Forensic Architecture is a multidisciplinary
research group based at Goldsmiths,
University of London, that uses architectural
techniques and technologies to investigate
cases of state violence and violations of
human rights around the world.

Goldsmiths, University of London
8 Lewisham Way
London SE14 6NW
United Kingdom

forensic-architecture.org

Methodology Report

‘Tear Gas Tuesday’ in downtown Portland, 2 June 2020

17 April 2023

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1. Introduction and Research Framework

The protests against police brutality and systemic racism that swept across the United States in the second half of 2020, catalysed by the murder of George Floyd by police officers in Minneapolis and under the banner of 'Black Lives Matter' (BLM), was among the largest protest movements in the country in recent decades. A protest movement which grew as a response to police violence, it was met, across the country, by further police violence; across the country, US police deployed a range of so-called 'less-than-lethal' munitions against civilian protesters, including the use of impact munitions, chemical munitions, and physical restraint practices, as well as tactics such as the use of kettling and LRAD devices in relatively populous urban areas.

Injury and health impacts were widely reported. Physicians for Human Rights reported that more than 100 civilian protesters were struck in the head by 'less-lethal munitions', causing permanent ocular damage in around 30 cases.[1] Surveys recorded extensive health impacts as a result of tear gas inhalation and individual and collective experience of trauma.[2] Forensic Architecture (FA) worked with Bellingcat and a network of volunteer investigators to gather and verify visual evidence of police violence against protesters in the context of the 'BLM' protests from May 2020 until January 2021. The project documented just over a thousand incidents.[3]

That work was later published at blmprotests.forensic-architecture.org, and its findings were submitted to the UN Human Rights Council, and to the office of the UN Special Rapporteur on Contemporary Forms of Racism. Building upon that work, FA has developed a second investigation, narrowing its focus to a single city, and a single day, to add further resolution to the picture of contemporary counter-protest tactics employed by US police – with a particular focus on the use of chemical munitions, especially those known as 'tear gas'.

FA was subsequently commissioned to produce new work on policing in Portland, Oregon, by the Vital Projects Fund. Portland stood out among all major US urban areas for the scale and durability of its own particular iteration of the BLM protest movement. Protests in Portland were also subjected to significantly more tear gas use than other major urban areas, according to the data gathered in the context of the FA's previous research.

For its second investigation, FA took as its focus the events of the evening of 2 June 2020—a day which became known locally as 'Tear Gas Tuesday'. Our research methodology brought together open-source investigation, digital modelling, video analysis, document data-mining, public records requests, and computer fluid dynamics (CFD) simulation, as well as the expertise of independent weapons analysts and chemists.

The use of tear gas has long been a part of the modern toolkit of policing, even as the use of chemical munitions was outlawed in conflict by successive international treaties and conventions. Due in part to its intangible nature, it has until recently seemed almost impossible to 'measure' tear gas use with any degree of precision—such that, for example, the use of tear gas by a police force might be held up against recognised safety standards, such as safe concentration levels. FA's research in this case builds upon previous casework[4] to demonstrate and deploy a methodology for simulating, and thereby estimating, airborne concentrations, and ground deposits, of tear gas over time.

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[1] phr.org/our-work/resources/shot-in-the-head/
[2] See for example: www.theguardian.com/us-news/2021/apr/29/teargas-protest-menstrual-cycles-health-impact and www.phr.org/our-work/resources/expert-statement-on-individual-and-community-effects-from-trauma-due-to-nypd-use-of-force-in-response-to-the-mott-haven-protest-on-june-4-2020/
[3] It should be noted that *under*reporting is built into such research; the actual number of incidents is certain to be higher.
[4] https://forensic-architecture.org/investigation/tear-gas-in-plaza-de-la-dignidad

2. Summary of Findings

This methodology report should be read alongside the video report at: vimeo.com/813137872

The central finding of that investigation is:

> On 2 June 2020, the Portland Police Bureau (PPB) used tear gas against civilian protesters in quantities which very likely significantly exceeded federally-recognised safe levels of airborne CS concentration for human exposure[5] – values that are cited in documents published by the PPB.
>
> At every location sampled by our methodology, those safe levels were exceeded. In some locations, concentrations were estimated to be more than 800 times the federally-recognised maximum safe value.
>
> As a result, the actions of the PPB very likely constituted an 'immediate danger to life' for those protesters.

Detailed findings are found in **section 6**.

[5] According to the federal Occupational Safety and Health Administration (OSHA)

3. About Forensic Architecture

FA is a research agency based at Goldsmiths, University of London. Our team includes architects, scientists, filmmakers, journalists, developers, technologists, and other specialised professionals. The agency undertakes advanced media and spatial research with and on behalf of legal teams, human rights organisations, environmental justice groups, and communities affected by state violence. Since 2011, FA has published over ninety investigations and presented them in national and international courts, truth commissions and exhibitions worldwide.

We have provided research and evidence for numerous human rights investigations and prosecutions under international law, including on drone warfare at the UN General Assembly in New York in October 2013 and the Human Rights Council in Geneva in 2014.

Our report on the Use of White Phosphorous in Urban Environments was presented at the UN Human Rights Council in Geneva in November 2012, and in March 2011 in the Israeli High Court.

Our Forensic Oceanography team presented the case of the Left-to-Die-Boat before the French Tribunal de Grand Instance in April 2012, the Brussels Tribunal de première instance in November 2013, and in the courts of Spain and Italy in June 2013.

In 2017, our investigation into the murder of Halit Yozgat was presented to the Committee of Inquiry of the Hessen Parliament, and cited in the final reports of both this Committee, and the second Federal Committee of Inquiry into the NSU killings.

Our investigation of the murder of Pavlos Fyssas was played before the Court of Appeal of Athens in 2018, as part of the ongoing trial of 69 members of the Golden Dawn political organisation, helping in their conviction.

Our investigation into the 2014 presence of Russian military units in eastern Ukraine was submitted to the European Court of Human Rights in 2019 as part of an ongoing case.

In 2020, our investigation into intentional fire-setting to clear rainforest land in Papua contributed to legal challenges against the palm oil agglomerate Korindo, by Greenpeace and partners, and was presented in Indonesian courts.

More information at www.forensic-architecture.org

4. Methodology

This investigation introduced computer fluid dynamics (CFD) simulation alongside a more 'traditional' open source investigative workflow, which included video synchronisation, online and social media research, geo- and chronolocation, architectural modelling, and the use of public records requests.

Our methodology can be broken down into these steps:

- Geolocate and 'synchronise' the available video evidence
- 'Tag' within that video evidence all deployed and discharged munitions
- Determine a geographic set of 'emission points' based on that set
- According to known data about what munitions PPB held, define a set of munition 'types' and assign a quantity of CS and OC to each
- Categorise each of the 'tagged' munitions according to the munition 'types'; thereby defining a CS and/or OC value at each 'emission point'
- Use 'emission points' as the basis for a CFD simulation to estimate airborne concentrations and ground depositions of CS and/or OC

When CFD is combined with investigative techniques such as digital modelling, image and video analysis, and archival research in this way, one can confidently draw connections between an emission source, e.g., a tear gas canister, and the final resting location of the emitted chemicals.

4.1. Video synchronisation and geolocation

FA gathered video material from online sources including news broadcasts, social media (including recorded and archived 'live streams'), and news broadcasts, as well as directly from protesters and activists. We 'synchronised' hundreds of such videos from the evening hours of 2 June 2020, a process which involves aligning each video with one another, and with 'real time', by matching corresponding features and events across different video sources, and where possible relying on metadata encoded in video files. The resulting 'sync' – a multi-screen composite video as in figure 1, captures around three hours of the night of 2 June 2020, throughout downtown Portland.

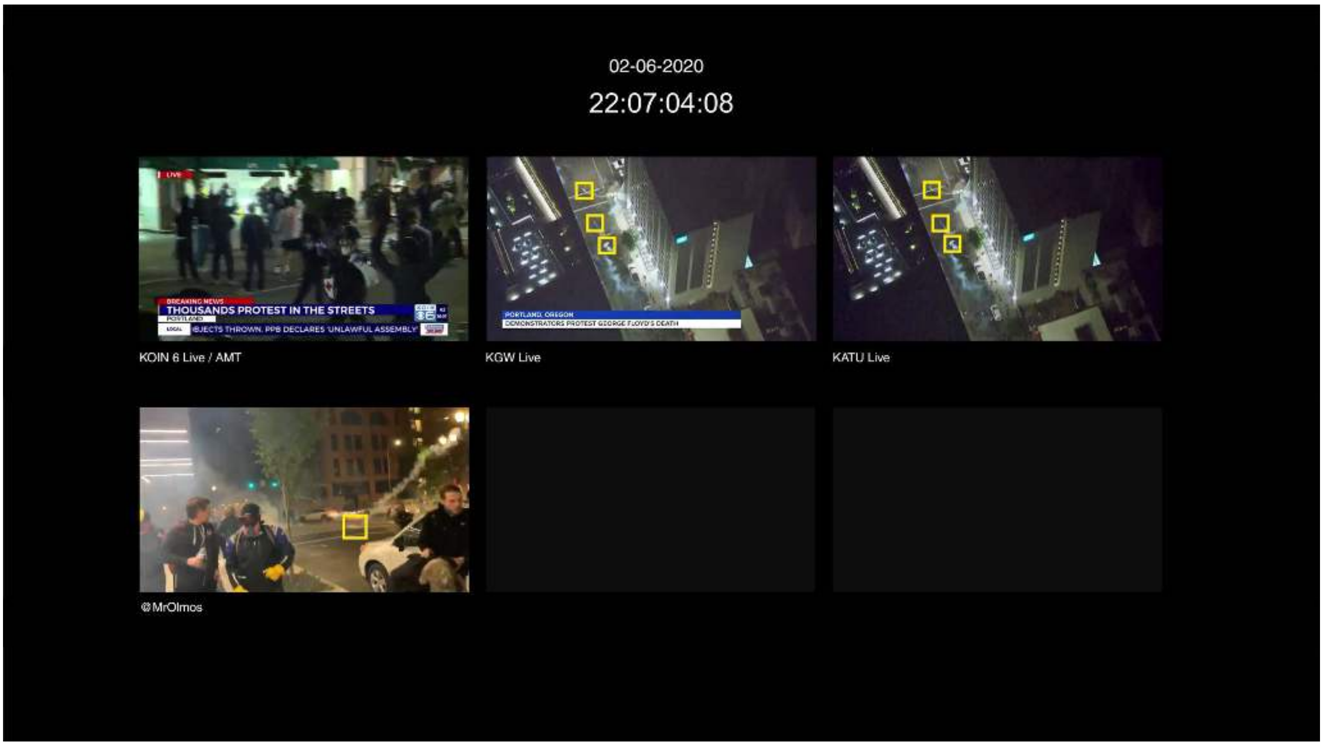

Fig 1: Multi-screen composite of our video synchronisation that combined all available footage of the night into one continuous sequence

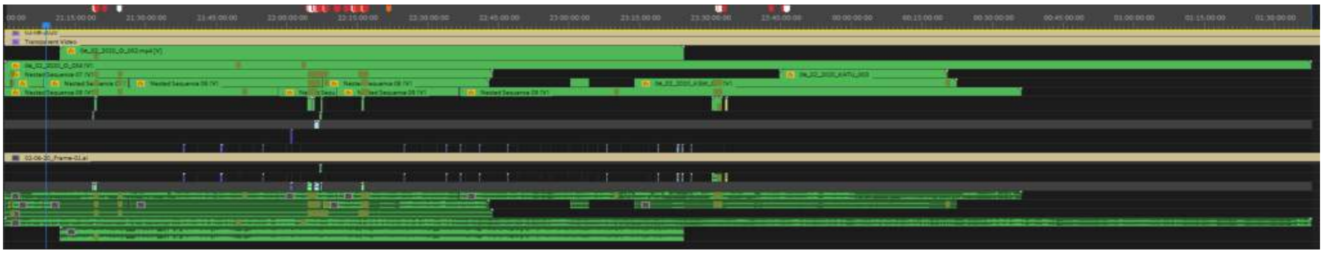

Fig 2: A screengrab from our video 'sync'

At the same time as synchronising the gathered video material, we also geolocate it, thereby establishing both the 'when' and the 'where' of the available video evidence. Geolocation of an image or video relies upon the identification of notable features within the image frame – such as a distinctive shopfront, skyline, or other landmark – and subsequently demonstrating the 'real life' location of those features by reference to satellite imagery, or proprietary cartographic data such as Google Maps and Google Street View.

4.2. Architectural Modelling

Using the open source software Blender,[6] we built an architectural digital model of the area of downtown Portland surrounding the sites of the 2 June protests.

A version of the model is first used within the software Visit,[7] as the digital environment in which the CFD simulation is conducted. Later in the research process, the results of the simulation are transposed into a version of the in Blender, where the results of the CFD simulation are visualised and integrated with other parts of FA's methodology, including image-to-model 'photomatching'.[8]

4.3. Document review: Force Data Collection Reports

The PPB is required to produce reports known as Force Data Collection Reports (FDCRs) after every 'use of force' incident in the course of their policing operations.[9]

Many of those reports concerning the period June and December 2020 were published by the Public Records Division of the PPB, in response to public records requests made by FA and others. The reports give insight into the perspective of individual officers and their superiors, particularly of their justification for, and understanding of, the force applied through the use of chemical munitions. Close study of these documents informed our contextualisation of the results of our CFD simulation.

4.4. Munition count and ID

The PPB apparently did not keep a record of how many munitions, or what kind of munitions, were used by their officers on 2 June 2020.[10] Our methodology attempted to fill this gap – first, by counting how many munitions were used, where, and when.

With the available video evidence geolocated and a precise chronology established, we marked where the deployment and/or discharge of munitions was visible in the video 'sync'. Each potential instance was carefully verified and double-checked; many instances were captured in multiple videos, improving our ability to use the 'sync' to corroborate each deployment or discharge. We counted 148 munitions used by the PPB on 2 June.

After marking all clear instances of discharge and deployment in the video 'sync', using Adobe Premiere Pro,[11] these points – referred to subsequently as 'emission points' – were recorded on a map of downtown Portland using Google Earth Pro.[12] Each 'emission point' was thus assigned location and time data.

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[6] www.blender.org
[7] https://visit-dav.github.io/visit-website/index.html
[8] 'Photomatching' is a process of matching the location and direction of an image to the corresponding place within a digital model of that location. More here: forensic-architecture.org/methodology/image-data-complex
[9] These reports are an outcome of the settlement agreement that followed the case United States of America v. City of Portland in 2012.
[10] https://www.portland.gov/sites/default/files/2022/dojletter-to-ppb-may52021-pb-letter-re-2020-protest-master-after-action-report-5-5-21-final-1_watermarked.pdf
[11] It should be noted that not all cases of deployment and discharge are *clear*. It is likely that the number of munition discharges counted by this methodology *under*reports how many munitions were used. See section **7.1**.
[12] A version of this map is available at www.google.com/maps/d/edit?mid=1ID4BItT3BwGyeZzJVVCpIBBzcmy88TE

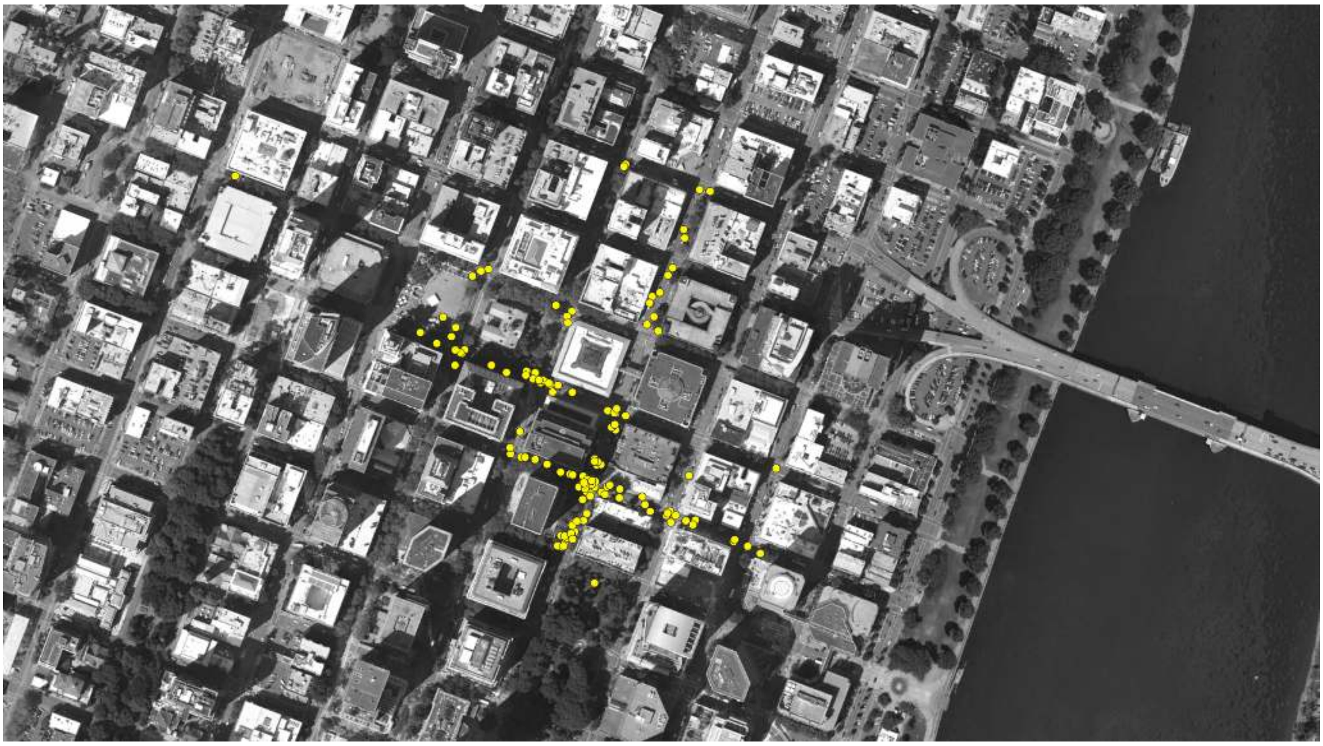

Fig 3: Geolocated emission points spread over a map of downtown Portland

4.5. Munition identification

Once we had established how many munitions were used by PPB on 2 June, we next sought to identify what each of those munitions likely was, and whether they contained ‘tear gas’ chemicals. Our investigation is concerned with two chemicals widely referred to as ‘tear gas’: CS and OC. Different chemical munitions contain different quantities of CS and OC; for many munitions common to US law enforcement, the quantities of CS and OC contained in a single munition are a matter of public record.[13]

The nature of the available video evidence is such that it is often not possible to know precisely what make and model of munition was used in a given instance. In the absence of clear self-reporting by PPB, we sought to develop a methodology that would arrive at a minimum threshold estimate for the amount of CS or OC contained within a documentation munition discharge.

That methodology combined visual indicators about a given munition from the video ‘sync’ with other available data about what munitions *could* have been used, including documents and invoices made public by the PPB in response to public records requests.

[13] At sites including sds.chemtel.net, for example

4.5.1. Visual indicators

Working with expert weapons analysts from Omega Research Foundation (ORF), we cross-referenced a range of public data with the produced munition count to determine six ‘emission types’ covering all of the munitions conceivably used by the PPB on 2 June 2020.

A central determining criterion for those ‘emission types’ was the visual signature of each munition, which were variously described (for example) as a ‘golden flash followed by multiple visible canisters’ (a Triple-Chaser grenade)[14], to a ‘launched projectile, multiple munition pieces’.

These visual indicators were cross-referenced with the relevant technical specifications, guided by the expertise of ORF, whereby we could understand whether a munition carried an explosive charge that would result in a ‘golden’ flash (e.g. a Triple-Chaser; type 1) or would lead to a secondary explosion, with a flash and smoke (e.g. a Rubber ball blast grenade; type 2), and what the visual indicators for either would be.

4.5.2. PPB documents and invoices

The PPB admits to using at least eight different kinds of chemical munition between June and September 2020.[15] Notably, many of these munitions come in three variations: two of these contain the chemicals CS or OC, and often a third variation is either ‘inert’, or contains a smoke whose chemical composition is a proprietary trade secret (though often still very likely harmful).[16]

In response to public records requests, PPB has published invoices and receipts for its munitions purchases between 2016 and 2020.[17] This data gives us an estimate of the PPB’s stockpile of each munition and – importantly for this methodology – data on how many of one munition the PPB held, compared to another.

4.5.3. ‘Emission types’

In partnership with ORF we developed a typology of six ‘emission types’ by which to classify the set of 148 emission points. This typology began from the set of known chemical munitions used by the PPB, and relied upon visual indicators such as explosion pattern and emission density.

For each emission type, we ‘weight’ the quantities of CS and OC according to the variations that PPB admit to using, and according to the number of those munitions purchased by PPB between 2016 and 2020.

The results of this process of identification, corroboration, and weighting, is a table of minimum estimated quantities of CS and OC for each ‘emission type’, a public version of which is here. These quantities form the basis of our simulation.

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[14] https://www.defense-technology.com/product/triple-chaser-separating-canister-cs/

[15] portlandor.govqa.us/WEBAPP/_rs/(S(darpghg0piruhlb2gatuq2pl))/BusinessDisplay.aspx?sSessionID=&did=17&cat=0

[16] blog.ucsusa.org/science-blogger/top-us-chemical-weapons-company-selling-lethal-smoke-as-non-hazardous/

[17] portlandor.govqa.us/WEBAPP/_rs/(S(t4eugqvp30mzxpdvxo05duqo))/BusinessDisplay.aspx?sSessionID=&did=21&cat=0

	PRODUCER	MUNITION	ID No.	PIECES	ACTIVE AGENT	GRAM PER MUNITION	GRAM PER PIECE	DURATION (SEC)	# MUNITIONS PURCHASED BY PPB TOTAL	# MUNITIONS PURCHASED BY PPB / ACTIVE AGENT	AS PROPORTION OF MUNITIONS PURCHASED BY PPB	CS (g)	OC (g)
TYPE 1	DEFENSE TECHNOLOGY	TRIPLE CHASER CS	1026	3	CS	92	30.67	20-30	1010	520	0.51	15.79	2.18
	DEFENSE TECHNOLOGY	TRIPLE CHASER OC	1020	3	OC	30	10.00	20-30	1010	220	0.22		
	DEFENSE TECHNOLOGY	TRIPLE CHASER SAF	1027	3	SAF SMOKE	0	0	20-30	1010	220	0.27		
TYPE 2	DEFENSE TECHNOLOGY	RUBBER BALL BLAST GRENADE	1095SC	1	OC	4.2	4.2	20-30	518	140	0.27	0	1.14
	DEFENSE TECHNOLOGY	RUBBER BALL BLAST GRENADE	1098SC	1	N/A	0	0	20-30	518	247	0.48		
	DEFENSE TECHNOLOGY	STINGER GRENADE	1087SC	1	N/A	0	0	20-30	518	131	0.25		
TYPE 3	DEFENSE TECHNOLOGY	TRIPLE CHASER CS	1026	3	CS	92	30.67	20-30	1010	520	0.29	9.86	1.45
	DEFENSE TECHNOLOGY	TRIPLE CHASER OC	1020	3	OC	30	10.00	20-30	1010	220	0.12		
	DEFENSE TECHNOLOGY	TRIPLE CHASER SAF	1027	3	SAF SMOKE	0	0	20-30	1010	270	0.15		
	DEFENSE TECHNOLOGY	SKAT SHELL 40MM CS	6172	4	CS	25.2	6.30	10-25	590	200	0.15		
	DEFENSE TECHNOLOGY	SKAT SHELL 40MM OC	6170	4	OC	5.2	1.30	10-25	590	240	0.18		
	DEFENSE TECHNOLOGY	SKAT SHELL 40MM SAF	6173	4	SAF SMOKE	0	0	10-25	590	150	0.11		
	DEFENSE TECHNOLOGY	FLAMELESS TRI-CHAMBER CS	1032	1	CS	20	20	20-30	25	25	0.005		
TYPE 4	DEFENSE TECHNOLOGY	SKAT SHELL 40MM CS	6172	4	CS	25.2	6.30	10-25	590	200	0.34	2.14	0.53
	DEFENSE TECHNOLOGY	SKAT SHELL 40MM OC	6170	4	OC	5.2	1.30	10-25	590	240	0.41		
	DEFENSE TECHNOLOGY	SKAT SHELL 40MM SAF	6173	4	SAF SMOKE	0	0	10-25	590	150	0.25		
TYPE 5	DEFENSE TECHNOLOGY	N/A	n/a	1	N/A	0	0	0.1	-	-	1	0	0
TYPE 6	N/A	BASELINE OPTION	N/A	1	CS	5	5	25	-	-	0.5	2.5	1
	N/A	BASELINE OPTION	N/A	1	OC	2	2	25	-	-	0.5		

Fig 4: Combining a variety of documents, police munitions purchase receipts, and information extracted from the video, we created a table of six different emission types with averaged amounts of chemical contents

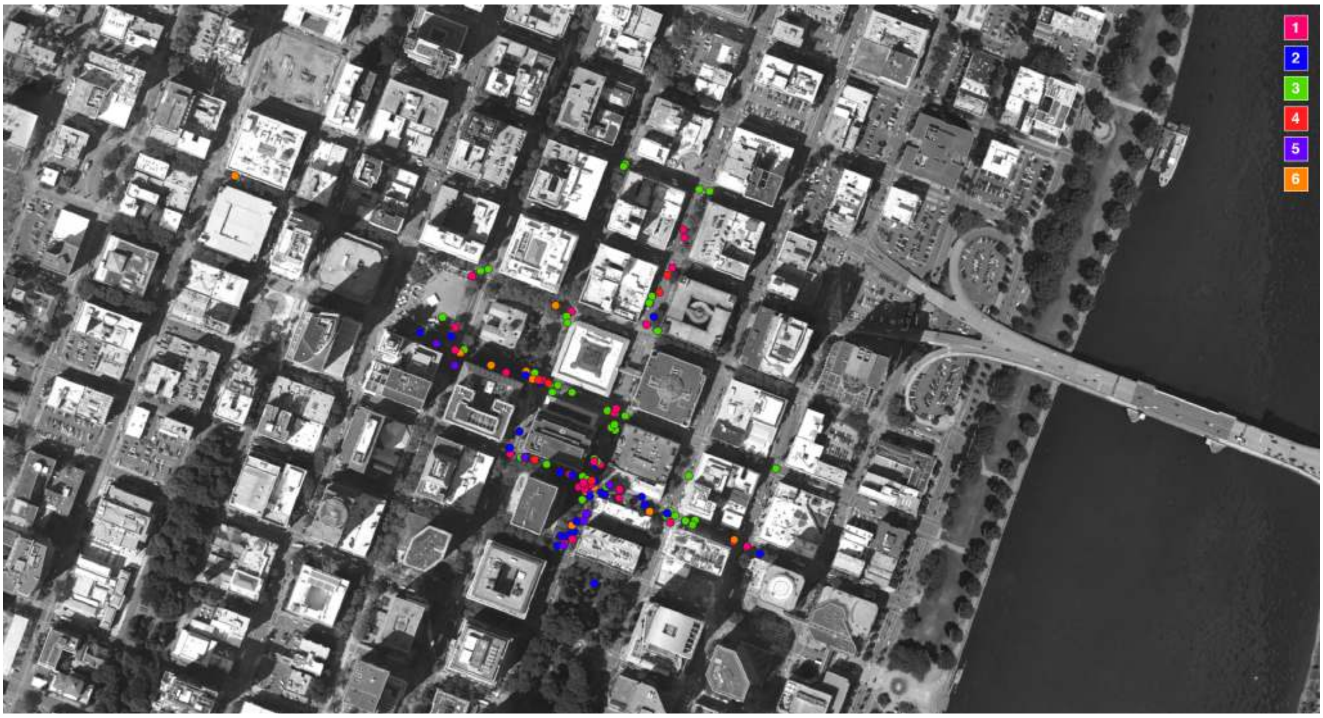

Fig 5: Taking the information of figure 4, we geolocated the all munitions and associated them with a munition type

4.5.4. Randomised emission point ‘scattering’

Two of the six emission types describe munitions composed of multiple parts or ‘sub-munitions’. In reality, when these munitions are deployed, they create a series of separate ‘emission points’ at locations near to the original point of discharge/detonation. To simulate this dispersion, the methodology includes a script for randomised distribution of ‘sub-munition’ points relative to the point of deployment or discharge, according to the category of munition. The character and boundaries of that randomised distribution was determined in each case by the available technical specifications for each munition.[18]

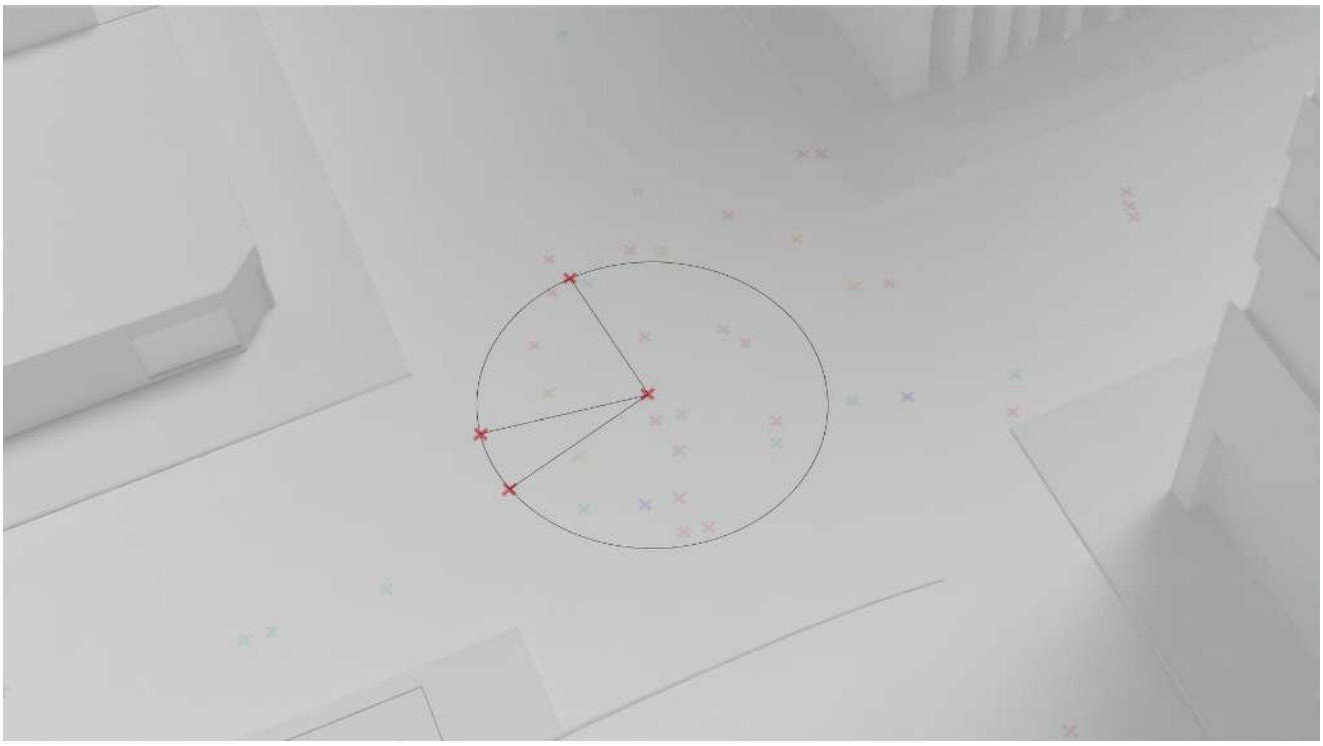

Fig 6: Based on technical data obtained from munition manufacturers, we defined a boundary within which the sub-munitions were randomly scattered for certain munition types (3 and 4)

[18] This process applies specifically to types 3 and 4, which describe a ‘Triple-Chaser’ (see here: www.defense-technology.com/wp-content/uploads/2020/06/Triple-Chaser-Grenade.pdf) and a ‘Skat Shell’ (see here: www.defense-technology.com/wp-content/uploads/2020/06/40mm-Skat-Shell.pdf)

4.6. Computational Fluid Dynamics (CFD) Simulation

Computational fluid dynamics (CFD) simulations are used to model the behaviour of one fluid in another.[19] Most commonly this method finds its application in industrial and commercial contexts, but in this case, the fluids in question are air, and aerosolised ‘tear gas’ chemicals.

FA has partnered with the Department of Mechanical Engineering (DME) at Imperial College London on at least six investigations. At the forefront of CFD simulation, the DME at Imperial College London has assisted in translating the application of CFD to the context of human rights research and ensuring highest academic standards.

A specific mathematical model within the field of CFD, known as Large Eddy Simulation (LES), can be used to simulate large-scale ‘turbulent mixing’ and fluid problems, i.e., how air moves around a (natural or urban) environment in certain weather conditions, and more pertinently, how emitted gaseous or airborne chemicals behave, and move, within that air flow.[20] LES can thus be used to trace the movements of particles and gaseous compounds through space and time.[21]

The simulation process starts by defining the ‘domain’ that surrounds the ‘model’. In this example, the model is a digital reconstruction of the urban fabric of downtown Portland. The domain is the fluid environment around that fabric; the local atmosphere. Defining the ‘domain’ that surrounds the ‘model’ creates a ‘volume’, which contains all the features of the model, and the ‘empty space’ or ‘atmosphere’ around the model.

Next, the domain must be ‘discretised’. Discretisation is the division of dimensions (i.e., length, height and width) of the created volume into finite lengths (dx, dy, dz). The size of the finite length affects the resolution of the simulation’s output ‘solution’; the smaller the size of the finite length, the higher the resolution, i.e. the smaller that length, the more fine-grained the resulting simulation. (At the same time, the smaller that finite length, the more computationally intensive the solution becomes.)

The preparation of the spatial components of the simulation process finishes with a simple manual check, to confirm that all parts of the 3D model lie inside the domain.

Next, the durational component of the simulation is prepared. Two variables are set: the number of simulation ‘steps’ and the ‘step length’. Multiplied together, these values give what is called the ‘simulation time horizon’. Simply, ‘steps’ are essentially the ‘frame rate’ for the simulation: just as films are commonly ‘24 frames per second’, an LES simulation may have a total step number of 6, and a ‘step length’ of 10s, resulting in a simulation time horizon of 60s, or 1 minute.

(Again, both time-related parameters affect the fidelity of the resulting solution: the smaller the timestep, and the larger the number of steps, the higher the resolution of the solution. Again, however, there is a cost calculation to be made, between resolution and computational demand.)

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[19] See Topics: Computational Fluid Dynamics, ScienceDirect, https://www.sciencedirect.com/topics/engineering/computational-fluid-dynamic

[20] See U Piomelli, *Large eddy simulations in 2030 and beyond*, The Royal Society Publishing (Aug 2014)

[21] LES was first developed by Smagorinsky (1963) and Deardorff (1970) to simulate atmospheric air currents.

The CFD simulation is performed on the fluid ‘domain’. As above, this fluid domain is essentially the total domain minus the 3D model. At the boundary of the fluid domain, starting conditions are given for the simulated weather phenomena; in this case, the weather conditions in downtown Portland as recorded by meteoblue.com, or other weather data providers. These initial conditions include air velocity, direction and temperature, ambient humidity, and barometric pressure. These values create the ‘initial turbulence’ for the system, which is propagated throughout the fluid domain.

The calculation of the turbulence is done by numerically solving the Navier-Stokes (N-S) equation (Eq. 1, below).[22] In LES a ‘low-pass filter’ (Eq. 3) is inserted in the N-S equations system, where the smallest simulation lengths are ignored, reducing computational cost.

$$\rho\left[\frac{\partial \boldsymbol{v}}{\partial t} + \boldsymbol{v}\cdot\nabla\boldsymbol{v}\right] = \rho\boldsymbol{g} - \nabla p + \mu\nabla^2\boldsymbol{v} \quad (1)$$

Where **ρ** is the density of the fluid, **v** is the velocity of the fluid, **g** is the gravitational force, **μ** is the viscosity of the fluid and **p** is the pressure. This equation works for both laminar and turbulent flows. The variables **v**, **g** are vectors and therefore, Eq.1 becomes three distinct equations for each coordinate $\partial v/\partial x, \partial v/\partial y, \partial v/\partial z$.The continuity equation (Eq. 2) must also be satisfied.

$$\nabla\boldsymbol{v} = \boldsymbol{0} \quad (2)$$

Again **v** is a vector and the Eq.2 becomes three equations for each **v** coordinate $\partial v/\partial x, \partial v/\partial y, \partial v/\partial z$.

$$\overline{\varphi(\boldsymbol{x},t)} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\varphi(\boldsymbol{r},t')G(\boldsymbol{x}-\boldsymbol{r},t-t')dt'dr \quad (3)$$

Where **φ** is the spatial and temporal field, and the bar denotes the filtered field and **G** is a convolution kernel unique to the type of the filter used.

If necessary, weather conditions can be changed at certain preset time points, and the turbulence calculations are then adapted appropriately. By the time the simulation reaches its end time point (i.e. its final ‘step’), a dynamic ‘4D’ (i.e. changing over time) turbulence field has been created, surrounding the topography. This field can confidently predict the movement and the turbulence of the air in the given time and weather conditions.

That 4D turbulence field becomes, essentially, the backdrop for the dispersions from the ‘emission points’; it is saved, and used to calculate the concentration gradients of any substances that are dispersed in the simulated environment.

First, the duration, and temporal and spatial location, of the emission sources is determined. The emission is an emission of simulated molecules, each of a certain weight and density. Total emission is calculated from the duration and rate of the emission, and the density of the substance.

[22] The Navier-Stokes equations are explained accessibly here: en.wikipedia.org/wiki/Navier%E2%80%93Stokes_equations

When this emission point data is combined with the spatial data of the 3D model and the turbulence field, the movement of each substance molecule can be “tracked” through space and time, to its final resting position on the urban topography of the model. Through this process, the spatiotemporal dispersion of a substance is predicted, and a gradient map created, showing hotspots of high concentrations of the substance at the end of the simulation time horizon.

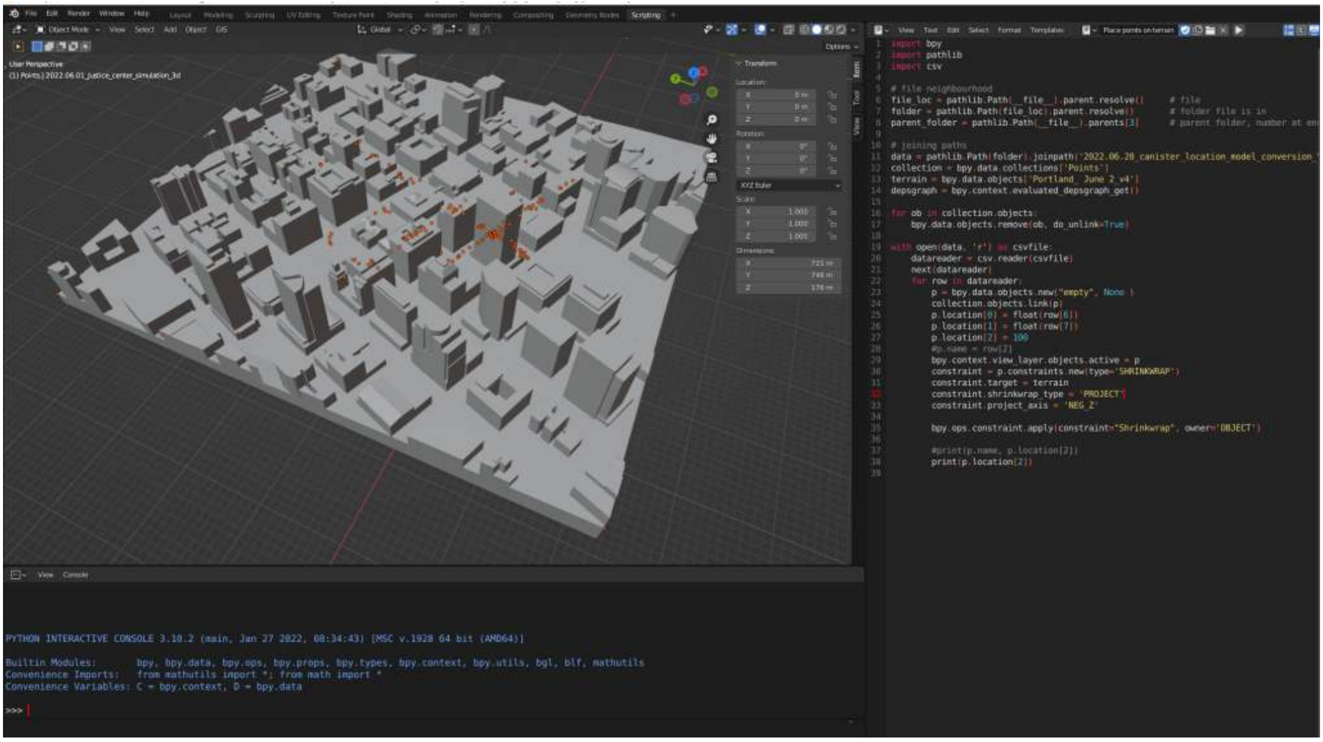

Fig 7: Emission points within a 3D model of downtown Portland

To visualise and process the simulation results (the turbulence, as well as the dispersion of the chemical molecules), the data generated by the simulation are loaded into a data visualisation software, in our case Visit,[23] which ‘maps’ the spatiotemporal data onto the 3D model (in this case, of downtown Portland), allowing the user to observe data, and compute airborne and ground concentrations.

[23] https://visit-dav.github.io/visit-website/index.html

5. CFD simulation results format

The simulation, supported by the methodology outlined above, produced results in two formats: values for airborne concentration, and ground deposition.

5.1.1. Airborne Concentration

Airborne concentration measurements refer to measurement of concentrations of OC or CS particles in air. Both chemicals are composite powders that are ‘aerosolised’ when discharged. These particles can be measured by weighing their cumulative, respectively averaged concentration over time in any given volumetric body.

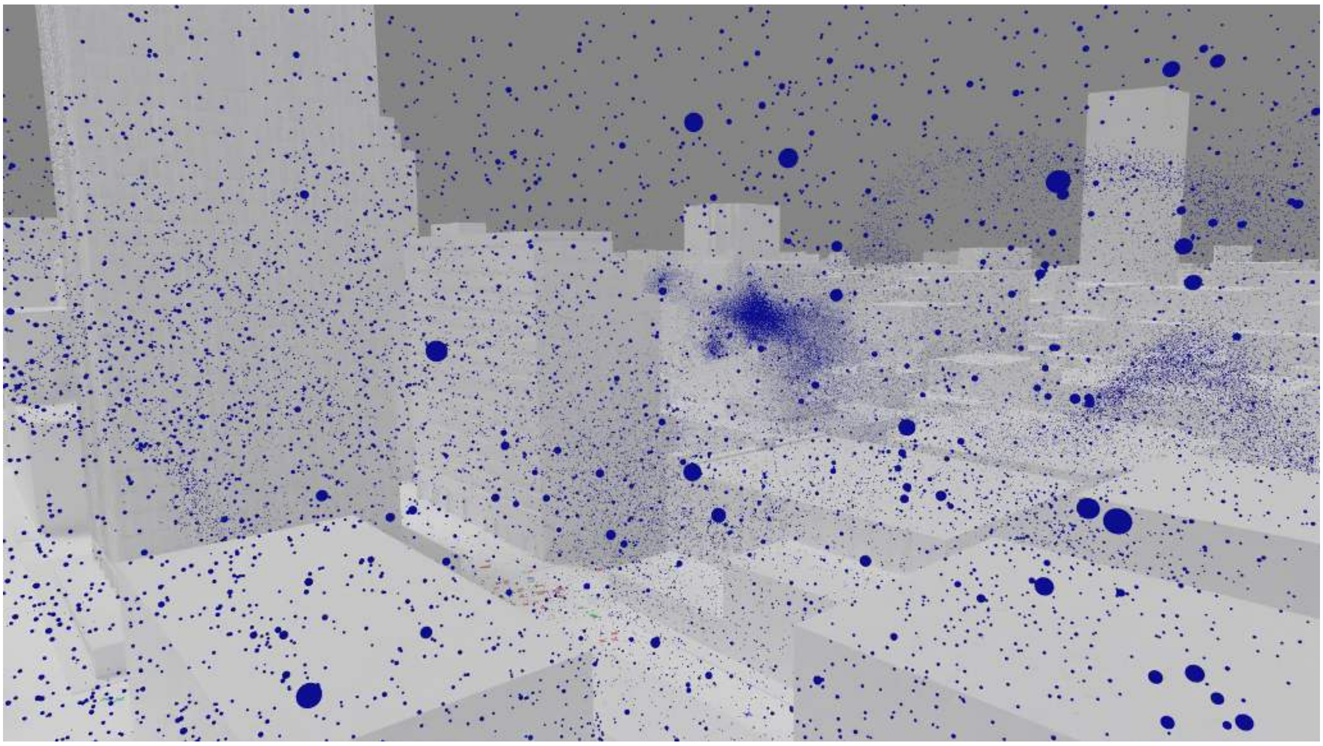

Fig 8: A simulation of the airborne CS particles in the model

5.1.1.1. Volume Measurements

To determine airborne concentrations in CFD simulations, we measure the mass of particles passing through a defined volumetric body. The combined mass of particles is measured in milligram (mg), in relation to the volume as measured in cubic metres (m^3), resulting in a mg/m^3 value.

For the purposes of this investigation, a volume of 6 x 6 x 3m was defined. According to the ‘Jacobs’ Method’,[24] this volume – an area of 6m by 6m, with a vertical height of 3m – could hold around 150 protesters at a

[24] Which gives the ‘rule of thumb’, when estimating crowd size, of $0.23m^2$ per individual.

maximum comfortable density, though at most times during the evening of 2 June 2020 the protests were less dense than that.

Measurements within each volume were taken every ten seconds during the simulation; every ten seconds, the simulation was paused as if in a ‘freeze frame’, and we counted the number of particles within the volume. The overall absolute mass of those particles is then divided by the overall volume (108m^3 and subsequently scaled down to the relative volumetric unit - one cubic metre. This way the overall concentration is averaged out across the entire volume of the cube.

This process of spatial averaging does twofold: (1) it enables representative measurements across volumes that reflect a volume through which protestors easily pass (at different speeds, e.g. walking as well as running) within ten seconds, (2) it averages out extreme concentrations that do not necessarily represent close to reality conditions to which protesters were exposed.

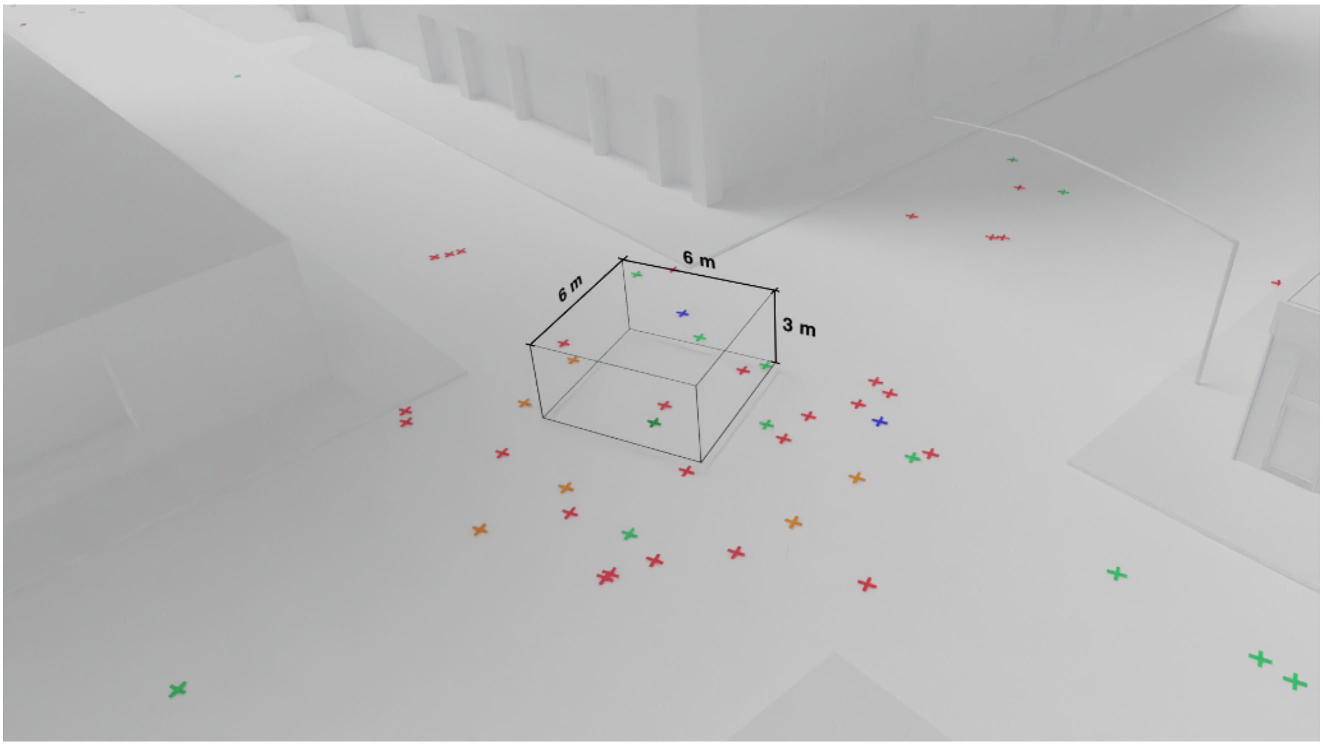

Fig 9: A measurement volumes (Sample point A) used to determine airborne concentrations

5.1.1.2. Measurement Distribution

To determine airborne concentrations across different parts of Portland according to the simulation, we placed identically sized ‘volumes’ at different points within our digital environment.

Informed by our analysis of the video data, we sampled volumes near to the protest area – sites dense with emission points – but also at locations further from the protest area, in order to test our hypothesis that dangerously high airborne concentrations might still be recorded at locations far from the emission points, along the direction of the wind.

Fig 10: Airborne concentration sample points at 15 different locations across downtown Portland

5.1.2. Ground Deposition

Ground depositions describe the concentration of chemical particles of CS or OC aerosols that accumulate on the ground through deposition after their dispersal and flight through the air. Ground deposition was both measured for solid grounds (concrete, soil etc.) as well as for non-solid grounds like adjacent water bodies such as the Willamette River.

The method of measurement is based on the calculation of deposited particles in milligrams (mg) per square metre (m^2) - mg/m^2. Ground deposition measurements make it possible to calculate the spread of chemical particles after their launch, respectively discharge, as the ‘aerosolised’ particles stay afloat and are carried by wind for hundreds of metres. The spread of particles can therefore be measured in the distance they travel from their original point of discharge as well as the overall area across which the particles spread.

Additionally, these measurements allow sampling across points close to highly frequented locations across downtown Portland or specifically sensitive locations, such as medical facilities, restaurants, bodies of water or sewage drains, highly frequented streets, as well as hotels, offices, educational facilities such as schools or colleges and shopping centres.

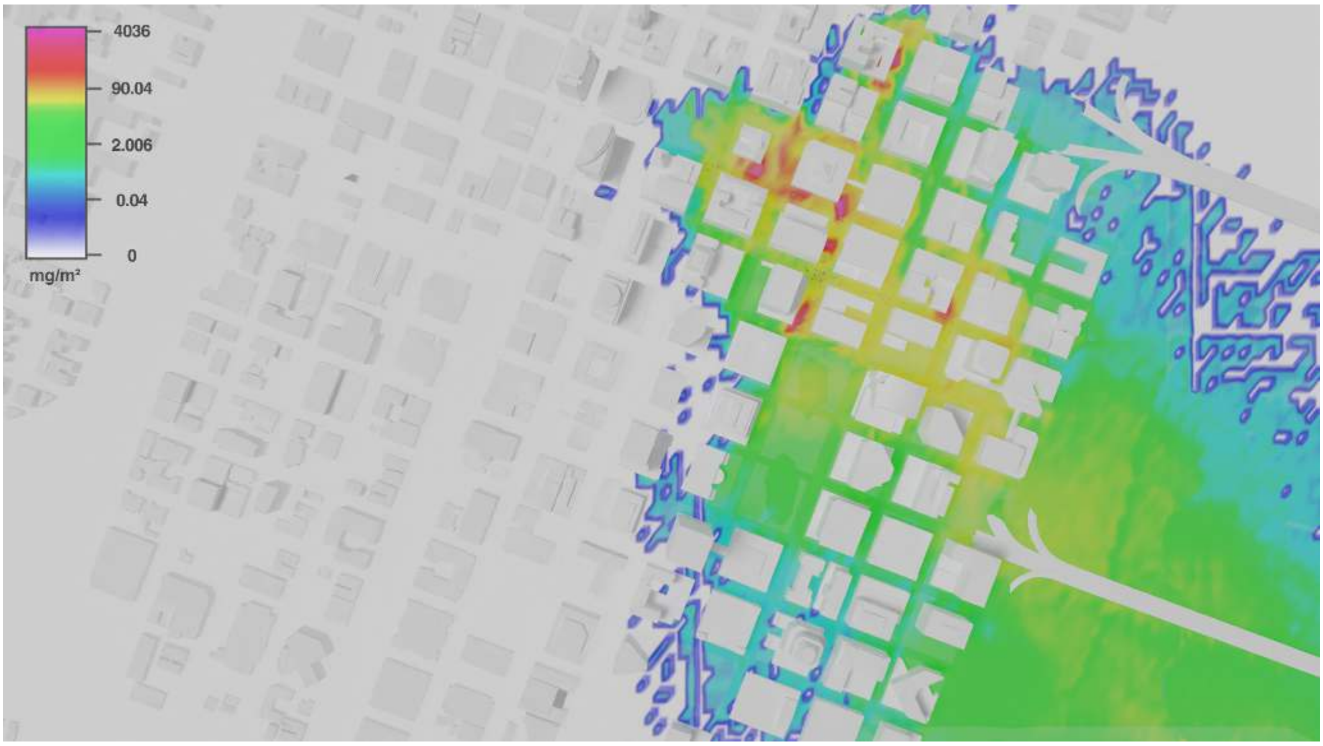

Fig 11: The simulated ground deposition of CS particles, following the prevailing wind

6. Findings

6.1. Findings pertaining to airborne concentrations

On 2 June 2020, the PPB used at least 148 munitions of which at least 138 were identified as containing 'tear gas' chemicals in an area of 18 blocks of downtown Portland, over the period of around 2 and a half hours.

In all 15 sampling locations within our CFD simulation, airborne concentrations exceeded the OSHA-defined 'Immediately Dangerous to Life or Health' (IDLH)[25] value of 2mg/m^3. In all 15 sampling locations, the 2mg/m^3 threshold was exceeded for a continuous period of at least 30 seconds.

At 19 separate instances across the sampling locations, the 2mg/m^3 threshold was exceeded continuously for more than a minute.

The simulation records a cumulative total of more than 73 minutes during which the 2mg/m^3 was exceeded across the 15 sampling locations. The simulation also records a cumulative total of 9 minutes and 20 seconds

[25] IDLH values are described as follows by the National Institute for Occupational Safety and Health (NIOSH): *"Acute or short-term exposures to high concentrations of some airborne chemicals [which] have the ability to quickly overwhelm… resulting in a wide spectrum of undesirable health outcomes that may include irritation of the eyes and respiratory tract, severe irreversible health effects, impairment of the ability to escape from the exposure environment, and, in extreme cases, death."* See https://www.cdc.gov/niosh/idlh/default.html

during which airborne concentrations reached 100mg/m^3 – 50 times the IDLH threshold – across the 15 sampling locations.

At sampling location A, which simulates conditions at the intersection of SW 5th Avenue and SW Yamhill Street in downtown Portland, the IDLH value was continuously exceeded for 6 minutes and 20 seconds. The maximum airborne concentration recorded at sampling location A was 443.9 mg/m^3.

The highest airborne concentration value recorded was 4568 mg/m^3.

6.2. Findings pertaining to ground deposition

According to the simulation, CS particles would have spread at least 809m across downtown Portland as a result of the actions of PPB on 2 June 2020, carried southeast by the prevailing wind on that day. While footfall in much of downtown Portland was significantly reduced on 2 June as a result of an ongoing ‘lockdown’ necessitated by the COVID-19 pandemic, PPB and federal agents from DHS and ICE continued to use large quantities of tear gas in the area throughout the second half of 2020.

To the east of the protest areas is the Willamette River. According to the simulation, more than 2kg of CS is likely to have been deposited into the river as a result of police actions on 2 June 2020. Among other native species, the Willamette is home to rainbow trout, to which CS is known to be acutely toxic.[26]

This finding is particularly notable since Portland’s Bureau of Environmental Services already found elevated levels of CS residue in storm drains leading to the Willamette River.[27] They did not at the time, however, consider the additional possibility of CS being deposited on the surface of the river.

[26] F.S.H. Abram, P. Wilson, ‘The acute toxicity of CS to rainbow trout’, Water Research (Vol. 13, 7), 1979, pp631-635
[27] www.portland.gov/bes/news/2020/9/10/environmental-services-releases-results-cs-gas-residue-sampling-city-stormwater

7. Concluding observations

Documents released by the PPB in 2020 reveal that the institution was aware of the existence of a 2mg/m3 'IDLH' threshold. The potential health impacts of the use of CS and other chemicals is also widely understood in scientific literature.[28]

However, in FDCR reports from 2 June 2020 and throughout the period of the 2020-21 protests, PPB officers make no mention of any such threshold, and seem to show little comprehension of the danger to public health that is constituted by the excessive use of chemical munitions which contain numerous different toxic chemicals in quantities and combinations which have not been adequately tested before use on a general population.

Consider, for example, the officer who claimed that 'I observed no injuries to anyone involved as a result of my deployments'[29]. This understanding is, indeed, to some extent reflected by previous academic studies of CS and its health impacts, which have extrapolated from studies conducted on extremely small and unrepresentative sample groups.[30] By contrast, a survey of individuals active in the 2020-21 protests in Portland report lasting health impacts, including nausea, abnormal menstruation, and severe headaches.[31]

7.1. Caveats and considerations

A CFD simulation is always a model of reality; it will diverge from the real event that it models insofar as any input conditions diverge from the real inputs. Moreover, CFD is a *stochastic* simulation, i.e. its variables are themselves subject to minor randomisations, meaning that every iteration of a simulation from the same starting conditions will be marginally different, within certain fine margins of error.

This means that our findings in relation to airborne concentrations and ground depositions should be taken as *guides*, or as example figures within a margin of error. However, given the extraordinarily high concentrations established by the simulation – for example, airborne concentrations regularly 30 times higher than federally-recognised safe levels, and reaching up to around 2200 times higher – we believe that even within a modest margin of error, the results of the simulation remain extremely concerning.

Our 'emission types' methodology is necessitated by the fact that neither individual officers, nor the PPB as a whole, kept a count of the chemical munitions deployed during the protests on 2 June 2020 (or seemingly on any other day during that protest period). While a robust and reliable identification of munitions from analysis of video and image data is possible and has been deployed in a wide range of open source investigative (or 'OSINT') reporting (indeed, both FA and our partners at the Omega Research Foundation bring years of

[28] See for example: Morman, A., Williams, Z., Smith, D., Randolph A.C. (2020). Riot Control Agents: Systemic Reassessment of Adverse effects in Health, Mental Stability, and Social inequities. Published June 26th, 2020; as well as Facts About Riot Control Agents, Centers for Disease Control and Prevention, https://emergency.cdc.gov/agent/riotcontrol/factsheet.asp (last visited Jan. 30, 2022)

[29] Force Data Collection Report No. 50575, Case No. 2020-680557 (record release: GO 42 2020-680557), p. 73

[30] For example, 'one oft-cited study deemed CS tear gas safe on the basis of outcomes of controlled exposures of 35 healthy male volunteers, without considering the effects on children, women, the elderly, or subjects affected by preexisting conditions.' C. Rothenberg, S.Achanta, E.R. Svendsen, S.E. Jordt, 'Tear gas: an epidemiological and mechanistic reassessment', Ann N Y Acad Sci., 2016 (Vol. 1378, 1), p96-107

[31] B.N. Torgrimson-Ojerio, K.S. Mularski, M.R. Peyton, E.M. Keast, A. Hassan, I. Ivlev, 'Health issues and healthcare utilisation among adults who reported exposure to tear gas during 2020 Portland (OR) protests: a cross-sectional survey', BMC Public Health, 2021 (Vol. 26, 21)

extensive applied experience to this task), it is inevitable that some munitions will have been missed, or misidentified, meaning that the quantity of CS in the simulation varies from the 'real conditions' of 2 June 2020.

However, it is important to note a handful of factors which mitigate this divergence. First, the 'Triple-Chaser'-style emission type, (Type 1), is both the most clearly identifiable – by virtue of its relatively large size, and its 1-into-3 discharge pattern – and the emission type which contains the most CS or OC by mass. This has the result that we can be most confident about our identification of the most harmful munitions.

Second, given that most munitions can be identified with a high degree of confidence, and given that our video 'sync' cannot cover 100% of the protest area and related PPB actions, it is very likely that there were additional chemical munition deployments that were not captured by this analysis, meaning that the overall count – and quantity of chemicals – would likely be higher than accounted for by our simulation.

8. Credits

Researcher-in-Charge
Robert Trafford

Project Coordinator
Lola Conte

Research
Yannis Zacharopoulos
Imani Jacqueline Brown
Duncan Salkovskis
Jasper Humpert
Kishan San
Alyssa C. Smith
Andra Pop-Jurj
Jacob Bolton
Grigory Gorbun

Video editor
Natalia Sliwinska

Research Support
Eyal Weizman
Samaneh Moafi

Our thanks to
Neil Corney, Omega Research Foundation
Dr Salvador Navarro-Martinez, the Department of Mechanical Engineering, Imperial College London
Dr Anita Randolph and Teressa Raiford, Don't Shoot PDX
Kelly Simon, ACLU Oregon
Dr Rohini Haar, Physicians for Human Rights
Dr Nina Amstutz, University of Oregon
The Oregon-based citizens and activists who shared video material and their experiences