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.

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Methodology Report

Chemical Fire at Marathon Refinery

Garyville, Louisiana | 24-28 August 2023

29 August 2024

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Introduction

Marathon Petroleum Corporation's facility in Garyville, Louisiana is one of the largest refineries in the western hemisphere. Nearby residents of 'fenceline' communities, which directly border this and other facilities across Louisiana's 'Cancer Alley',[1] are forced to breath in some of most polluted air in the US[2]—a direct result of these plants' emissions. These communities face a cancer risk seven times higher than the U.S. national average.[3]

On 24 August 2023, a tank at the Marathon facility containing naphtha, a volatile hydrocarbon chemical mixture, began leaking, and later ignited. Over the course of 33 hours, 3.76 million kg (8.3 million lbs) of toxic, flammable material was released, amounting to the second largest chemical spill in the thirty years since the Environmental Protection Agency (EPA) began monitoring hazardous facility incidents in the US.[4]

Residents and local media captured visual evidence of a thick, black plume that stretched across several of the surrounding communities for two days following the start of the fire. While residents reported severe health impacts, including several hospitalisations, state and corporate officials claim that there were no impacts beyond Marathon's property line.

With our partners at the Guardian, we interviewed residents of fenceline communities that abut Marathon's property. We situated their testimony, along with a fluid dynamics simulation of the plume, in a 3D model of the site, mapping the dispersal of toxic and criteria air emissions across several communities. Finally, we developed an online platform to host these models, enabling users to track the incident's development, and the state's response, over time.

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1 Cancer Alley is most commonly defined as a region spanning 85 miles of the Mississippi River between the Louisiana state capital of Baton Rouge and New Orleans where cancer risk is the highest in the United States. The moniker was coined by environmental activists in the 1980s; in 2018, activists with Rise St James and Concerned Citizens of St John the Baptist Parish offered the additional nickname of 'Death Alley'.

2 Younes, Lylla and Shaw, Al, 'How We Found New Chemical Plants Are Being Built in South Louisiana's Most Polluted Areas', *ProPublica,* 30 Oct 2019. Available at: https://www.propublica.org/article/how-we-found-new-chemical-plants-are-being-built-in-south-louisianas-most-polluted-areas.

3 Maite Amorebieta, 'Toxic school: How the government failed Black residents in Louisiana's 'Cancer Alley'', *NBC* News, 16 Mar 2023. Available at: https://www.nbcnews.com/news/us-news/toxic-school-government-failed-black-residents-louisianas-cancer-alley-rcna72504/.

4 EPA Risk Management Program, 'Section 6.: Accident History'. Last accessed: 19 March 2024.

Summary

This investigation utilised computer fluid dynamics (CFD) simulations alongside a more ‘traditional’ open-source investigative workflow, which included video synchronisation, open source research, geo- and chronolocation, architectural modelling, and analysis of public records.

Our methodology can be broken down into the following steps:

Geolocation and synchronisation

We geolocated and synchronised the available visual evidence to study the timeline and progression of the fire. According to the Louisiana Department of Environmental Quality’s (LDEQ) incident report,5 the event starts at 18:38 on 24 August 2023 with a leak of naphtha from Tank 150-11. The EPA reports that 3.76 million kg (8.3 million lbs) of ‘flammable mixture’ was ‘released’ over 33 hours, which would suggest the event concluded at 03:38 on 26 August.6 However, CTECH’s emissions monitoring registered values of PM 2.5 between 36 and 181 $\mu g/m^3$ from 14:42 on 25 August all the way until 10:45 on 28 August.7 Based on this, we established 28 August as the ‘end’ of the event, even though impacts including those related to residents’ health, continued well beyond this bracketed time frame.

Architectural modelling

We determined the location and contents of the chemical storage tanks reported to have sustained damage, based on incident reports, visual material, permit applications and other documents pertaining to the Marathon Garyville Refinery accessed through the LDEQ’s Electronic Document Management System [EDMS].[8]

Using the open-source software Blender,[9] we built an architectural digital model of the site of the Marathon Garyville Refinery and surrounding area. A version of the model was input to the software OpenFOAM,[10] producing the digital environment in which the CFD simulation was then conducted.

[5] Louisiana Department of Environmental Quality (LDEQ), 'Monitoring Report Form', LDEQ-EDMS Document 13991584, received in response to a Public Record Request in November 2023, p.7. Also available at https://www.deq.louisiana.gov/page/edms

[6] EPA Risk Management Program, ‘Section 6.: Accident History’. Last accessed: 19 March 2024.

[7] Louisiana Department of Environmental Quality (LDEQ), 'Monitoring Report Form', LDEQ-EDMS Document 13991584, received in response to a Public Record Request in November 2023, p.8. Also available at https://www.deq.louisiana.gov/page/edms

[8] https://edms.deq.louisiana.gov/

[9] http://blender.org

[10] http://openfoam.com

Document Analysis

In addition to visual analysis, we conducted a rigorous and sustained comparative analysis of the sequence of events recorded in incident reports from LDEQ[11] and the Louisiana State Police (LSP),[12] as well as in post-incident reports submitted by Marathon to LDEQ[13] and the EPA.[14] This analysis enabled the assembly of a detailed timeline of events, including the progression of the leak and the resulting fire. Data from those reports also informed the parameters of the Computer Fluid Dynamics (CFD) simulation of the plume and some of its constituent pollutants.

Interviews and consultations with residents and experts

With our partners at the Guardian, we conducted in-person interviews with seventeen residents from fenceline communities that border the Marathon Garyville Refinery, including Garyville, Lions, and Reserve. Members of these communities reported feeling largely abandoned by state and corporate officials, and provided first-hand accounts of events surrounding the incident, which challenged the accounts provided by authorities.

We consulted with local experts from the Tulane Environmental Law Clinic. A major concern they raised was to do with the air quality monitors used by Marathon and third-party consultant CTEH, which they confirmed were insufficiently sensitive to reliably detect dangerous levels of pollutants, hence the consistent ‘no detect’ readings reported.[15]

Given the alarming accounts from local residents and unreliable monitoring by Marathon and CTEH, we introduced the simulation as an additional tool for estimating the quantities of emissions released over the course of the incident.

CFD simulation

FA partnered with the Department of Mechanical Engineering (DME) at Imperial College London to produce a Computational Fluid Dynamics (CFD) simulation of the combustion of naphtha and the movement of combusted gases through the air between 6:30am on 25 August and 4:50am on 26 August 2023. This is one of more than a dozen such research-focused partnerships between the two

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[11] LDEQ, ‘Field Interview Form’, LDEQ-EDMS 13974338, received in response to a Public Record Request in October 2023. Also available at https://www.deq.louisiana.gov/page/edms

[12] Louisiana State Police (LSP), LSP/DEQ Incident Report, received in response to a Public Record Request in November 2023.

[13] Marathon Petroleum Company LP, DEQ/AQD Emergency Occurrence and/or upset notification form, submitted on 20 December 2023. Two updates were issued on 26 April and 18 June 2024 by Garyville Refining Logistics LLC, a subsidiary of Marathon Petroleum Company. A third update is expected in August 2024. We reviewed the updated findings, which appeared to be consistent with the findings from the December 2023 report.

[14] EPA Risk Management Program, ‘Section 6.: Accident History’. Last accessed: 19 March 2024.

[15] Louisiana State Police (LSP), LSP/DEQ Incident Report, received in response to a Public Record Request in November 2023.

groups since 2016.

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. LES can in this way be used to trace the movements of particles and gaseous compounds through space and time.

We determined the volumes of compounds contained in each of the tanks at the time of the incident and studied their compositions.

We defined the simulation inputs—timeframe, meteorological data, volume and chemical composition of combusted material, and average decay coefficient of the fire—to estimate the movement of particles and airborne concentrations of the emitted pollutants.

Marathon’s report to LDEQ identified nine emitted pollutants, but did not list particulate matter (PM 2.5).[16] We simulated the combustion process, along with the movement of two toxic and criteria air pollutants: benzene and PM 2.5.

[16] Marathon Petroleum Company LP, DEQ/AQD Emergency Occurrence and/or upset notification form, submitted on 20.12.2023. Two updates were issued on 26.04.2024 and 18.06.2024. We reviewed the updated findings, which appeared to be consistent with the findings from the December 2023 report.

Detailed Methodology

Visual Analysis

We created an interactive timeline and 3D platform, which incorporated a digital simulation of the plume and the distribution of several of its chemical components over time. The platform allowed us to situate residents' testimony within space and time, alongside the various claims made by state and corporate officials.

a. Video synchronisation, geolocation, and chronolocation

FA gathered videos and images taken in the proximity of the Marathon Petroleum Refinery from online sources, including news broadcasts and social media, and from residents of the affected areas. For that material to be useful as visual evidence, we had to determine when and where those videos and images were captured. To establish when material had been captured, we synchronised and 'chronolocated' the videos; to establish where, we 'geolocated' the material.

'Synchronising' visual data involves matching consistent features and events-over-time across different media sources. Metadata encoded in media provides a starting point. To confirm that metadata, or to establish the approximate time that images and videos lacking metadata were taken (accurate to within 15-30 minutes), we 'chronolocated' the available media by analysing the length and direction of the shadows visible in them, among other features. A detailed how-to guide on 'chronolocation' is available here: https://www.youtube.com/watch?v=OONjbRAR-TM.

In the process of synchronising the available media, we also geolocated it. Geolocation of an image or video relies upon the identification of notable features within the image frame—such as a skyline, distinctive structures, or other landmarks—and subsequently determining the 'real life' location of those features by referencing satellite imagery or cartographic data such as Google Maps and Google Street View.

The resulting time-space 'sync' captured the unfolding incident on 25 August 2023 between the hours of 8:30 and 13:30, as well as in the evening between 18:44 and 19:23. A 'sync' will naturally contain gaps, in both time and space, between the events and across the environments captured within the available media.

b. Architectural modelling
Using the open-source software Blender, we built an architectural digital model of the area surrounding the site of the Marathon Garyville Refinery. A version of the model is first used within the software OpenFOAM, 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 model 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'.

Computational Fluid Dynamics (CFD) Simulation

CFD simulations are used to model the behaviour of one fluid in another.17 Most commonly, this method is used in industrial and commercial contexts; in this case, the fluids in question are air and combusted components of naphtha.

FA has partnered with the Department of Mechanical Engineering (DME) at Imperial College London on at least six investigations. Internationally recognised as leading experts in 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 the highest academic standards.

a. Modelling the conditions of the Atmospheric Boundary Layer

CFD simulation in environmental contexts begins from a detailed understanding of airflow close to the earth's surface. The Atmospheric Boundary Layer (ABL) is the part of the atmosphere that exchanges information with the earth's surface over a short timescale of less than one hour. The ABL extends to 1 km above the surface, and encompasses a region where the airflow is particularly turbulent and where eddies promote mixing. Turbulence is suppressed by string surface cooling during the night/day cycle and the turbulent cascade through air viscosity and friction close to the surface.
During the first day of the incident in question, the temperature changed very little, with minimum and maximum temperatures between 28–36 degrees C (82.4–96.8 degrees F). For the purposes of the simulation, the air temperature and humidity were assumed to be constant. Under the assumption of constant temperature, atmospheric pressure changes with altitude, following the formula:

$$p = p_0 \exp\left(\frac{-gzM}{RT}\right)$$

(Fig. 1)

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

where p_0 is the pressure at sea level, T is the temperature, g the gravity, the mean molecular weight of air and R the universal gas constant. Before the fire started, the boundary is assumed to be neutrally stable. This is a common approximation of constant temperature where surface cooling effects are not accounted for.

b. Turbulence Modelling

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.[18] LES can thus be used to trace the movements of particles and gaseous compounds through space and time.[19]

In general, Large Eddy Simulation (LES) has proven superior to other methods when describing the ABL. LES focuses on directly simulating the larger, energy-containing eddies and uses sub-grid scale models to approximate the effects of smaller, unresolved scales. This approach balances computational cost and accuracy, making it particularly useful for studying complex flows. LES spatially filters the fluid equations of motion. The equations solved at each time step (in this case, every fraction of a second) are the filtered Navier-Stokes equations, a set of equations which account for buoyancy effects and moderate compressible effects.

These equations assume that the flow is much slower than the speed of sound, which implicitly assumes that pressure variations are much smaller than atmospheric pressure given by expression (Fig. 1). At each time step, the equation provides results pertaining to data including wind, concentration of pollutants, particle position, pressure, temperature, etc. This process is repeated for each fraction of a second until the end of the simulation timeframe. Sub-grid turbulence is modelled using a WALE model.[20] After modelling the turbulence, the final equations (equations that are solved within the simulation software) are solved for filtered velocity, enthalpy and species mass fraction.[21]

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

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

[20] Nicoud, F., & Ducros, F. (1999). Subgrid-Scale Stress Modelling Based on the Square of the Velocity Gradient Tensor. *Flow, Turbulence and Combustion*, *63*, 183–200.

[21] Thierry Poinsot, Denis Veynante, (2005) Theoretical and Numerical Combustion R.T. Edwards, Inc.

c. ABL representation and boundary conditions

Under neutral stability conditions, the initial velocity profile is defined by the formula:

$$U(z) = \frac{U^*}{\kappa} \ln\left(\frac{z + z_0}{z_0}\right)$$

(Fig. 2)

where κ is von Karman's constant, U^* is friction velocity and z_0 is the roughness length (a corrective measure to account for the effect of the roughness of a surface on wind flow), taken as 0.5 for large vegetation, farms, groves of trees and swathes of forest, which form the largest part of the domain. The friction velocity is defined by the formula:

$$U^* = \kappa \frac{U_{ref}}{ln\left(\frac{Z_{ref}+z_0}{z_0}\right)}$$

(Fig. 3)

where Z_{ref} is a reference height, taken in this case at 100m, and U_{ref} the wind velocity at that height. The wind speed U_{ref} is a function of time and is given every hour (see Fig. 4) obtained from FA and MeteoBlue at a location in the centre of the Marathon site. Similarly, the wind direction is provided at the same time intervals.

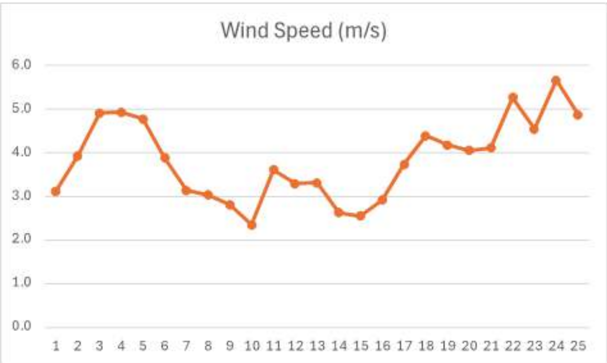

Fig. 4: Wind velocity in the vicinity of Marathon (LON 30, LAT -90.50)

d. Software

The filtered governing equations were solved using an unstructured, finite volume method implemented in the open-source software OpenFOAM.[22] OpenFOAM is a leading open-source software for Computational Fluid Dynamics (CFD), widely used and validated across various engineering and scientific fields, including atmospheric flows.[23] A second-order accurate scheme is employed for spatial discretisation. Temporal discretisation utilises a second-order accurate backward scheme, with a variable time step adjusted to maintain Courant numbers below 0.6, ensuring the stability of the solution. The time steps range from 0.1 to 0.6 seconds.

The simulation process starts by defining the 'domain' that surrounds the 'model'. In this example, the model is a digital terrain reconstruction of a 16km x 10km (9.94mi x 6.21mi) area encompassing Marathon Garyville Refinery, as well as the communities of Garyville, Lions, Reserve and Edgard. 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.

To generate realistic inflow turbulence, the simulation was run for one hour prior to the fire with the wind 'frozen' at 06:30 conditions and superimposed fluctuations to trigger turbulence development. This solution was used as starting flow field for the simulation.
To represent the wind changing direction, a driving pressure gradient (a force) is superimposed such that the conditional planar velocity (in x-y) relaxes to a prescribed vertical profile (2) as a function of time given by Figure 1 (with a similarly obtained wind direction). This is called the 'nudging model' in LES[24] where the large-scale forcing is constructed based on observations from measurement campaigns. The forcing can be described by the formula:

$$\vec{f} = -\frac{\langle \vec{u} \rangle - \vec{u}^{MS}}{\tau}$$

(Fig. 5)

[22] OpenFOAM Foundation (2021). OpenFOAM version 10. Retrieved from https://openfoam.org
23 Schalau, S.; Habib, A.; (2021) Michel, S. Atmospheric Wind Field Modelling with OpenFOAM for Near-Ground Gas Dispersion. Atmosphere 2021, 12, 933;
Cavar, D., Réthoré, P.-E., Bechmann, A., Sørensen, N. N., Martinez, B., Zahle, F., Berg, J., & Kelly, M. C. (2016). Comparison of OpenFOAM and EllipSys3D for neutral atmospheric flow over complex terrain. Wind Energy Science, 1(1), 55–70 ;
Temel, O., Bricteux, L., & van Beeck, J. (2018). Coupled WRF-OpenFOAM study of wind flow over complex terrain. Journal of Wind Engineering and Industrial Aerodynamics, 174, 152–169.
24 Heinze, R., Moseley, C., Böske, L. N., Muppa, S. K., Maurer, V., Raasch, S., & Stevens, B. (2017). Evaluation of large-eddy simulations forced with mesoscale model output for a multi-week period during a measurement campaign. *Atmospheric Chemistry and Physics*, 17(11), 7083–7109.

Where the angle brackets denote planar x-y average, and MS indicates the measured constructed profiles and t is the relaxation time scale, which defines the strength of the nudging and must be small enough to capture rapid overall wind changes but larger than the actual time step.

e. Geometry

A Digital Elevation Model (DEM) provided a terrain extending 16km x 10km (9.94mi x 6.21mi) around the Marathon site. The model does not include buildings, but accounts for elevation differences. The geometry of the terrain was used to build a three-dimensional computational domain 2km in vertical height, using OpenFOAM utilities called blockMesh and snappyHexMesh.[25] The computational domain is divided into approximately 2 million cells creating a 'mesh', where the size of the cells decreases as it approaches the terrain (therefore increasing the resolution). Similarly, the mesh is refined close to the site. The mesh size in this area is approximately 6m in the vertical direction. Fig. 6 shows a detail of the mesh close to the site.

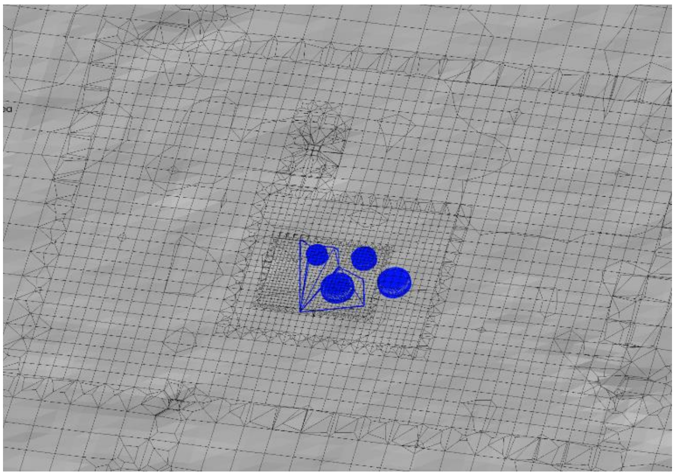

Fig. 6: Detail of the mesh resolution close to the Marathon site. The tanks and containment area of interest are presented in blue. The resolution at the edges of the domain compared to the 'centre' of the domain at the source point decreased by a factor of 8.

[25] OpenFOAM Foundation (2021). OpenFOAM version 10. Retrieved from https://openfoam.org

f. Fire Modelling

The fire is modelled as a boundary condition on the tanks and containment area. The solver requires velocity, temperature, and species boundary condition. Major species CO_2, H_2O,N_2 and O_2 are determined using stoichiometric combustion, where the closest alkene to naphtha is propene (C_3H_6) and the closest alkene to Diesel is n-heptane (C_7H_{16}), the fuel species are only used to determine the condition of major species and are not transported. The containment area burns lean (with excess air), just at the upper limit of Lower Flammability Limit. The temperatures are obtained from experimental numbers of pool fires. Based on the Incident Documentation[26] a timeline is established (see Table 1).

Marathon's report identified nine emitted pollutants[10]. We simulated the combustion process, along with the movement of two toxic and criteria air pollutants: benzene and particulate matter (PM 2.5).

We established a timeline of events by analysing documents by LDEQ and the LSP, which informed the evolution of the simulation.

The average mass flow rate can be estimated based on the mass of fuel consumed. Using the chemical reaction and temperature, the species composition and density can be determined. The average velocity, derived from the area of the burning location, can then be imposed as a boundary condition. These values for the containment area, Tank 150-11, and Tank 300-7 are 0.18, 0.2 and 1.7 m/s, respectively. However, to represent the unsteady behaviour of the fire a further step is needed.

Generally, four stages describe the evolution of a fire: incipient, quick growth, a stationary phase and decay.[27] All tanks and containment locations are assumed to follow an unsteady profile with growth, stationary phase and decay (see Fig. 7). The growth and decay phase are quadratic proportional to t^2 and the different profiles are adjusted based on the reported value of Table 1 to provide the average mass flow rates previously calculated. This creates unsteady boundary conditions on velocity and temperature. The hot gases rise and quickly accelerate the flow due to entrainment effect to a maximum value of approximately 20 m/s (compared to maximum winds of 7-10 m/s).

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[26] Marathon Petroleum Company LP, DEQ/AQD Emergency Occurrence and/or upset notification form, submitted on 20.12.2023. Two updates were issued on 26.04.2024 and 18.06.2024. We reviewed the updated findings, which appeared to be consistent with the findings from the December 2023 report.

[27] H-Y Kim and D G Lilley, (2000) *Heat Release Rates of Burning Items in Fires*, AIAA 2000-0722

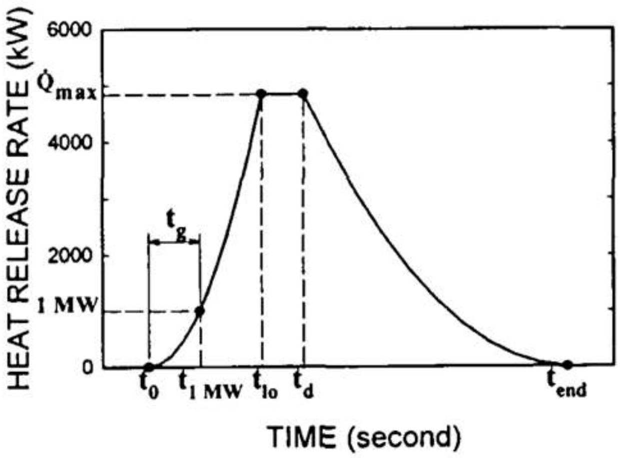


Fig. 7: Heat release as a function of time (Reproduced from H-Y Kim and D G Lilley (2000)). Mass flow rate is directly proportional to heat release rate.

g. Air Emissions

Air emissions were selected based on data from the Emergency Occurrence form to LDEQ[28] The minor species identified include CO, benzene, SO_2, xylene, and NOx. Although additional species are present in the emissions from the fire, these four were chosen due to their relatively high toxicity. The concentrations of these minor species are small compared to the major components and do not significantly affect the gas mixture's specific heat or density. By using the mass flow rate and comparing it to the total gas produced, the boundary conditions for the mass fractions of these species can be determined.

[28] Marathon Petroleum Company LP, DEQ/AQD Emergency Occurrence and/or upset notification form, submitted on 20.12.2023. Two updates were issued on 26.04.2024 and 18.06.2024. We reviewed the updated findings, which appeared to be consistent with the findings from the December 2023 report.

h. Smoke Visibility

Smoke visibility is a post-processing technique used to estimate the size of the smoke column. An estimate of the visibility, *S*, in metres is given by:

$$S = C/K$$ (Fig. 8)

where C is a constant between 3 and 8 (taken as 3 following FDS) and *K* is the light extinction coefficient that is proportional to the 'smoke' concentration which is a function of the local CO2 mass fraction, smoke yield, and density.[29] Smaller visibility values will indicate very thick smoke.

[29] Jin, T. (1997). Studies on Human Behavior and Tenability in Fire Smoke. *Fire Safety Science*.

Findings

Benzene

More than 635kg (1,400lb) of benzene—nearly 150 times the state's daily limit—were released over the course of the incident.[30]

At 14:30 on 25 August, concentrations of benzene reached 0.17ppm—more than 18 times the US Centers for Disease Control's standard for acute exposure (0.009ppm over a two-week period) in Lions.[31] At 20:40 the same day, concentrations of benzene reached 0.04ppm—more than four times the CDC's standard.

According to the US National Institutes of Health (NIH), benzene is a known human carcinogen, and acute benzene exposure can lead to ailments of the neurological and cardiovascular systems.[32]

Acute incidents such as this one compound the effects of St John residents' chronic exposure to regularly permitted carcinogenic emissions from the half dozen facilities in St John the Baptist Parish.

PM 2.5

The PM 2.5 particle simulation was unable to accurately account for surface turbulence, and is therefore lacking the resolution necessary to make a reliable assessment of concentration levels close to the ground.

Other

Although we focused our study of gaseous compounds on benzene, other compounds including SO_2, xylene, and NOx may be understood as directly proportional to benzene in terms of spatial distribution. Their concentrations can be derived from the simulation results pertaining to benzene.

[30] Marathon Petroleum Company LP, DEQ/AQD Emergency Occurrence and/or upset notification form, submitted on 20 December 2023. Two updates were issued on 26 April and 18 June 2024 by Garyville Refining Logistics LLC, a subsidiary of Marathon Petroleum Company, p. 4.
[31] Minimal Risk Levels (MRLs) are derived for acute (1-14 days), intermediate (>14-364 days), and chronic (365 days and longer) exposure durations https://www.atsdr.cdc.gov/mrls/index.html
[32] https://pubchem.ncbi.nlm.nih.gov/compound/241#section=Toxicity-Summary

Caveats and considerations

Fluid Mechanics, Domain and Resolution

We conducted two experiments to determine the concentrations of PM 2.5 across the CFD simulation domain. In both experiments, each parcel, or point within the point cloud, represents 1 billion particles. These particles are small and do not affect the main flow field.

In the first experiment, the resolution at the edges of the domain compared to the 'centre' of the domain at the source point (the burning tanks) decreased by a factor of 8. In other words, the resolution within the domain decreased progressively according to distance from the tanks. The highest resolution—which offered the greatest accuracy in approximating concentration levels—was in areas in close proximity to the tanks, including the community of Lions. The lowest resolution—offering the lowest degree of accuracy—was in the community of Garyville, which lies at the edge of the domain.

In the first experiment, the domain contained a mesh made up of 1,534,626 points and 1,471,166 cells (each composed of multiple points). Around 200,000 parcels were present in the simulation at any given time. In a second experiment, we ran another version of the simulation that increased the resolution of the Garyville area by a factor of 2. The height of the simulation domain was also increased from 2km to 4km. The domain of the second experiment contained 1,944,487 points and 1,885,079 cells. In the second experiment, around 400,000 parcels were present in the simulation at any given time. In this second experiment, we increased both the resolution of the mesh and of the point cloud.

The conditions modelled within the domain in which the simulation is run are approximated based on numerous assumptions about meteorological turbulence, air temperature, and surface temperature. The model is able to account for terrain—which is in this case flat—but it cannot account for the presence of buildings in the real-world terrain, which would increase turbulence close to the ground.

According to our partners at Imperial College London, the turbulent flow close to the ground tends to yield a more complex dispersion of particulates, requiring a higher resolution to be accurately rendered than is necessary to simulate particulate dispersion higher up in the airspace in the more visible segments of the plume.

Since the simulation is unable to accurately represent surface turbulence, it is not sufficiently sensitive to accurately approximate concentrations close to the ground. The resolution of the domain and the limitations of the mathematical model are indirectly proportional. Working with a lower resolution domain also exacerbates modelling challenges, as key variable factors are accounted for less accurately—such as, in this case, the constantly shifting direction of the wind and the waxing and waning of the fire over time. The large size of the domain combined with the long temporal frame (approximately 24 hours) compounded these challenges. This impacts the simulation of both PM 2.5 and benzene.

However, in the context of the PM 2.5 particle simulation, a larger uncertainty is present. This can be attributed to:

- the fact that Large Eddy Simulation (LES) can only be applied to gases and not particulates;
- the negligible weight and size of PM 2.5, which make its deposition even more sensitive to turbulence and therefore it is more impacted by:
- the uncertainties in the particle dispersion within the turbulent boundary layer (which controls dispersion close to the ground).

As a result of all these compounding factors, the highest concentrations of PM 2.5 recorded by our simulation in both experiments are considerably lower than the levels measured by handheld monitors during the event (2.11 μg/3 vs 139-341 μg/m3). Therefore, both experiments of simulating PM 2.5 particles can be considered inconclusive. Given more time and resources, the simulation experiment could be repeated with higher resolution given to more narrow domains.

In the context of gases such as benzene, the mathematical model known as Large Eddy Simulation (LES) has proven superior to other methods when describing the ABL, and was applied to the simulation of turbulent mixing for benzene. LES focuses on directly simulating the larger, energy-containing eddies and uses sub-grid scale models to approximate the effects of smaller, unresolved scales. This approach balances computational cost and accuracy, making it particularly useful for studying complex flows.

While the benzene simulation is more reliable and conclusive than the simulation for PM 2.5, it likely represents the conservative estimate, or lower limit, of exposure.

Tank Contents

Marathon's reports of the incident are contradictory. In one report submitted to LDEQ (first submitted on 20 December 2023, and updated on 26 April and 18 June 2024), they state that 22,013 barrels of naphtha had been released into the soil from a single source (Tank 150-11), with 0 barrels released from Tank 300-7, Tank 200-7, and Tank 300-8.

In a separate report to the EPA's Risk Management Program[33], Marathon states that 8,300,000 lbs (28,000 barrels) of so-called 'flammable mixture' had been released from two different sources (not specified), as well as 1,400,00 lbs of hydrogen sulfide.[34]
We were informed by the Guardian of the results of their subsequent follow-up with the EPA, who clarified that, according to their assessment, 'when the fire started at Tank 150-11, it affected another tank, Tank 200-7, and this is the reason there are two different entries for flammable mixture'. We can conclude from this that the reports submitted by Marathon to LDEQ and EPA are inconsistent.

Because there is no conclusive information about the contents of the two tanks in the report to the EPA, we relied on information reported by the Louisiana State Police in their incident report.[35]

The quantity of 'flammable mixture' from the two sources referred to in Marathon's report to the EPA is more or less consistent with the quantities of ULSD and naphtha reported in the LSP's incident report. Discrepancies are likely the result of rounding errors and conversions of units of measurement.

Simulation Inputs

Given these inconsistencies, a combination of the two contradictory sources outlined above informed the design of the simulation scenario. The following tank contents were used as inputs for the simulation:

- Tank 150-11 contained 22,013 barrels of naphtha according to Marathon's report to LDEQ[36]
- Tank 300-7 contained 40,000 barrels of ULSD according to the LSP[37]
- Tank 200-7 contained 766.66 barrels / 2.300.000 lbs of gas oil according to Marathon's report to EPA[38]

All simulations are based on data on 'total air emissions released during the event' provided by Marathon's reports to LDEQ and EPA. Chemicals such as carbon monoxide (CO), benzene,

[33] EPA Risk Management Program, 'Section 6.: Accident History'. Last accessed: 19 March 2024. Accurate as of 12:00am EST 19 March 2024.
[34] EPA Risk Management Program, 'Section 6.: Accident History'. Last accessed: 19 March 2024.
[35] Louisiana State Police (LSP), LSP/DEQ Incident Report, received in response to a Public Record Request in November 2023.
[36] Marathon Petroleum Company LP, DEQ/AQD Emergency Occurrence and/or upset notification form, submitted on 20 December 2023. Two updates were issued on 26 April and 18 June 2024 by Garyville Refining Logistics LLC, a subsidiary of Marathon Petroleum Company, p. 4.
[37] Louisiana State Police (LSP), LSP/DEQ Incident Report, received in response to a Public Record Request in November 2023. Pg. 4
[38] LSP reported 10,000 barrels but we chose the more conservative figure of 2.300.00 lbs as reported in EPA Risk Management Program, 'Section 6.: Accident History'. Last accessed: 19 March 2024, p. 41.

sulfur dioxide (SO_2), xylene, and nitrogen oxides (NOx) are highly sensitive to local conditions, primarily temperature, but also turbulence, both of which could have had an exponential impact on the values of chemicals emitted. The values provided by Marathon are averaged over the course of the event, rather than instantaneous values. The values provided by Marathon and input into our simulation have an uncertainty of 50-60%, meaning that the values could be 50-60% higher or lower than reported.

Tank Identification

While the quantity of chemicals contained in the tanks were reported incorrectly, the tanks themselves are also likely misidentified in LDEQ's and the LSP's reports. The LSP appear to misidentify Tank 150-11 as 150-7, and misidentifies the quantity of naphtha as 20,000 bbl, in an entry at 09:16am on 25 August. LDEQ's Electronic Documents Management System (EDMS) did not provide site maps of the facility which could have been used to identify the tanks quickly and without question.

To confirm a correct labelling of the tanks involved in the incident, we began by looking through visual evidence sourced from local media and residents. One tank involved in the incident—300-8—is clearly labelled on its exterior, which is shown partially melted in a photograph captured by Sarah Sneath on 19 September 2023. We located visual evidence of the locations of two additional tanks—150-5 and 150-7—which were not damaged. Due to the complete meltdown of Tanks 150-11 and 300-7, however, no identifying labels were visible in the available visual evidence.

Next, we studied LDEQ's first incident report. An entry from 08:30-12:00 on 25 August informed us that the second tank involved in the incident (300-7, containing ULSD) was adjacent to the first tank (150-11, containing naphtha). The report also mentioned three additional tanks: 150-5 and 150-7 (08:30-12:00 on 25 August), which were protected by a water curtain and said to be adjacent to the first two tanks, and 200-7 (01:36 on 26 August), which contained 9,730 bbl. of gas oil and ignited in the early hours of 26 August 2023. Finally, in the LSP report, the sixth tank, 300-8, which was out of service at the time of the incident and was minimally damaged—consistent with visual evidence—is mentioned in an entry at 02:00PM on 26 August.

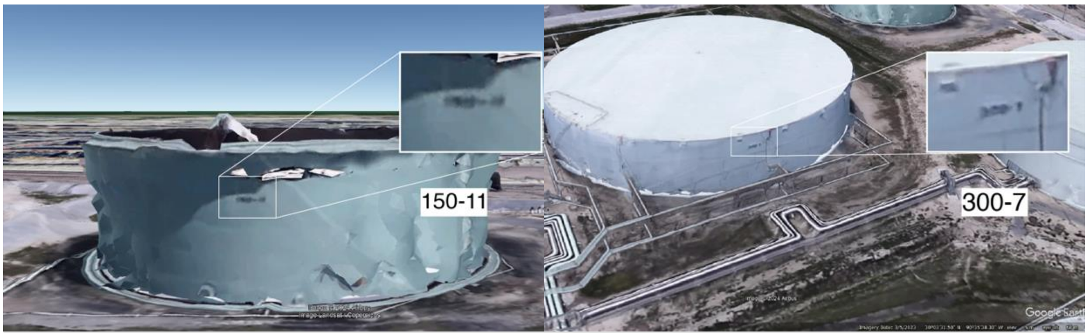
The earliest piece of visual evidence of the tanks on fire was captured around 8:30am on 25 August, at which time both tanks were said to be 'engulfed in flames'. Shortly thereafter, a photograph taken by Aviation Specialists, Inc., around 9am on 25 August, clearly shows two tanks on fire, which we identified as 150-11 and 300-7. Since we already knew the identity of Tank 300-8, a process of elimination led us to determine the identity of Tank 200-7.

This left only Tanks 150-11 and 300-7 to be identified. We considered the following sources in the identification process:

1. A satellite image captured by Planet Labs' PSB.SD instrument at 11:23 on 25 August showing the tank in the foreground covered in foam:

2. A comment from the LSP's incident report from 12:05pm stating that 'The fire from tank 300-7 was put out at 1123 hours', as well as repeat mentions of the naphtha fire reigniting (08:27pm and 10:15pm on 25 Aug; 02:11am, 04:11am, 11:04am on 26 Aug), suggesting that the tank visible in the Planet Lab satellite is 300-7, and that the recurrent naphtha reignitions are occurring in Tank 150-11, which was known to contain naphtha.[39]

3. To account for the possibility of a misidentified tank in the LSP report, we performed one final fact check by accessing Google Earth Pro 3D data. While blurry, the terrain layer of the software seems to show the labels 150-11 and 300-7:



Analysis of tanks visible in Google Earth Pro 3D. Imagery captured on 3/6/2023 and 3/5/2023.

[39] Louisiana State Police (LSP), LSP/DEQ Incident Report, received in response to a Public Record Request in November 2023, p. 4.

We asked Dr Navarro-Martinez whether a misidentification of the tanks would substantially impact our simulation's findings. According to Dr Navarro-Martinez, in the event that tanks 150-11 and 300-7 were misidentified, there might be some discrepancy in the representation of emissions values immediately adjacent to the tanks—i.e., within the containment area—because of minute discrepancies in local turbulence. However, the values would likely remain the same outside the containment area. This is because, even though there were two distinct fires, the plumes—in the real world, and in our simulation—collapsed into one single column. As such, it is very unlikely that any misidentification would substantially impact the overall findings resulting from the simulation concerning the distribution of benzene and PM 2.5 over the communities surrounding the facility.

About Forensic Architecture

Forensic Architecture (FA) is a research agency, based at Goldsmiths, University of London. The team includes architects, scientists, academics, journalists, technology experts and other specialized professionals and experts.

Forensic Architecture undertakes advanced architectural and media research on behalf of international prosecutors, human rights organisations, as well as political and environmental justice groups.

We have provided spatial research and evidence for numerous human rights investigations and prosecutions under international law, including at the UN General Assembly in New York in October 2013 and the Human Rights Council in Geneva in 2014 (on drone warfare via the UNSRCT[40]).

We presented evidence in the Israeli High Court for the (Palestinian) village of Battir vs. the Ministry of Defence through Michael Sfard, who won this case on 4 January 2015.

Our report on the Use of White Phosphorous in Urban Environments was presented at the UN Human Rights Council Geneva in November 2012 and in March 2011 at the Israeli High Court (for Yesh Gvul via Michael Sfrad).

The Forensic Oceanography team (Charles Heller and Lorenzo Pezzani) from Forensic Architecture 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 on June 2013.

The Gaza Platform and our Rafah: Black Friday report about the 2014 Gaza War, developed together with Amnesty International, was submitted to the UN Independent Commission of Inquiry in March 2015 and to the ICC2[41] in March and September 2015.

For more info, please visit: **www.forensic-architecture.org**

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[40] United Nations Special Rapporteur for Counter Terrorism
[41] International Criminal Court