Small-Scale Industrial Explosions

The Search for Known Unknowns

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Quick Introduction to Me

- I am a Process, Safety and Equipment Consultant
- One of my specialist areas is DSEAR/ATEX – particularly dusts
- Industry sectors
  - Pharmaceuticals – Most of my work is in this sector.
  - Food
  - Specialist chemicals
- Mainly batch processes
- Scale – kgs to 10s of tonnes
- I have more problems with the small scale then the larger scale.
- I am an active volunteer with IChemE

Presentation Overview

- Project Overview
- Project Outcomes
- Example Known Unknowns

How Small is Small?

- BS EN IEC 60079-10-1 includes the following definition
  - hazardous area <on account of explosive gas atmosphere> - area in which an explosive gas atmosphere is present or can be expected to be present, in quantities such that special precautions for the construction, installation and use of equipment are required
- BS EN IEC 60079-10-2 includes the following definition.
  - hazardous area (dust) - area in which combustible dust, in the form of a cloud is present, or may be expected to be present, in quantities such as to require special precautions for the construction, installation and use of equipment.
- But what is the quantity? Or how small is small?
- BS EN IEC 60079-10-1 – Zone of negligible extent.

DSEAR and Small Quantities

- Regulation 8(4)
- Paragraphs (1) to (3) shall not apply where—
  - (a) the results of the risk assessment show that, because of the quantity of each dangerous substance at the workplace, there is only a slight risk to employees;
  - and (b) the measures taken by the employer to comply with his duty under regulation 6(1) are sufficient to control that risk.
- So again, quantity is important, but what is it? How small is small.
- Zone of negligible extent relevant again?

Project Definitions

- Small-Scale
  - Kilogrammes NOT grammes and NOT tonnes
  - Litres NOT millilitres and NOT cubic metres
  - Note HSEs Guidance Hazardous area classification and Laboratory operations defines this as medium-scale operation.
- Industrial
  - Manufacturing
  - Research and Development
  - NOT Academic Establishments
- Dusts and Vapours

Project Approach

- Define project for IChemE learned society.
- Seek IChemE permission
- Call for volunteers
- Develop questionnaire
- Explain questionnaire
- Call for response to questionnaire.
- Collate responses
- Analyse results

I would like to acknowledge the contribution of my fellow IChemE volunteers and IChemE staff for their help in setting up and the running of this project.

Initial Project Outcome

- 37 Problems listed as a result of questionnaire. 2 of which were duplicates
- 10 Known Unknowns
- 20 Unknown Knowns
  - This illustrates a strong need for further education and training.
- 7 Unclassified

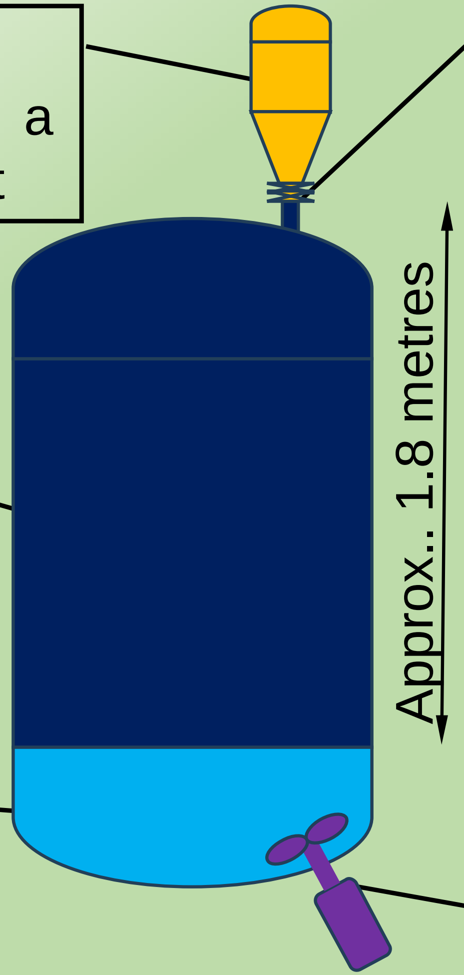
Case Study 1

Charging Powder By Gravity

Overview

- Charging 25 kg of dry sieved fine sugar by gravity into a 3000-litre agitated (bottom mounted) stainless vessel.
- Vessel contains 500 litres of water, which covers the agitator.
- Powder is charged from a 50-litre pot via a 150 mm dia powder containment valve.
- Powder takes 2 minutes to charge
- Powder easily dispersed

Layout of Charging Process



Sugar Physical Properties

- d_{50} = 25 µm
- Minimum ignition energy = <10 mJ
- Minimum explosive concentration = 30 g/m^3
- Maximum explosion pressure = 9.1 bar
- Explosion constant K_{st} = 140 bar m/s
- Minimum ignition temperature
  - Dust cloud = 350°C
  - Layer = 420ºC
- Particle density = 1.58 kg/m^3
- Limiting oxygen concentration = 9%

How Much is Dispersed

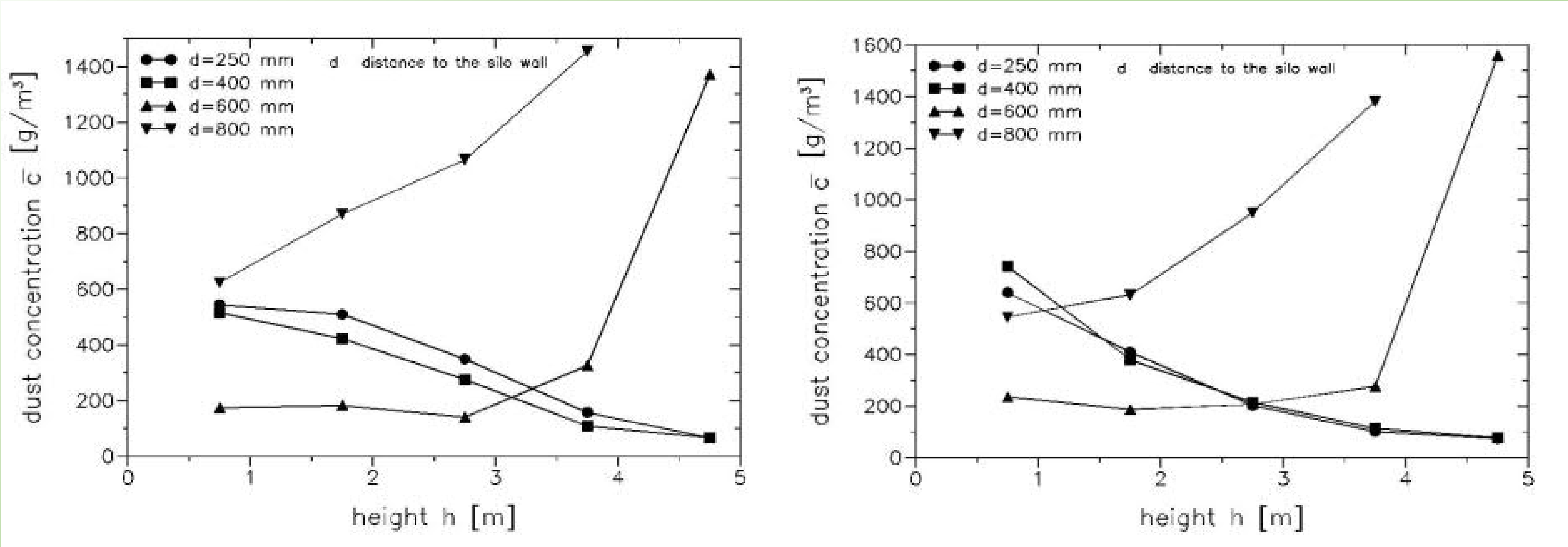
Assumes that a homogeneous mixture is formed.

Mass of Solid Charged to 1m³ vessel (kg)	Percentage Dust Generation		
	0.5% {1}	3.0% {2}	17.0% {3}
2.5	12.5 g/m³	75.0 g/m³	425.0 g/m³
5.0	25.0 g/m³	150.0 g/m³	850.0 g/m³
10.0	50.0 g/m³	300.0 g/m³	1700.0 g/m³

The higher concentrations are in line with tests at an industrial scale as shown on the next slide.

{1} Plinke, A. E., Leith, D., Boundy. M. G., Löffler, F. (1995) Dust generation from handling powders in industry, Am. Ind. Hyg. Assoc. J., 56, pp 251-257- High (> 1%) moisture content solids
{2} Plinke et al - Low (~0.1%) moisture content solids
{3} Ansart, R., de Ryck, A., Dodds, J. A. (2009) Dust emissions in powder handling: Free falling particle plume characterisation, Chemical Engineering Journal, 152, Issues 2-3, pp 415-420

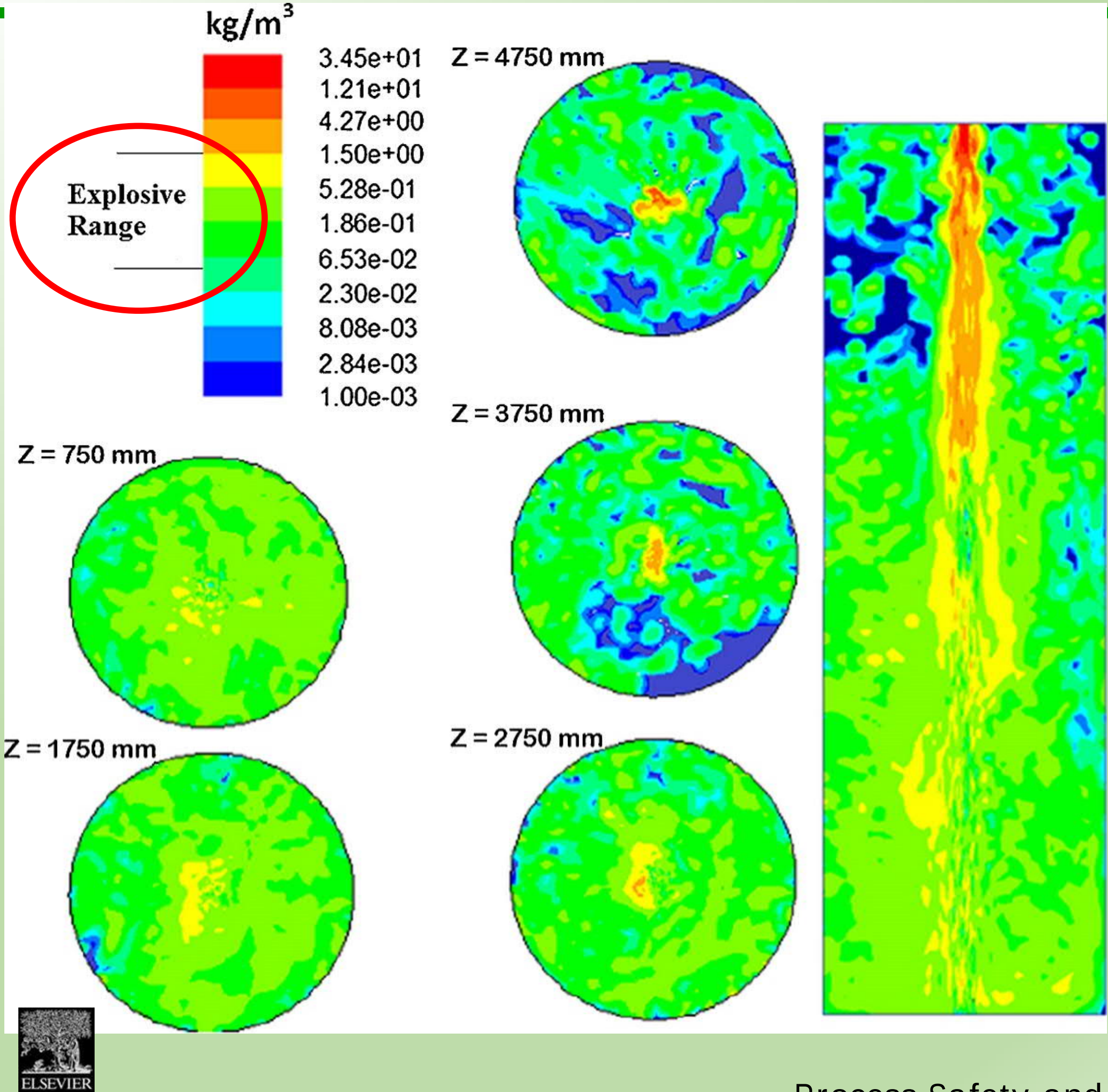
Dust Concentration in a 12 m^3 Silo



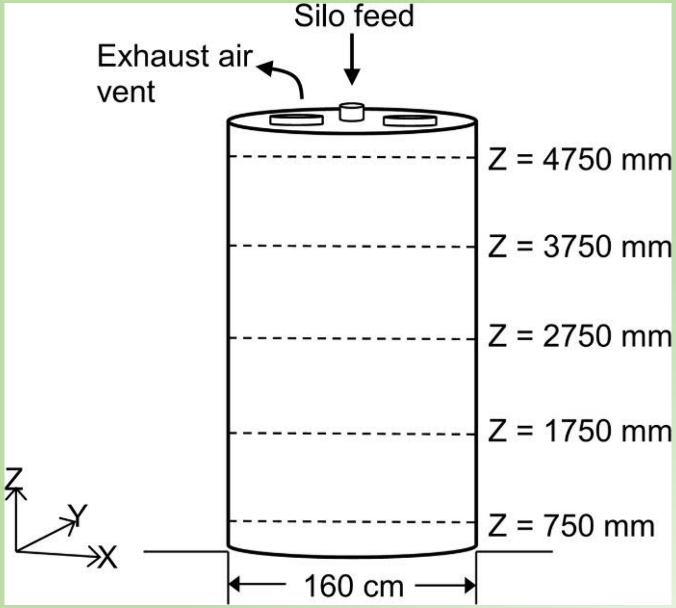
Solid fed pneumatically via a vertical nozzle at the centre of the top of 12 m^3 silo. With no solid in the hopper in the left-hand graph and with solid in the hopper in the right-hand graph.

See "Hauert, F., and Vogl, A., Measurement of Dust Characteristics in Industrial Plants, Final Technical Report, January 1995" for more details

Dust Concentration in a 12 m^3 Silo



Concentration after 80 seconds



Validated against experimental results. See for Hauert and Vogl for experimental results.

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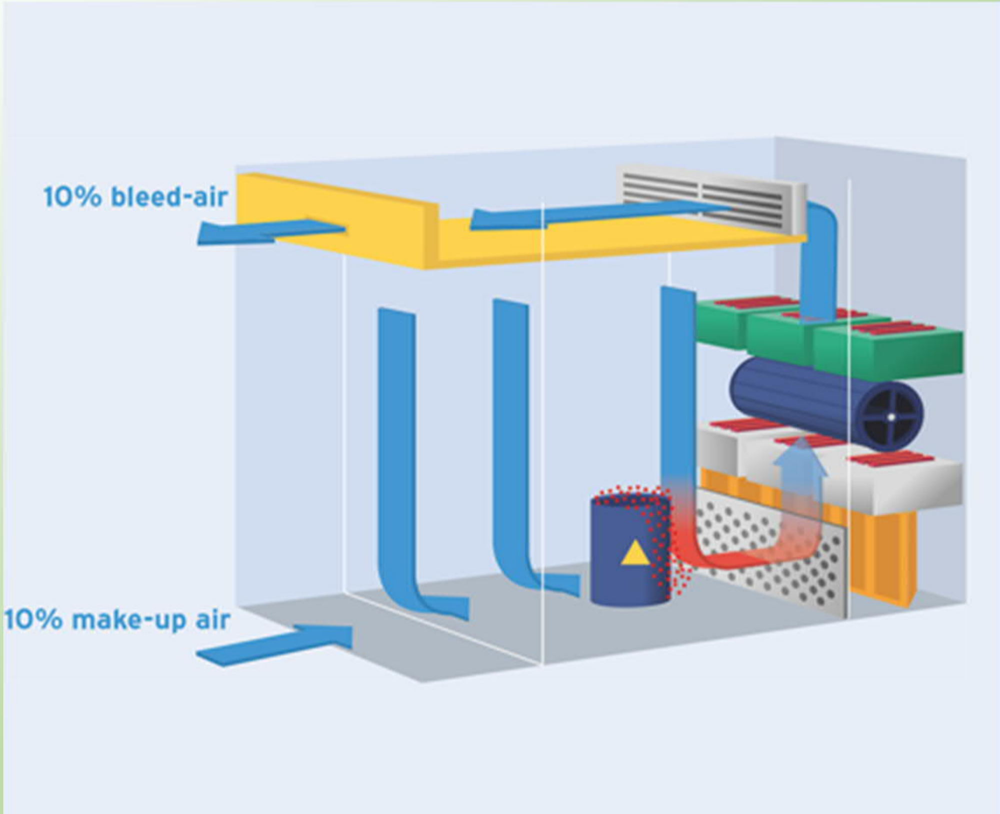
Issues

- How much dust is dispersed?
- Should the vessel internals be Zone 21 or Zone 20?
- What happens if the water is not added?
- Known Unknowns –
  - How much dust is dispersed or what is the dust concentration.
  - How much static electricity can be generated.
- Bottom mounted agitator is a potential source of ignition.

Case Study 2

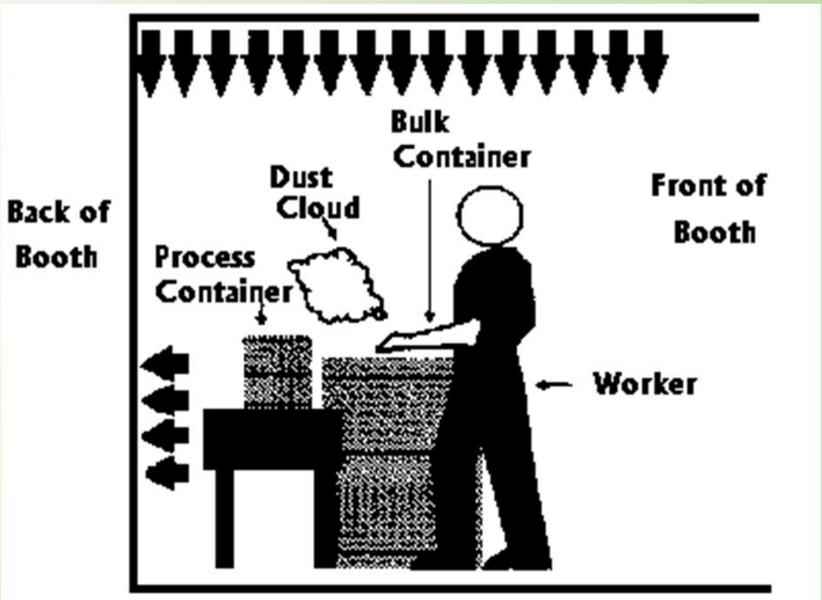
Dispensing in a Downflow Booth

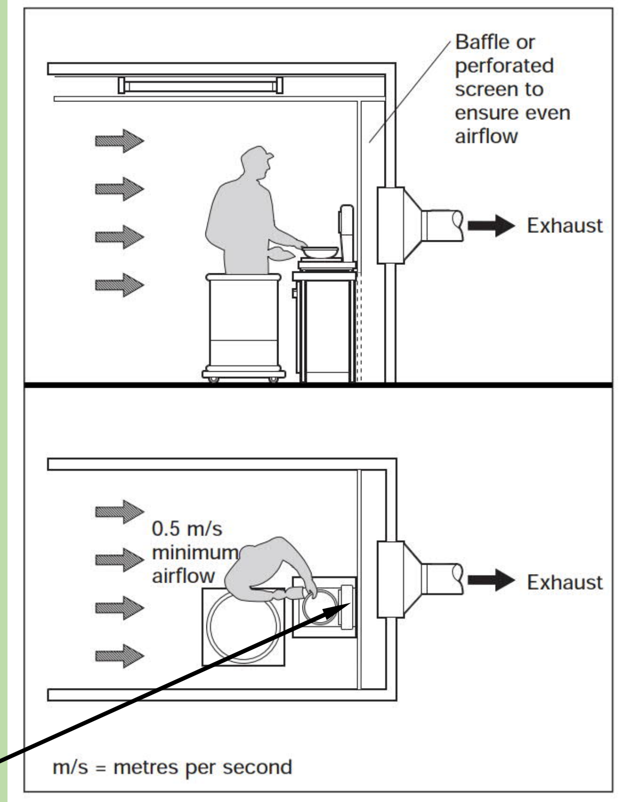
Downflow Booth



Working Principle

Dispensing





Frequently the process container is stood on a weigh scale

Issues

- Downflow booth is designed to protect the operator down to levels of 100 µg/m^3. This is 4 orders of magnitude lower than the MEC for most powders.
- Dispensing usually carried using a hand scoop in aliquots of 0.1 to 0.5 kg.
- Much of the equipment inside downflow booth is not ATEX rated.
- Known Unknown – How big are the zones.
  - My usual zoning solution is a Zone 1 in the process container which extents a short distance from the top of the container. Plus, a Zone 22 which extents for a short distance around the process container and includes the weigh scales.
  - How short is short?

Case Study 3

Liquid Spillage

Liquid Spillage on Laboratory Floor or Bench

How Big is the Pool of Liquid?

- The area of pool *Ap* can be estimated by calculating the depth of the pool *Dp* and assuming the quantity of liquid spilt, for example, 2 litres from broken Winchester.

$$Dp = ((1 - \cos(\theta))\sigma/\rho g)^{0.5}$$

- Where
  - θ = Angle of contact
  - σ = Surface tension
  - ρ = Liquid density

Calculate Evaporation Rate

- The evaporation rate can be estimated using equation B.6 in BS EN IEC 600079-10-1

Then the evaporation rate could be estimated by using following equation:

$$W_e = \frac{18{,}3 \times 10^{-3}\ u_w^{0{,}78}\ A_p\ p_v\ M^{0{,}667}}{R \times T} \text{(kg/s)} \qquad \text{(B.6)}$$

Issues

- If a glass bottle is dropped will the whole contents spill?
- Few values for θ in the public domain.
- Literature sources for θ indicate that for methanol it is less than 1°, which results in pool sizes that are very large.
- HSE laboratory guidance indicates that only a pool fire would occur i.e. a zone of negligible extent, but my calculations suggest that for methanol and highly volatile liquids a significant hazardous zone will form.
- Is equation B.6 relevant to indoor locations?

Size of Hazardous Zone

- The method for calculating the size of hazardous zone given in BS EN IEC 60079-10-1 appears to massively overestimate the size.
- Possibly this is because this calculation method assumes pseudo-steady state whereas the evaporation from a pool will be non-steady state particularly for highly volatile liquids.
- I have had results that indicate the hazardous zone completely fills the laboratory when the quantity of liquid, if completely evaporated, would only provide enough vapour to create a hazardous zone very much smaller than the laboratory in question.

HSE Guidance for Laboratory

- HSE Guidance - Hazardous area classification and Laboratory operations states:

Medium scale operations
Where quantities are larger but still manipulated on the open bench, for example up to 2.5 litres, in a Winchester bottle, the risks are more significant. The actual extent of a flammable atmosphere following a spill may well be a radius of up to a metre, but only a very small height above the liquid level. Any ignition of a spreading pool will produce a fire that quickly extends to the whole area of the spill, and could cause a risk to laboratory staff. Particular dangers arise if the spill enters the drains, as an explosive atmosphere could then form in an enclosed space.

- Pool size may be correct for many solvents but not those with a low angle of contact such as methanol.
- Volume of flammable atmosphere may be greater than implied by this guidance.

Next Stage – Further Research

- Progress education
- Further analysis of the responses.
- Carry out further detailed research by identifying partners to move Known Unknowns into Known Knowns.
  - Literature searches
  - University projects undergraduate and postgraduate.
  - Industrial research organisations potential via joint industry partnerships.

Many thanks for listening

And again, many thanks to my fellow IChemE volunteers and IChemE staff.

I will now answer questions