David Purser

# Grenfell Tower Inquiry
## Phase 1 Report Presentation

***Exposure of Grenfell occupants to toxic fire products***
***– effects on escape and survival***

***Part 3***
***Possible Toxicity Performance of Materials Present at Grenfell Tower***

**Prof. David Purser CBE**
**Hartford Environmental Research**

HER

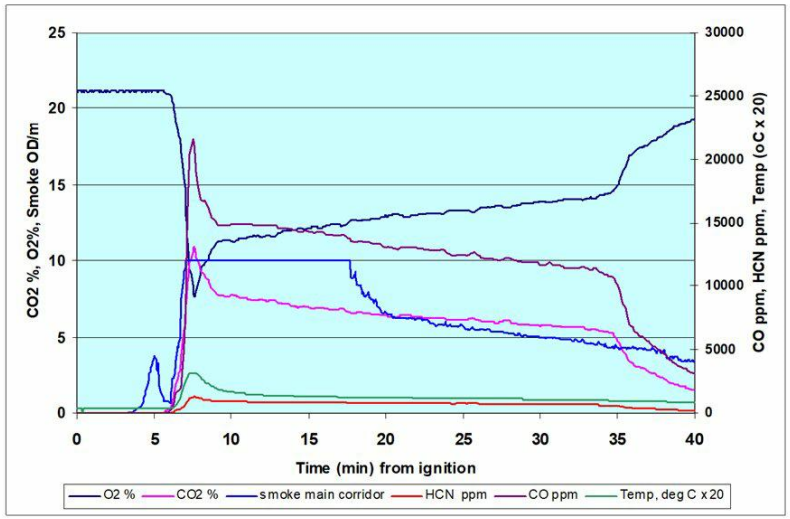
David Purser

## Contribution of materials to toxic hazards in flats

- Contribution of any burning materials to toxic hazards at Grenfell depend on extent that their combustion products form part of the time-concentration curves for toxic smoke and gases inhaled by each occupant
- Depends on:
  - Mass burning rate (kg/s)
  - Yields of toxic products (for example kg CO per kg material mass burned)
  - Volume into which the products are dispersed (kg/m$^3$ )

- Yields of smoke and toxic gases from any material depend on:
  - Elemental composition: mass % C,H,O N,Cl,Br,P inert fillers
  - Organic composition (type of polymer):
    - e.g. polystyrene (XPS) or polyisocyanurate (PIR)
    - Flame retardant additives
  - Combustion conditions
    - for flaming fires the fuel to air equivalence ratio [φ]

  i.e. For well ventilated fires the yields of toxic smoke products is low; for under ventilated fires, the yields of toxic smoke is high




Rosepark: smoke heat and gases in open bedroom off fire corridor

HER

David Purser

## Conditions in flats

- For developing hazards for each Grenfell flat there are three main fuel packages of interest:
- Combustible parts of rainscreen cladding and insulation
    - Reynobond 55 rainscreen panels 3 mm thick polyethylene (LDPE) (estimated density 0.92 g/cm$^3$ , 2.8 kg/m $^2$ )
    - 2 x Celotex RS5080 panels on spandrels 80 mm thick polyisocyanurate foam (PIR) (density 2.8 kg/m$^2$ )
    - 1 x Celotex RS5100 panels on columns 100 mm thick polyisocyanurate foam (PIR) (density 3.38 kg/m$^2$)
- Combustible parts in the window surrounds and between the windows
    - Exterior window infill panels 25 mm thick extruded polystyrene (XPS) estimated density 38 g/cm$^3$ , 0.95 kg/m$^2$
    - window surround 9.5 mm thick polyvinylchloride (uPVC) (estimated density 1.5 g/cm$^3$ ,14.25 kg/m$^2$)
    - Other smaller component of window surround not considered include polyurethane foam “Purlboard” insulation above windows, foam backing of uPVC and expanded foam infill, items of PIR foam around windows, wood, EDPM rubber weatherproofing membrane on interior sides of windows

•Combustible flat contents

- solid and upholstered furniture, appliances, soft furnishings and clothing, cupboard, storage and interior doors

Rosepark closed bedroom

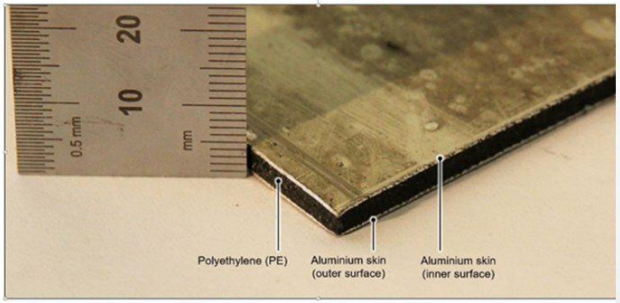
HER

David Purser

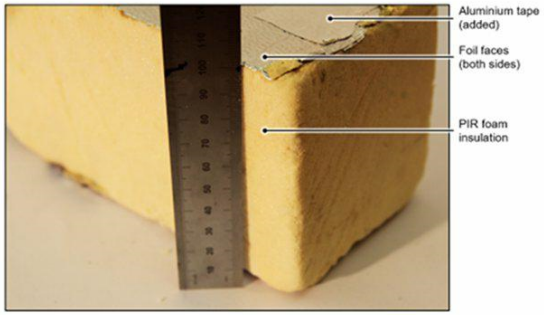
# Grenfell structural materials

## Reynobond PE

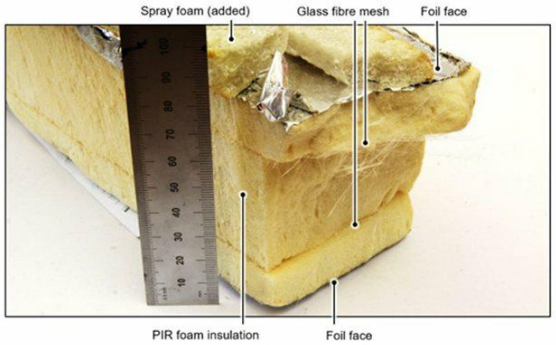
Rainscreen Cassettes & Architectural Panelling



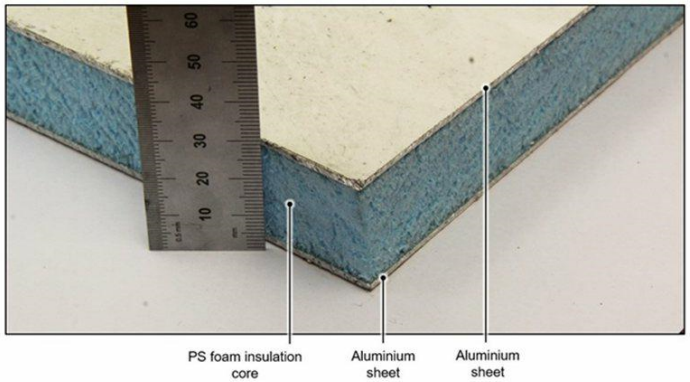

## Polyisocyanurate (PIR) Foam Insulation (on Column Sectior



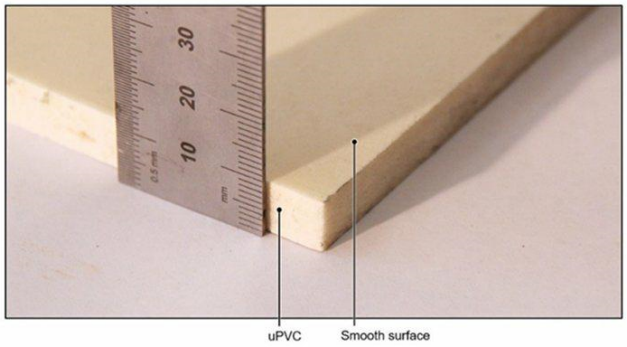

## PIR Foam Insulation (on Spandrels Sections)




## Window Infill Panels




## uPVC Window Boards

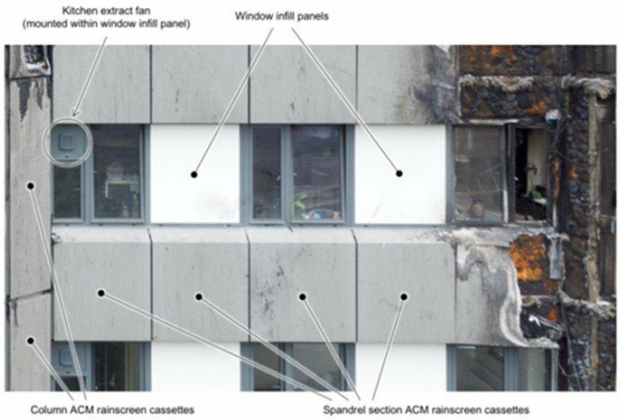



Images from Bisby Phase 1 presentation

HER

David Purser

# Locations and damage to structural materials and contents




cladding, insulation, and window infill panels Bisby Fig 9 MET00004480

Upper floors of Tower showing extensive loss of cladding, insulation, and window infill panels MET00004491

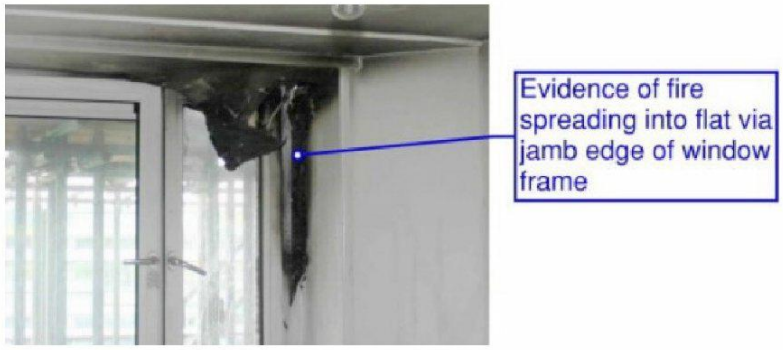



Figure 10.52: Burned uPVC frame in Flat 15

Burned uPVC window frame in Flat 15

Figure 43: Kitchen window, Level 6, Flat 36

Fire damage around window and some damage to flat contents Flat 36

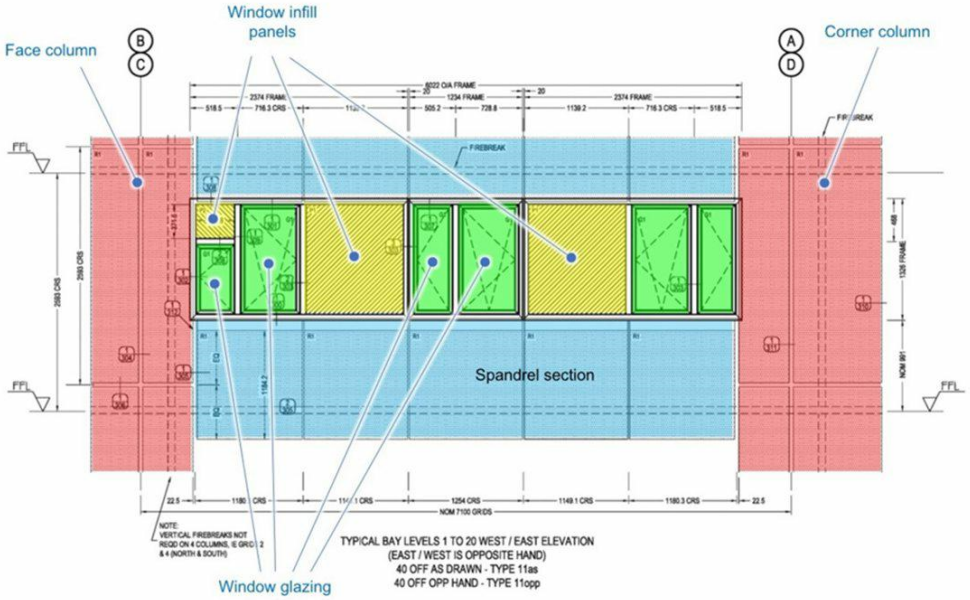
Torero Figure 43

HER

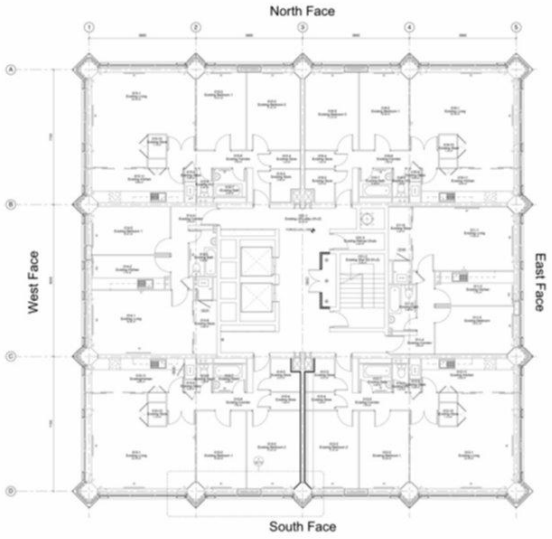
David Purser

## Tower dimensions

Area and mass of fuel items outside and around windows of one and two bedroom flats calculated from Tower dimensions in Bisby Phase 1 report  Figures 5,8 and 36.




Bisby Figure 8 Tower floor elevation dimensions east and west faces




Bisby Figure 5 Tower floor plan dimensions

HER

David Purser

## Combustible masses for each flat

- Combustible contents of individual flats unknown and variable.
- Estimate made of typical flat combustible contents including solid and upholstered furniture, appliances, soft furnishings and clothing, cupboard, storage and interior doors.
- Carbon and nitrogen estimated from generic composition of these items

**Table 1: Approximate masses(kg) of combustible fuels per flat**

| | PIR | LDPE | XPS | PVC | Flat contents |
|---|---|---|---|---|---|
| 1 bedroom flat | 66.3 | 35.3 | 2.9 | 78.8 | 471 |
| 2 bedroom flat | 158.4 | 90.1 | 7.2 | 183.8 | 661 |

- Combustible mass of flat contents is greater than that of the other components
- Total mass of PIR insulation in columns and spandrels outside each flat is large = ~25% of total flat contents mass
- Total mass of LDPE in rainscreen cladding also large = ~14% of total flat contents mass
- Total mass of XPS panels is small = ~ 1% of flat contents mass
- Total mass of uPVC around window interiors is large =~28% of total flat contents mass

As an approximate guide, the combustion products from at total of 5-7 kg or material dispersed into the volume of a flat would produce dense smoke and a toxic gas environment capable of causing incapacitation and death after a few minutes exposure

HER

David Purser

## Composition of fuel materials

**A list of toxic gases that may be produced by Grenfell Related Material (including flat contents)**

- Composition measured for generic materials of the same polymers as at Grenfell (Purser and Purser 2003 [see Table 3 in Purser Phase 1 report]).
- Same source used for a polymer mix to estimate the generic composition of the total contents of a flat

**Table 3: Mass percentages of carbon, nitrogen and chlorine in Grenfell-related materials**

| | Carbon | Nitrogen | Chlorine | | |
|---|---|---|---|---|---|
| Polyisocyanurate PIR | 66.3 | 6.15 | 3.65 | | |
| Low density polyethylene LDPE | 85.6 | 0 | 0 | | |
| Polystyrene foam (XPS) | 92.3 | 0 | 2 | | |
| Polyurethane foam (PUR) | 56.5 | 8.2 | 2.53 | | |
| Polyvinylchloride (PVC) | 38.4 | 0 | 56.7 | | |
| Plywood | 46.3 | 0.32 | 0 | | |
| Mixed flat contents (approximate) | 50 | 3.7 | 2.0 | | |

Note: these proportions are for materials tested from Table 2, not for actual products present at Grenfell and may vary slightly in commercial products with different formulations.

- All have a high carbon content – producing smoke (soot) particles, organic irritants and carbon monoxide during combustion
- PIR and PUR have a high nitrogen content – producing oxides of nitrogen (NOx) and hydrogen cyanide (HCN)
- PVC has a high chlorine content and PIR (also possibly XPS) a significant chlorine or bromine content, producing highly irritant hydrogen chloride (or hydrogen bromide) during combustion
- This also reduces combustion efficiency, increasing yields of CO and HCN from other fuels
- Mixed flat contents has a significant nitrogen content from PUR and other materials and chlorine from additives and PVC

HER

David Purser

# Yield data used for flat toxic hazard assessment

- LDPE cladding and XPS panels burned mainly in open air on the building exterior: so estimated reasonably well-ventilated combustion condition
- PIR insulation burning in cavity likely to be under-ventilated (φ 1.5-2.0), but when cladding falls or it is exposed to the open air so likely to become well ventilated (φ <1)
- Therefore I used both cases.
- PVC window surround was initially well-ventilated and produced similar yields across φ range – used φ 1
- When flat contents became involved, the conditions were already under-ventilated so I used (φ 1.5-2.0)
- Smoke and toxic gas yields measured using the ISOTS19700 test method and validated using large-scale compartment fires (Purser 2003 and Phase 1 report Table 4)
- smoke, CO and HCN yields lowest under well-ventilated flaming combustion conditions (φ 0.5-1) but higher for under-ventilated combustion

HER

David Purser

# Potential contribution to toxic hazards from different materials in a two bedroom flat

- Some diluted outside smoke from floors below enters flat: hazard low.
- Fire outside flat: flames and dense toxic smoke enter: immediately very hazardous
- Two-bedroom flats most vulnerable: greater mass of cladding, insulation and window surround materials
- Most people took refuge in two-bedroom flats
- Time to untenable conditions depends on area of flat exterior and windows involved, and timing and extent of fire involvement of contents.

**Table 5: Two bedroom flat – potential mass concentrations and gas concentrations from different fuels**

| Material | φ | Mass (kg) total | Mass (kg) 5% | Mass Conc Kg/m$^3$ (5%) | $CO_2$ % | CO ppm | HCN ppm | Smoke Visibility (m) | Time to Asphyxia (min) |
|---|---|---|---|---|---|---|---|---|---|
| LDPE ACM | <1 | 90[1] | 4.7 | 0.025 | 3.5 | 598 | 0 | 0.25 | 160 |
| PIR insulation | <1<br>>1 | 79[2] | 4.0 | 0.022 | 2.1<br>1.1 | 2157<br>6247 | 95<br>389 | 0.39<br>0.21 | 23<br>2 |
| PS window | <1 | 7[1] | 0.4 | 0.002 | 0.02 | 94 | 0 | 2.66 | >180 |
| PVC window | <1 | 184 | 9.2 | 0.051 | 1.7 | 4414 | 552[3] | 0.22 | 13 |
| | | | | | | | | | |
| Flat contents | >1 | 661 | 3.3[4] | 0.018 | 1.5 | 2506 | 164 | 0.29 | 10 |

[1]Estimated 100% burned [2]Estimated 50% burned [3]HCl [4]0.5% burned

- Table shows potential contributions from materials to toxic hazards in two-bedroom flat (and lobby beyond).
- First burning materials generating toxic smoke into flat are the LDPE rainscreen cladding and the PIR insulation
- Exterior burn: most smoke flows up outside of Tower
- Proportion entering flats unknown, for calculations estimated:
  - smoke and gases from 5% of the mass combusted flow into the flat
  - smoke and gases from 95% of the mass combusted flows away up outside of Tower.
- Most cladding lost so estimated 100% combustion of the PE, producing lower yields of smoke and CO
- Most PIR insulation on columns lost and most of one of the two layers on the spandrels: so estimated 50% PIR burned depending on ventilated or under ventilated conditions, producing either lower or higher yields of smoke, CO and HCN
- Next involved window surround materials XPS panel burned away (100% combustion) on exterior (estimated products from 5% entered flat and 95% lost outside)
- PVC estimate for early stage fire with 5% of the mass is burned and products generated inside the flat
- Next involved flat contents: estimate situation an early stage for 0.5% of the fuel mass burned

HER

David Purser

# An overview of gas produced by toxic products

Toxic Products from each material considered alone:

- LDPE on its own will produce dense smoke but low concentrations of carbon monoxide
- PIR on its own will produce dense smoke, carbon monoxide and cyanide
- Polystyrene (XPS) on its own will produce some smoke but not much
- PVC on its own will generate dense, highly irritant smoke and carbon monoxide
- Flat Contents will produce dense smoke, carbon monoxide and cyanide

In combination:

- Overall effects from combustion of structural materials (LDPE, PIR, XPE,PVC) are additive
- This is predicted even if there is no involvement of the flat contents

HER