David Purser

Grenfell Tower Inquiry
Phase 1 Report Presentation

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

Part 2

Fire hazard scenario development and effects on occupants during the Grenfell incident

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Performance-based fire safety design principle

Performance-based design principle:

Fire hazards depends on two parallel processes:

- The time from ignition to when the fire become dangerous
- The time needed for occupants to escape

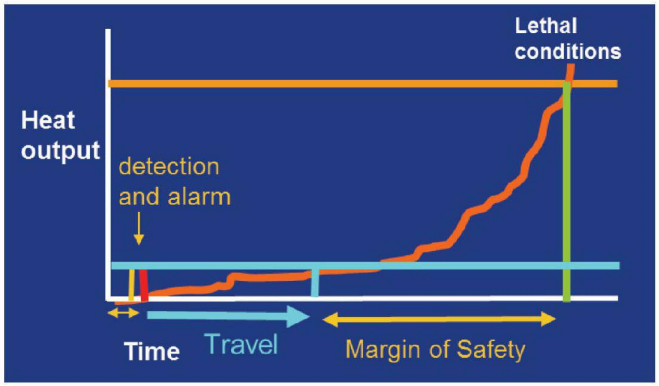
(or the time they can stay put in a place of safety)

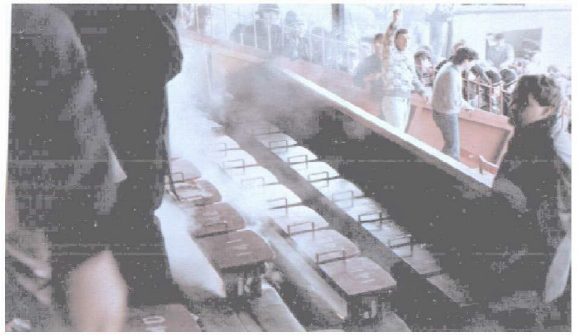
In any fire incident in a any building:

Available Safe Escape Time > Required Safe Escape Time by an appropriate safety margin

ASET = time from ignition to loss of tenability

RSET = time from ignition to escape





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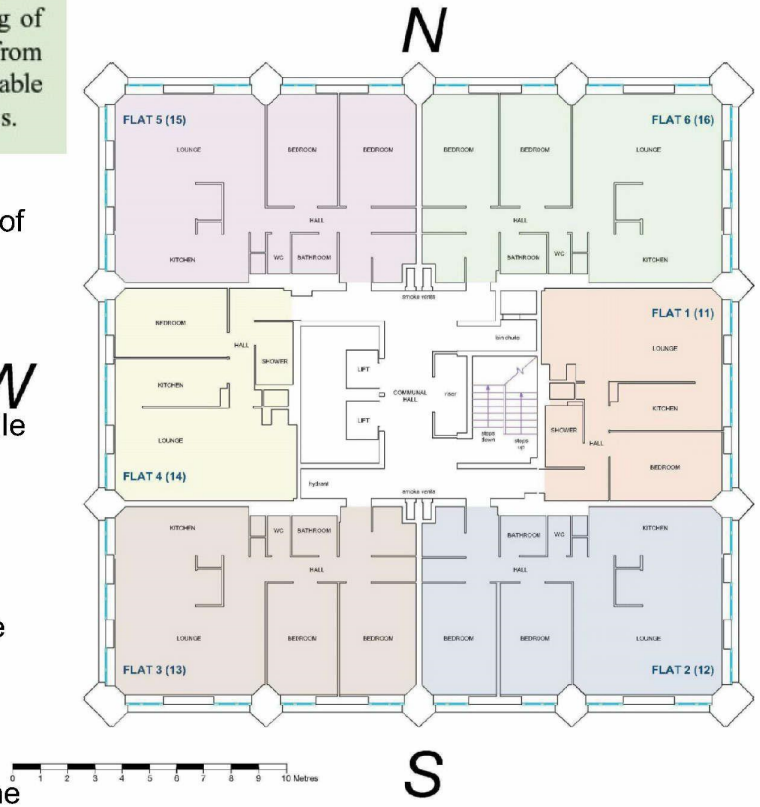
Grenfell Tower Design

Means of warning and escape

B1. The building shall be designed and constructed so that there are appropriate provisions for the early warning of fire, and appropriate means of escape in case of fire from the building to a place of safety outside the building capable of being safely and effectively used at all material times.

- Warning: Each flat is required to have smoke detector-alarm so that occupants of that flat are alerted and can escape quickly in case of fire
- Each flat is a fire resisting compartment with self-closing fire resisting front door opening into a fire protected and fire sterile communal lobby, containing lifts and escape stair, ventilated to disperse any smoke entering it
- Escape stair in fire and smoke resisting compartment shaft, with a fire and smoke resisting door to enter the stair at each floor.
- Smoke extraction system designed to extract smoke from a lobby and isolate the other lobbies



"Stay put" policy

- Residential blocks of flats and maisonettes are designed for a "stay put" policy in case of fire.
- This means that occupants of the fire flat should evacuate, but that all other residents are encouraged to stay put unless they feel threatened – but they should always be able to escape if they wish to.
- Each flat is fire compartment – designed with fire resisting construction so that the flat contents should be able to burn out within this time, with a very low probability that flames or smoke would be able to spread to other flats at all or stairs.
- The protected stair is designed to be a place to temporary refuge during a fire, so occupants should be able to escape safely once they have entered the stair.

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Grenfell design

Clearly all these requirements were failed at some time during the incident:

- External fire spread up the exterior
- Fire penetration around the windows of flats involving both exterior cladding and insulation but also structural materials around the windows
- Spread of smoke and later fire from burning flats into communal lobbies
- Failure to maintain as a safe escape route due to smoke spread into the lobbies and stair

For my investigation I am attempting to establish:

- How and when smoke and flames penetrated individual flats on the East side of the Tower from the exterior fire and how occupants were affected in terms of escape and survival
- How and when dense smoke penetrated into the lobbies and how this affected the behaviour, escape capability and survival of flat occupants
- How and when dense smoke penetrated into the stair and how this affected the behaviour, escape capability and survival of flat occupants
- How and when smoke and flames later penetrated other flats in the Tower where occupants had taken refuge (stayed-put) and how this affected the behaviour, escape capability and survival of flat occupants

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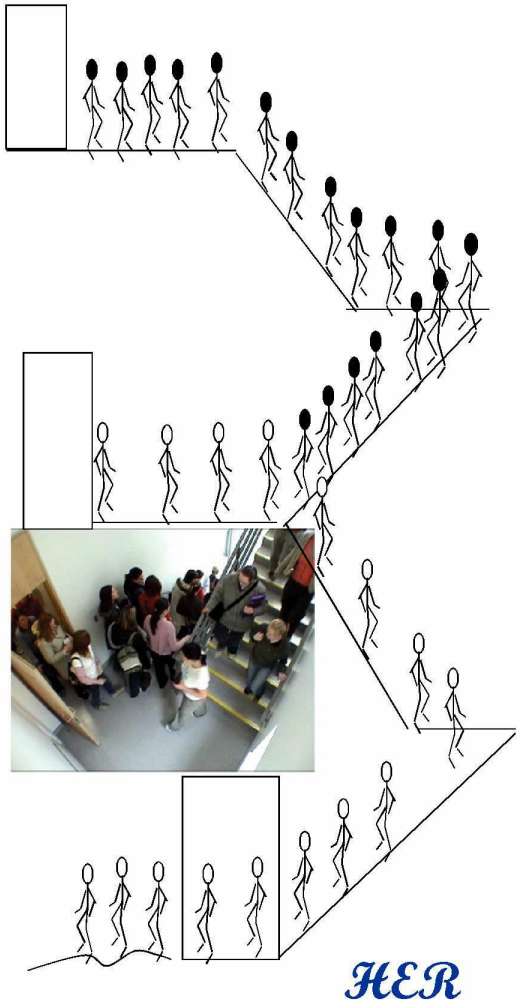
Evacuation of Grenfell occupants

Evacuation capacity of the Grenfell stair

- If 293 occupants in the Tower had decided to evacuate simultaneously soon after 01:00 hrs, before there was smoke in the lobbies or stair, how long would it take to clear the building?

Standing capacity in the stair:

- For buildings designed for simultaneous evacuation Approved Document B assumes a standing density in a stair of 4 person/m^2.
- For a 1 metre wide stair and landings over 23 storeys such as Grenfell the capacity would be ~ 920 persons (40 per floor). This would be very crowded with standing room only and people would have to wait in the stair until it cleared from below
- In practice during experimental evacuations I have carried out in tall buildings I have found people tend to adopt a maximum of 2 persons person/m^2 (capacity ~460 persons = 20 per floor). At this density occupants could walk down, but slowly due to the crowding.
- If 293 Grenfell occupants entered the stair simultaneously this represents 13 per floor (1.3 persons/m^2)
- So even in this extreme case the stair would not be crowded and occupants would be able to stand or move freely. In practice occupants never all start to evacuate at once, and at Grenfell they did so over an extended period, often individually or as small groups.



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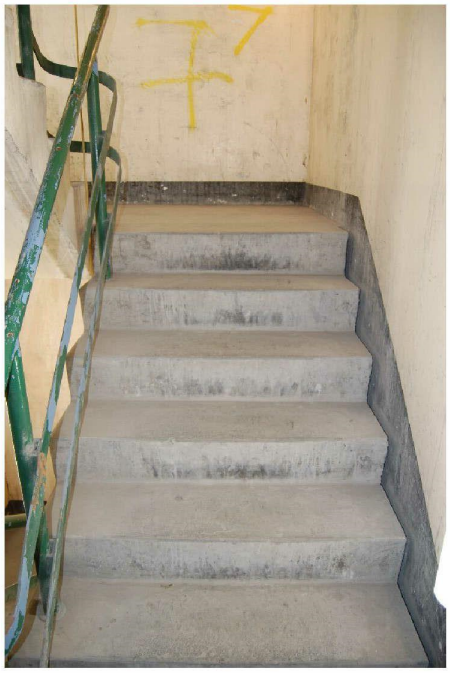
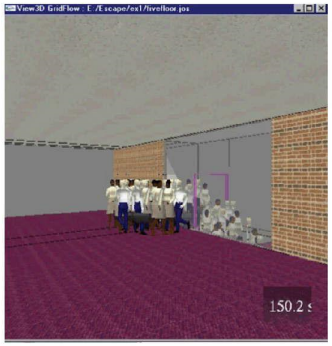
Evacuation of Grenfell occupants



Time required to descend the stair:

- Time required to clear the building using the stair for simultaneous evacuation depend on two main aspects:
  - Building height (number of floors)
  - Maximum flow capacity of the stair (persons/minute)
- During a visit to the Tower I measured my descent time (73 year old male wearing protective clothing, mask and heavy boots) at 9.3 seconds per floor. This represents a nominal unrestricted descent time over 23 floors for one person of 3.5 minutes
- But evacuation flow time depends on total number in building and stair width ~ 1 m
- Maximum flow down 1 metre wide stair is 42 persons/minute
- If occupants on night of fire 293 total (13 per floor)
- Evacuation flow time ~ 7 minutes
- In practice flat occupants include some babies, children and elderly or less able so time required for all to escape would be somewhat longer. Slower occupants can impede the flow on a stair. I confirmed at the Tower that it was possible to overtake on the Grenfell stair (and occupants reported overtaking on the stair during the incident).
- So although the single stair at Grenfell was quite narrow there was a good handrail and the physical capacity was sufficient for all occupants to have evacuated safely within minutes if there had been a means of alerting them to evacuate (such as a general Tower alarm system).



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Evacuation of Grenfell occupants

What happened on the stair during the incident?

Despite the lack of a general simultaneous alarm system the majority of Tower occupants became aware of the fire at an early stage from a variety of cues:

- smelling or seeing smoke, noises outside the Tower from the fire engines and gathering crowd, smoke alarms in their own or neighbours flats, warning telephone calls from friends and relatives inside or outside the Tower, reflections of the flames from nearby buildings, and warnings from neighbours from other flats on the same floor.
- Some decided to investigate below to see what was happening while many others realised the seriousness of the developing fire and decided to evacuate.

Figure 23 from my report shows the times at which evacuating occupants are estimated to have left their flats at different levels of the Tower

- Many evacuated before lobbies on most floors became smoke-logged and before significant smoke on the stair (before ~01:30 hrs)
- On 4th and 5th floor evacuation started at 00:58 hrs. 78% of occupants (28 of 36) starting by 01:30 hrs (0.4 persons/floor/minute)
- On floors 6-11 evacuation started at 01:08 hrs. 54% (40 of 74) starting by 01:30 hrs (0.3 persons/floor/minute)
- On floors 12-17 evacuation started at 01:01 hrs. 57% (43 of 76) starting by 01:30 hrs (0.2 persons/floor/min)
- On floors 18-23 evacuation started at 01:22 hrs. But only 8% (7 of 86) started by 01:30 hours (0.09 persons/floor/minute)

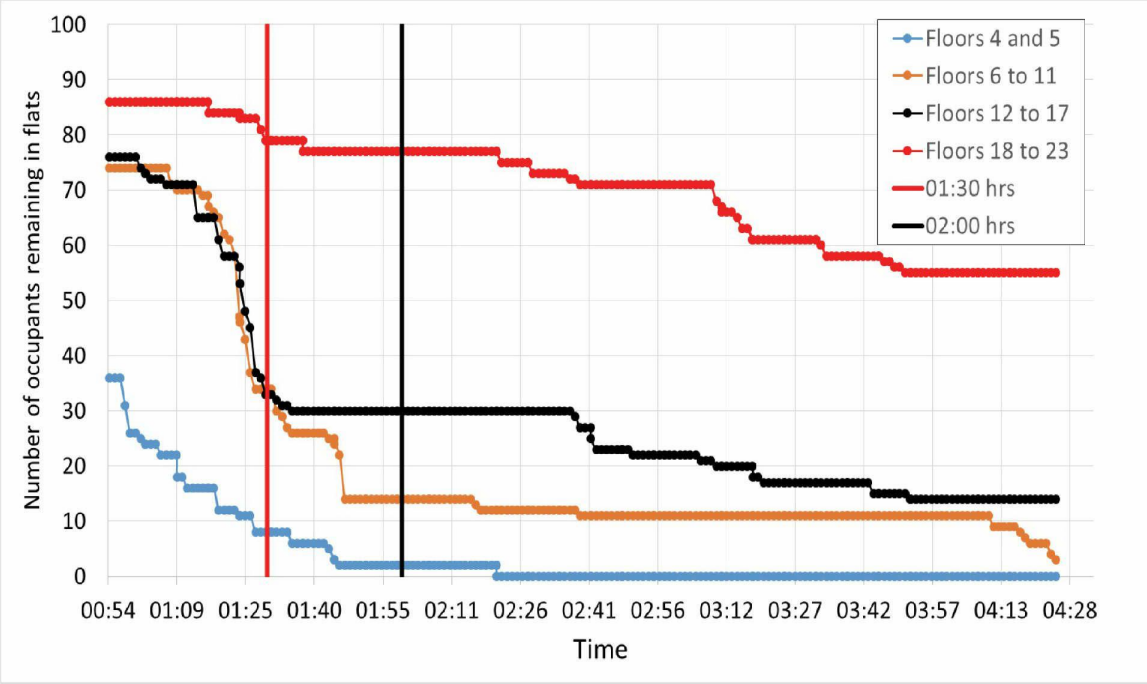

Figure 23: Evacuation pattern from different levels in the Tower

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Evacuation of Grenfell occupants

During the period up to 01:30 hrs 111 of 186 occupants on floor 4-17 started to descend and evacuated safely at a gradual rate (<1 person from each floor/minute) so stair was not crowded and the entire population on floors 4-23 (~272) could have evacuated over this period without difficulty.

- Those descending the stair aware of others and there was some overtaking of slower persons (See: Edward Daffarn, Hamid Wahbi, Sid-Ali Atmani, Maher Khoudair, Jose Vieiro, Richard Fletcher), also passing firefighters and hoses in the stair (See: Edward Daffarn, Jose Vieiro, Meron Mekonnen).
- Only 7 occupants descended from floors 18-23 before 01:30 hrs. Some occupants from floors 18 and 19 started to descend, but for some reason turned back and ascended to take refuge on the 23rd floor. The behaviour of this group and their physical presence filling the stair moving upwards acted as a temporary barrier to others on floors 20-23 who had planned to descend around this time (See: Flora Neda, Naomi Li, Meron Mekonnen, Helen Gebremeskel).
- In practice, had there been a method of encouraging them to do so, it would have been physically possible for all these occupants to have descended the stair and evacuated the Tower safely and without significant difficulty at this time, as did many others from all floors.

Statement of Meron Mekonnen Flat 163 19th Floor IWS00000912:
Exits Tower: 01:32:24 hrs: Left flat ~01:27 hrs then again ~1-2 minutes later.

> "*17. Amal's relative had remained on the landing and started to follow me and my children down the stairs. We had not gone far down the stairs, though I do not remember which floor we had reached, when we met a group of approximately 10 people on the stairwell (they all seemed to be other residents of the Tower). Someone below us shouted out, 'Go back, go back!'. The group, including me, my two girls, and Amal's relative, all started moving back up the stairs i.e. up the Tower.*
>
> *18. I got to the top of the stairs on my floor. I did not want to go back into my flat, so I decided to ignore the advice that had been shouted in the stairwell, to go back up, and I headed back down the stairs with my daughters. There was no one on the stairwell at this point. As we were walking down the stairs, the smoke was becoming thicker and thicker. It was dense and dark grey but I could see through it. I was able to breathe without any difficulty."*

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Evacuation of Grenfell occupants

Dr. Naomi Li 22nd floor Flat 195

IWS00000515 ~01:27 hrs (Exit 03:21:56)

"We immediately went to the staircase and opened the emergency door. At that point we intended to walk down the stairs and leave the building. We saw a lot of people walking up the stairs. I can't remember how many people were walking up. It was a lot, enough to mean we could not go downstairs. It was people constantly walking up. There was hazy smoke in the stairwell at that point. They looked normal walking upstairs, not screaming, running or anything unusual. We didn't talk to anyone. I was a bit stunned at that point, people walking upstairs wasn't something I expected to see."

(She was then invited into Flat 193 where they took refuge).

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Evacuation of Grenfell occupants

- From ~01:30 hrs
  - most lobbies were filling with dense smoke. However there was less smoke in the stair and quite good visibility.
  - Stair smoke was increasing but people were still able to descend safely if they were able to reach the stair at this time.
- From 01:30 to ~01:47 hrs
  - a further 31 persons entered the stair and evacuated from different floors up to the 20th up to ~01:49 hrs (see Petra Doulova)
- Then there was a period of 29 minutes when no occupants from floor 4 and above evacuated. The remaining occupants stayed in the Tower. The presence of dense smoke in the lobbies was a deterrent to leaving flats.
- After this period:
  - occupants evacuated in small numbers at intervals from all levels of the Tower, including the upper floors. In some cases being forced to evacuate their flats when fire penetrated.
  - Some occupants succeeded in evacuating the stairs without collapsing in the stair at intervals up to ~08:00 and some died in the lobbies or on the stair.
- Although conditions were hazardous, at no time was it impossible to descend the stair itself due to smoke and asphyxiant gases.
- Probability of collapse in the stair depended on a number of factors, including age and health status, but mainly on the extent of exposure to toxic smoke while staying-put in the flats for periods of an hour or more.
- Occupants inhaling a significant dose of asphyxiant gases, risked further exposure after leaving the flat leading to collapse.
- Those who were exposed a lower dose of asphyxiant gases before evacuating would be more likely to avoid collapse.

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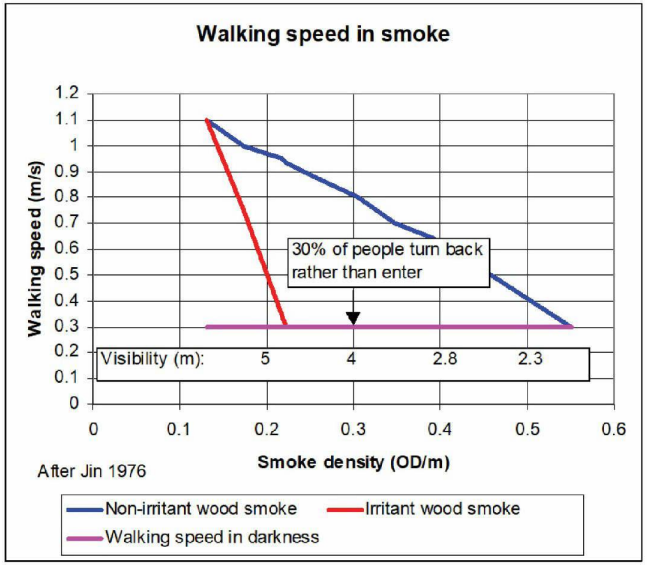
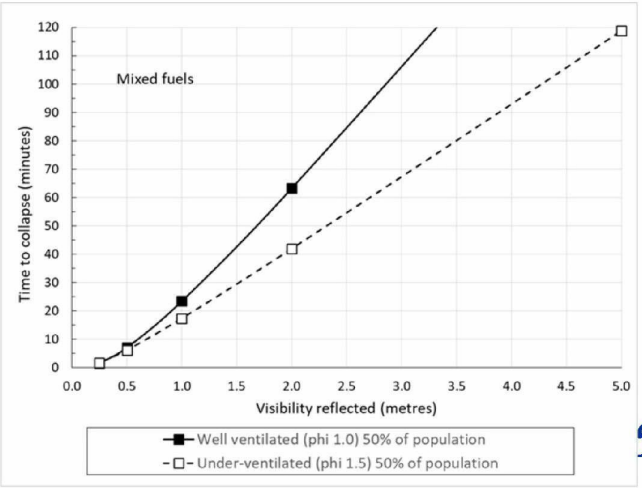
Effect of smoke on stair descent rate

- Walking speed in smoke slows in proportion to the smoke visibility and irritancy. This bore on movement through the lobbies and down the stairs;
- Experimental studies have shown people can move rapidly in smoke if they have a guide such as a rail;
- Some Grenfell occupants descending in dense smoke after 02:00 hrs said they were able to progress rapidly by holding the handrail.
- For a few people we can estimate the time it took them to leave their flats from their last 999 call and their exit from the tower; these estimates demonstrate that some occupants were able to descend the stair at a reasonably rapid state even in dense smoke





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Fire hazard development during Grenfell incident

Fire in Flat 16 at approximately 00:54 hrs

- Scenario in Flat 16: starts as typical small domestic fire
- Due to slow early growth of fire releases smoke and actuates detector
- Mr Kebede awakened and investigated; alerted other occupants and neighbours;called 999; closed flat door - without exposure to toxic smoke
- Some smoke was seen under 4th lobby ceiling when Miguel Alves left the lift at 00:57
- Fire still confined to the kitchen when firefighters arrive, some smoke likely to flow out of flat into lobby and from lobby into stair as doors opened during firefighting activities

Basic scenario: small enclosed domestic fire detected early and all occupants able to escape within minutes without exposure to smoke or toxic gases

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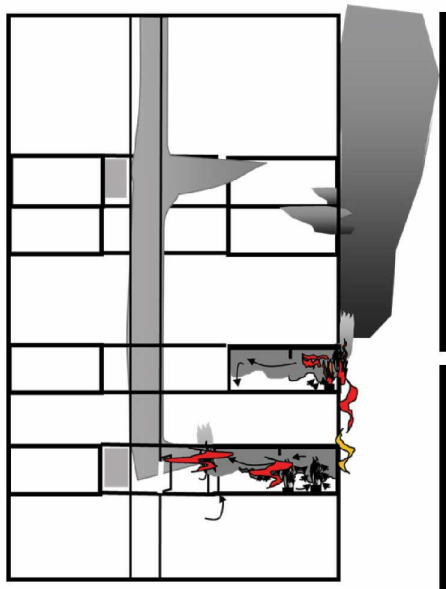
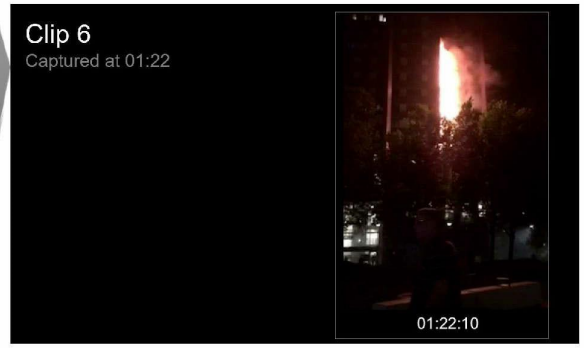
Fire hazard development during Grenfell incident

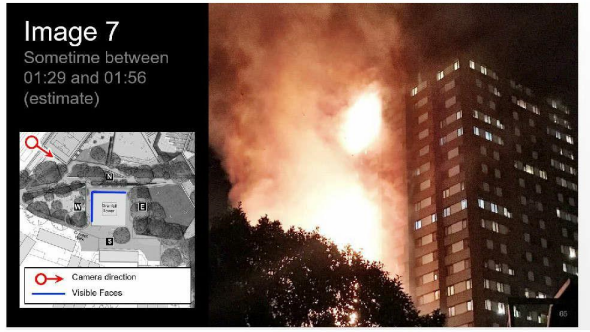
- From a few minutes after 01:00 hrs smoke flowing out from flat 16 kitchen window and exterior fire and smoke is starting to involve exterior rainscreen cladding and insulation.

- Smoke plume flows up Tower east side, entraining air and diluting. Some of this dilute smoke penetrates flats all the way up the Tower mainly on East side initially via:
  - Open windows
  - Normal ventilation
  - Gaps around windows
  - Other exterior gaps and penetrations

- Small amount of diluted smoke from Flat 4 may penetrate Tower interior, spreading possibly via:
  - Stair shaft
  - Lift shaft
  - Gaps and penetration in structure between floors
  - Ventilation system







- Very dilute smoke smell or haze detected by occupants in flats and lobbies as far up as 23rd floor from ~01:10-01:25 hrs
- Not in itself hazardous but one of the early cues to the fire detected by Tower occupants on many floors

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Fire hazard development during Grenfell incident

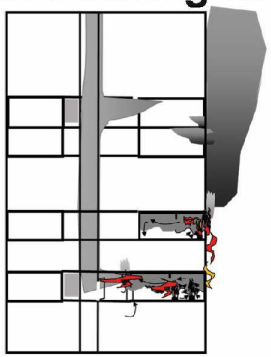
- Flames ignite exterior cladding and insulation outside Flat 16 at 01:15 hrs
- Fire spreads rapidly up column on north east side of Tower taking ~9 minutes to reach 23rd floor
    - 12th floor 01:21
    - 23rd floor 01:24
- Exterior fire penetrates kitchens of Flat 6 on each floor in sequence
- Flame and smoke penetration and fire growth in flats occurs in three stage sequence:

Stage 1: smoke and flame penetration from burning exterior

- Smoke generated immediately outside flats is dense and undiluted
- Two possible main early routes of dense smoke and flame penetration into flats as exterior fire reaches each floor from below:
    - From exterior plume involving cladding and insulation through open windows, kitchen ventilator openings and through holes in windows caused by partial heat glazing failure
    - From insulation fire burning in void behind column and spandrel cladding entering flat through penetrations around window frames
    - Dense smoke likely to contain high concentrations of irritants and asphyxiant gases (including CO and HCN)

Stage 2: Next stage is flame development and production of dense toxic smoke from combustible structural materials of window surround adding to flame and smoke development inside flats around windows especially Flat 6 kitchen and East side lounge windows.

Stage 3: Flame spread to involve flat contents, starting with combustible contents close to windows such as blinds and curtains, then spreading to involve upholstered furniture and other items,



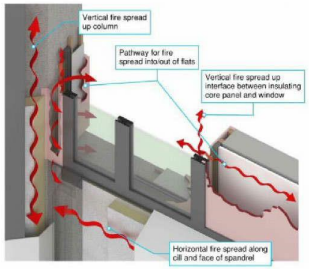


Figure 10.58: Pathway between external wall cavity and inside of flats

Figure 10.52: Burned uPVC frame in Flat 15

East face 01:21:37

Bisby Phase 1 Fig. 91

East face 01:25:36

Fire hazard development during Grenfell incident

- From first becoming aware of the fire flat occupants were repeatedly faced with the difficult decision of whether to stay-put or evacuate.

- This decision was affected by different considerations and experiences but the extent of exposure to irritant smoke or flames would be an important factor which at some stages encouraged evacuation and at some stages prevented it.

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Fire hazard development during Grenfell incident

- Early stages of development as fire penetrates Flat 6 on any floor is likely to be similar to typical domestic flaming fire, except that the first fuel involved is outside then structural materials around the windows.
- Flat 6 occupants were alerted by a variety of cues, including their flat smoke alarms in some cases
- The pattern of fire penetration varied somewhat for different flats ‘6’s
- Flat 6 occupants made rapid evacuations
- BRE Analysis shows that as little as 5-7kg of fuel burning over 5 to 10 minutes can produce sufficient concentrations of smoke and asphyxiant gases capable of causing incapacitation and death
- No Flat 6 occupant was overcome in their own property

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Fire hazard development during Grenfell incident

- Flat 6 occupants evacuated their flats before there was any or significant smoke in the lobbies
- A number evacuated the tower, others took refuge elsewhere;
- Some occupants stated that they left their Flat 6 doors open: an open door would be a route for smoke to flow into the lobbies;
- Where Flat 6 doors were left open dense smoke was observed to flow out into the lobbies, which rapidly filled down from ceiling level
- Where Flat 6 doors were closed the lobbies still filled with dense smoke over a period of minutes.
- It will be necessary in Phase 2 to look more closely at the lobbies where the doors of Flat '6s' were believed to be shut.

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Fire development within flats

- After occupants left Flats '6', continued fire development in each flat varied somewhat but many flats were almost completely burned out eventually
- These fires produced significant amounts of toxic smoke which could flow into the lobbies.
- An important variable was likely to have been the timing and extent of glazing failure
- When glazing fails the window opening supplies air to support combustion enabling rapid fire growth and spread within contents of rooms with windows (kitchen, lounge and bedrooms)
- Upper layer temperatures are very high (~600-900ºC) with ventilation controlled combustion and very high concentrations of smoke and toxic gases.
- Flashover ignites fuels away from the point of origin. Exterior photographs show intense fires in some flats.

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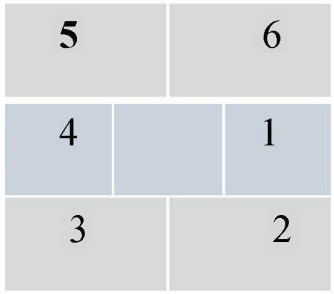
Fire development within flats

- Table 6 (from report) shows fatalities recovered from flats
- No bodies were recovered from Flat 6 on any floor - occupants either evacuated or took refuge elsewhere
- Most occupants remaining in the Tower took refuge in Flats 2 and 3, which were affected by fire and smoke spread later. Most deaths occurred in these flats
- Flat 5 and 1 were mostly evacuated – 205 and 201 being exceptions.
- Generally fewer occupants in the one bedroom flats (Flats 4 and 1). Some moved to join others in 2 bedroom flats



Floor plan

Table 6: Fatalities by flat floor and position

	Deaths in flats on West side of Tower			Deaths in flats on East side of Tower		
	NW	W	SW	NE	E	SE
Floor	Flat 5	Flat 4	Flat 3	Flat 6	Flat 1	Flat 2
23	4	1	6	0	7	4
22	0	0	11	0	0	0
21	0	0	0	0	1	5
20	0	0	0	0	0	2
19	0	0	0	0	0	0
18	0	0	0	0	0	0
17	0	1	0	0	0	4
16	1	0	0	0	0	1
15	0	0	0	0	0	1
14	0	0	3	0	0	0
13	0	0	0	0	0	0
12	0	0	0	0	0	0
11	0	0	0	0	1	0
10	0	0	0	0	0	0
9	0	0	0	0	0	0
8	0	0	0	0	0	0
7	0	0	0	0	0	0
6	0	0	0	0	0	0
5	0	0	0	0	0	0
4	0	0	0	0	0	0
3	0	0	0	0	0	0
2	0	0	0	0	0	0
1	0	0	0	0	0	0
	5	2	20	0	9	17

Estimated times Flat 6 occupants left their flats

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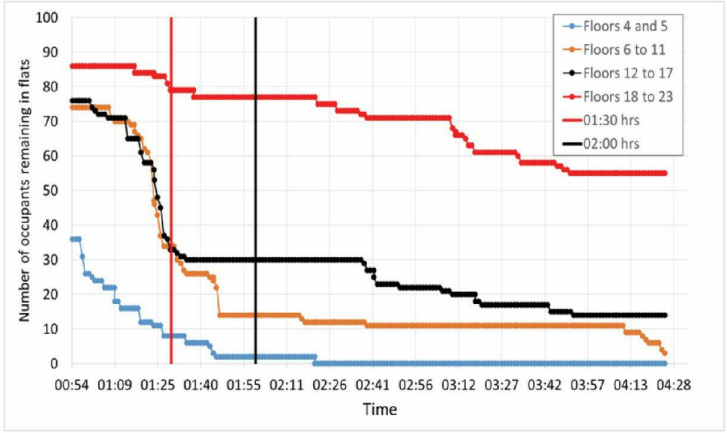
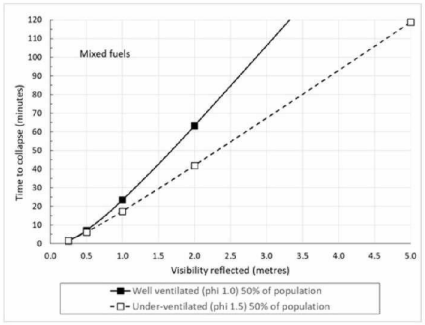
Conditions in flats and lobbies after ~01:30 and 02:00 hrs

- Up to ~01:30 most flats other than Flat 6 on each floor and possibly some in the Flat 1 position were generally smoke free.
- From ~01:30-01:35 hours lobbies on various floors filling with dense irritant smoke. Reports of almost zero visibility ("could not see their hand in front of their face"); difficulty breathing and irritant smoke

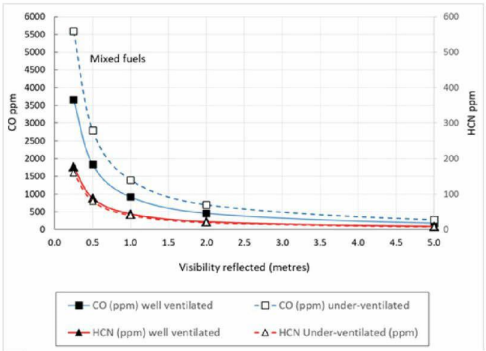
- Some occupants attempted to evacuate through this smoke (some more than once), feeling their way around the walls to find the door to the stair. (see Branislav Lukic).
- It is likely that this smoke contained high concentrations of asphyxiant gases (CO and HCN) capable of causing collapse if inhaled for more than a few minutes. Due to the short distances involved exposure times were limited to ~15-60 seconds, but people reported breathing difficulties and some dizziness while in the lobby. Occupants who entered the stair between 01:30 and 01:49 hrs found much clearer conditions than in the lobby (but not totally smoke free) and were able to descend safely without collapsing:
  - Samuel Daniels (16th floor – exit 01:38:30 hrs): reported zero visibility in lobby, Stairwell much less smoky. Waited in stair ~5 (total ~8) minutes while firefighters searched for his father.
  - Petra Doulova (20th floor – exit 01:41:57 hrs): reported poor visibility in stairwell, but able to see steps, handrail and feet. Thicker between 6th and 4th
  - Abraham Abebe (7th floor – exit 01:48:17 hrs) Two attempts to descend stair – first encountered heavy black smoke between 5th and 4th floor from open stair door (hose) on 4th landing – went back to flat – then told to evacuate by firefighters and came down through irritant smoke;
  - Branislav Lukic (11th floor – exit 01:49:20 hrs) Thick smoke in lobby, but relieved to find less smoke in stairwell, could see through it and more grey than black. Helped carry Clarita Ghavimi.



Estimated times all Flat occupants left their flats to evacuate



Time to collapse related to visibility



CO and HCN related to visibility (mixed fuels)

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Conditions in flats and lobbies after ~01:30 and 02:00 hrs

- After ~01:30 many occupants “stayed-put” in their flats (other than Flat 6) or in neighbouring flats on the same floor (or floor 23).
- The least affected flats were Flat 3 in the south-west corner of the Tower. Most people remained or took refuge in Flat 3 or Flat 2 (some Flat 5).

- Mostly smoke-free conditions in flats at first but slowly increased (Flat 201 rapid smoke filling – see Fadumo Ahmed).
- Some smoke entered from outside through leaks around windows.
- A route of slow smoke entry into flats was reported as from the lobbies, around the closed flat entrance door and through other penetrations and leakage paths, or rapidly for short periods when the flat entrance door was opened.
- Flat occupants attempted to limit smoke entry by putting towels against the door or opening windows when there was no smoke outside

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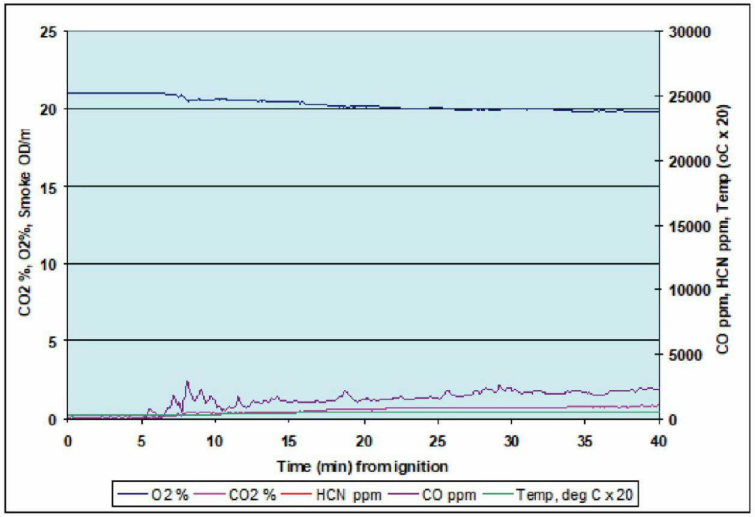
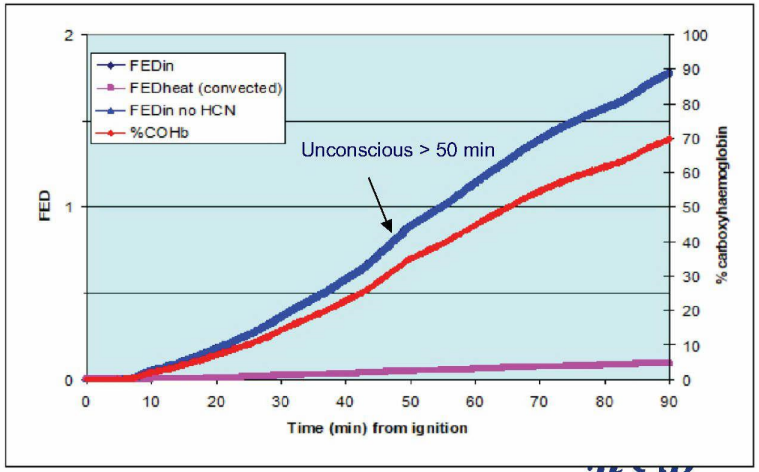
- In flats not penetrated by fire there was a slow increase in smoke and toxic gases over an hour or more. Visibility several metres, some irritancy, CO gradual increase to ~1000-2000 ppm, HCN too low to cause significant toxicity.
- It is predicted that flat occupants would initially be alert but there would be slowly increasing levels of COHb in the blood.
- When fire penetrates the flat from outside, there would be a more rapid increase in smoke and toxic gases to concentrations causing collapse, sometimes within a few minutes then death from asphyxia.
- If fire remains limited to an area within one room there is predicted to be dense smoke within minutes but occupants may reduce exposure to toxic smoke and heat by closing interior doors and taking refuge in other rooms; The smoke temperature and heat radiation will have also increased rapidly in rooms penetrated by flames.

- Flat occupants were able to shelter from heat and some smoke by closing interior flat doors and taking refuge in the hall or bathroom
- Heat also avoided by sheltering behind furniture or duvets
- From previous research, transcripts of 999 calls and very high blood %COHb in fatalities from flats my preliminary opinion is that these persons were likely to have been comatose or dead before they were exposed to sufficient heat to cause burns.

Conditions in flats





Rosepark closed bedroom

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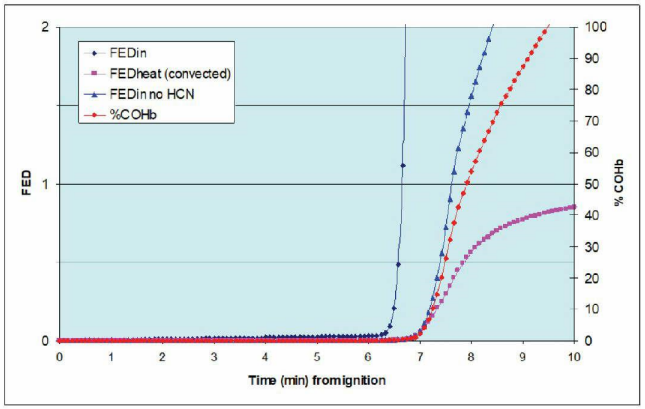
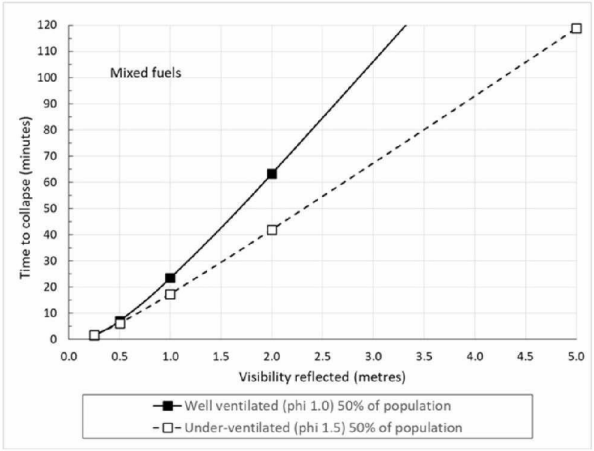
Conditions in lobbies and stair after ~02:00 hrs

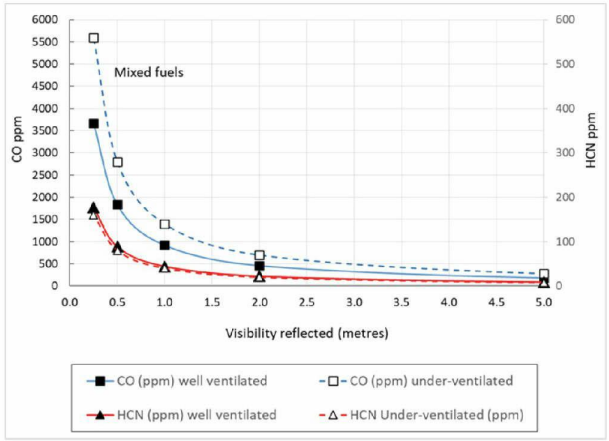
- If occupants attempted to evacuate into lobby they were then exposed to very high concentrations of smoke, CO and possibly HCN in the lobby and stair, also capable of causing collapse within minutes.
- The outcome depended on the dose accumulated while in the flat.
- If the flat had low smoke or they left after a short period (~02:30 hrs) they were able to descend the stair within a few minutes without collapsing,
- If the flat had high smoke or they left after ~03:00 hrs then they may reach the dose for collapse within seconds, collapsing in the lobby outside the flat or in the stair after descending one or two floors.
- Conditions in the lobby and stair were vey hazardous after ~02:00 hrs so that escaping occupants experienced near zero visibility, suffering from breathing difficulties with pain to eyes and throat. As they descended they were affected by asphyxiant gases, feeling weak and dizzy and in some cases collapsing on the stair.
- It was not impossible to descend the stair itself at any time, since some occupants succeeded in doing so at intervals from all floors up to ~8 am.



Rosepark open bedroom



Time to collapse related to visibility



CO and HCN related to visibility (mixed fuels)

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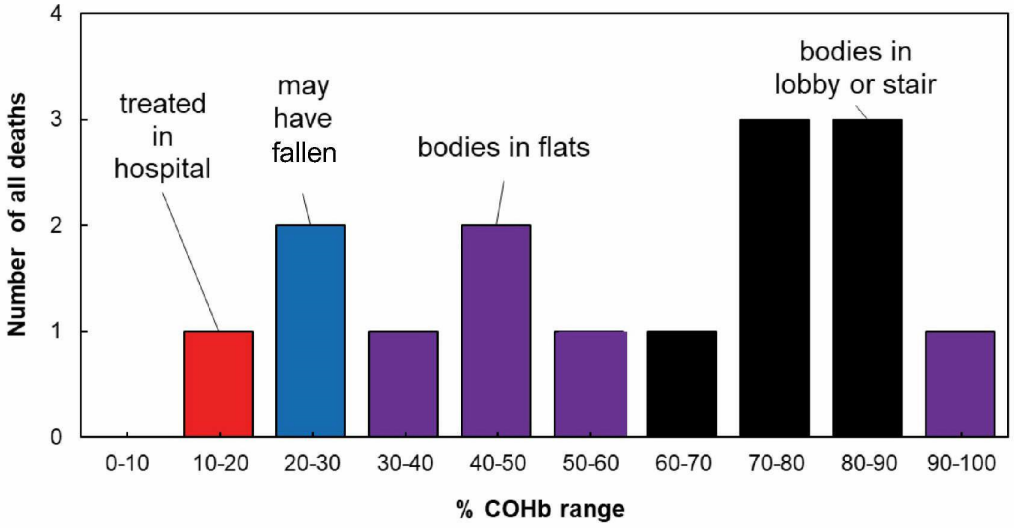
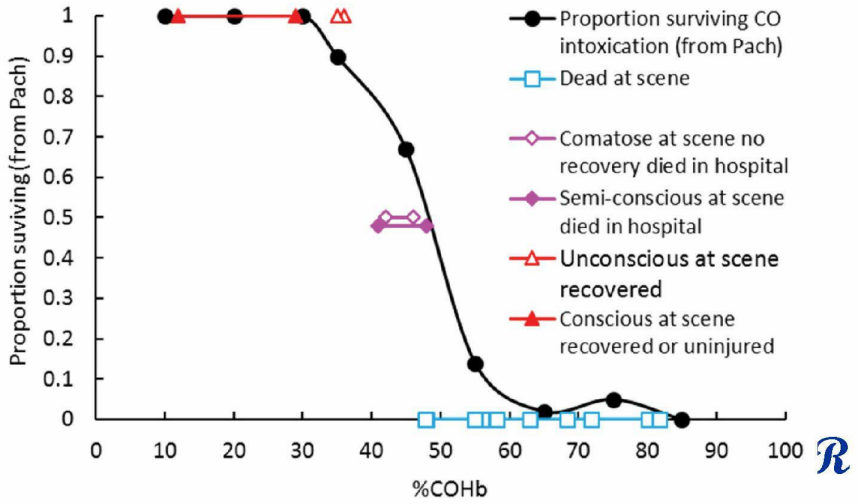
Blood toxicology

Of 15 samples with measurable %COHb levels:

- 1x ~10% COHb had been treated in hospital and small sample;
- 2x 20%COHb significant dose but below collapse threshold – may have fallen from Tower
- 5x 39-90% COHb from flats: high doses consistent with incapacitation and death from inhalation of asphyxiant smoke gases rather than heat and burns but bodies burned
- 7x 47-87 %COHb from lobbies or stair: high doses consistent with incapacitation and death from inhalation of asphyxiant smoke gases – bodies unburned



- If those persons found inside the flats had been overcome by heat and burns before they had time to collapse from asphyiant gases, they would have had low %COHb levels (<~20%COHb)



David Purser

Contributions of CO and HCN to Grenfell toxicity

At the time of the incident there were press reports of some survivors being treated for cyanide poisoning at Grenfell, so what is the likely contribution of hydrogen cyanide (HCN) in relation to other asphyxiant gases?

- The most important asphyxiant gases in fires are carbon monoxide (CO) and hydrogen cyanide (HCN)
- Both gases accumulate in the blood of exposed persons, remaining in the blood of fatalities
- Carbon monoxide in the blood as carboxyhaemoglobin routinely measured in fire survivors and fatalities. It is stable in the blood of fatalities, provides an important measure of the extent of exposure to toxic smoke products and is useful for establishing cause of death (and of incapacitation of survivors).
- Cyanide in the blood can also be measured and can provide an indication of the extent of exposure during a fire. The relationship between blood CN level and effects at the time of exposure is more complex than for CO, and cyanide is unstable in the blood of fatalities. It is not routinely measured and was not measured following Grenfell.
- I have requested measurement of cyanide in some preserved Grenfell blood samples. The need for information about post-fire treatment or blood measurements in Grenfell survivors will be considered for Phase 2.

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Contributions of CO and HCN to Grenfell toxicity

- All burning fuels at Grenfell contain carbon and produce CO when burned
- Fuels containing nitrogen also produce HCN. The main nitrogen-containing fuels present at Grenfell were the PIR insulation and upholstered furniture in the flats (especially those containing polyurethane foams, acrylic (polyacrylonitrile) or wool and polyamide).
- During the early stage of the fire (~01:15-02:00 hrs) the burning exterior rainscreen cladding, PIR insulation and structural materials around the windows all produced CO into Flat 6 and lobbies beyond on floor 4-23 of the Tower. The burning PIR will have produced some HCN.
- The conditions in Flat 6 on each floor rapidly became hazardous over a period of a few minutes. But all Flat 6 occupants were able to escape into the lobbies without showing signs of asphyxia (dizziness, collapse). Flat 6 occupants (and others) were therefore unaffected by CO or HCN exposure at this time.
- Occupants remaining in flats not penetrated by fire after ~01:30 hours experienced slowly increasing smoke concentrations in their flats. This smoke contained low concentrations of both CO and HCN, but at these dilute concentrations the main cause of toxicity was the accumulating dose of CO. The source of these gases was initially the exterior and other structural materials but increasingly the burning contents of other flats releasing toxic smoke into the lobbies.
- Whenever fire penetrated a flat the smoke generated into a flat from the burning structural materials contained high concentrations of CO, and that derived from PIR may have contained significant concentrations of HCN. Both gases are likely to have contributed to the incapacitation and deaths of flat occupants, with death mainly due to the effects of CO.
- Flat occupants attempting to evacuate after 02:00 hrs encountered hazardous concentrations of CO and also HCN in the lobbies, and o a lesser extent in the stairs. Inhalation of these asphyxiant gases in the flats, lobbies and stair caused weakness, dizziness, collapse and death of some escaping occupants. The source of the gases was a combination of structural and contents materials.
- The blood of fatalities collapsing in the lobbies or stair all had high blood %COHB levels consistent with death from CO poisoning, but it is possible that inhalation of HCN contributed to collapse in the stair and deaths of those who did not escape.

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