampling the surface



Protective Measures (3)

Direct Detection – Microwave Resonance Technology

- Microwave beam sets up an electric field within the powder. The resonance response from this can be measured
- Water has high relative permittivity – it resists the electric field within a medium
- This results in a reduction in the frequency, and increased attenuation and broadening of the resonance response



Graph from J. Peters et al: "Design, development and method validation of a novel multi-resonance microwave sensor for moisture measurement"

Protective Measures (4)

Direct Detection – Manual Sampling

- Established laboratory methods (e.g. Karl Fischer Titration, TGA) can be used to determine the moisture content of a sample
- Requires operator input, so lower down the safety hierarchy ; not continual monitoring

A Karl Fischer Titration setup

Protective Measures (5)

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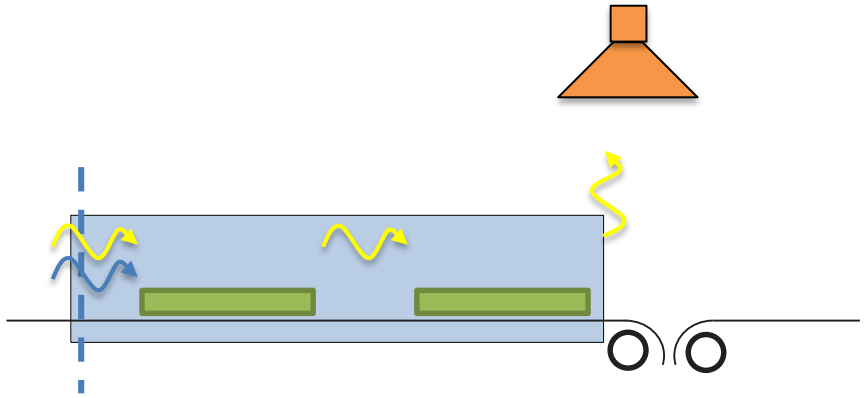
Indirect Detection

- Moisture / Hydrogen in cooling section atmosphere
- Instrumentation on isolation
- Flowmeters on supply feeds
- Thermometers on heated section



Case Study (1)

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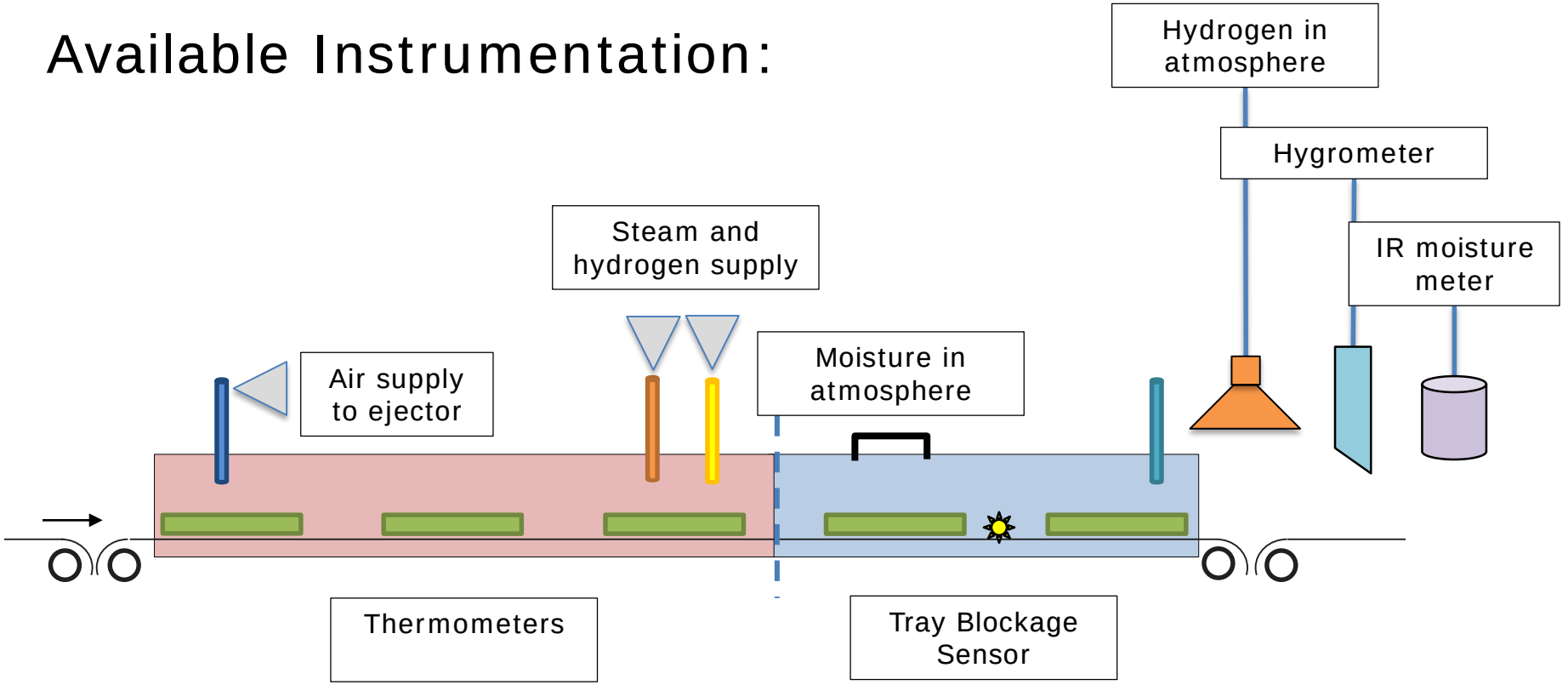
- An existing furnace system
- Hygrometer and infra-red moisture meter in place
  - Calibration of infra-red moisture meter requires significant operator input
  - Susceptible to changes in colour of the product, requiring recalibration
- Safety case methodology suggests two independent and diverse safety measures are in place to terminate progression to criticality

Case Study (2)

Available Instrumentation:



Case Study (3)

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Current Status

Operate under existing safety case with additional manual sampling

- Engineered protection is provided to shut down the furnace operation and steam supply
- The process remains safely subcritical under normal and credible abnormal conditions
- Whilst the sampling does still require operator effort it is considered the risk of criticality is as low as reasonably practicable (ALARP)

Conclusions

- The fault of condensing water into the UO_2 product cannot easily be dismissed
- Direct detection of moisture post-furnace provides the most robust protection for bulking subject to limited moderation control
- Instrumentation required is highly specialised and difficult to source

Case Study:

- No overall improvements to the criticality safety case were identified and it was recommended further consultation with instrumentation suppliers be undertaken

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