Application Note

Biological Aerosol Threat

What are aerosols?

According to the dictionary, an aerosol is a very fine liquid or solid particle suspended in a gas. Emitted by human or natural activities, aerosols affect the climate on a planetary scale and locally in air pollution phenomena.

Aerosols can be qualified according to four axes:
1. Their origin,
2. Their composition,
3. Their size,
4. Their number per unit volume.

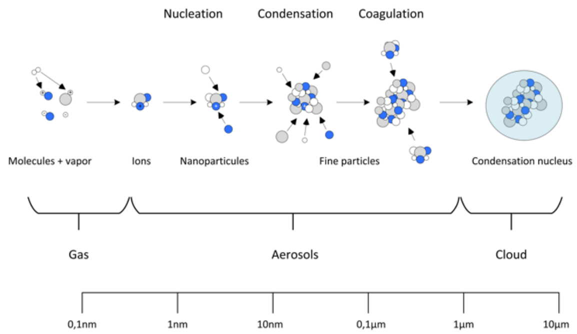
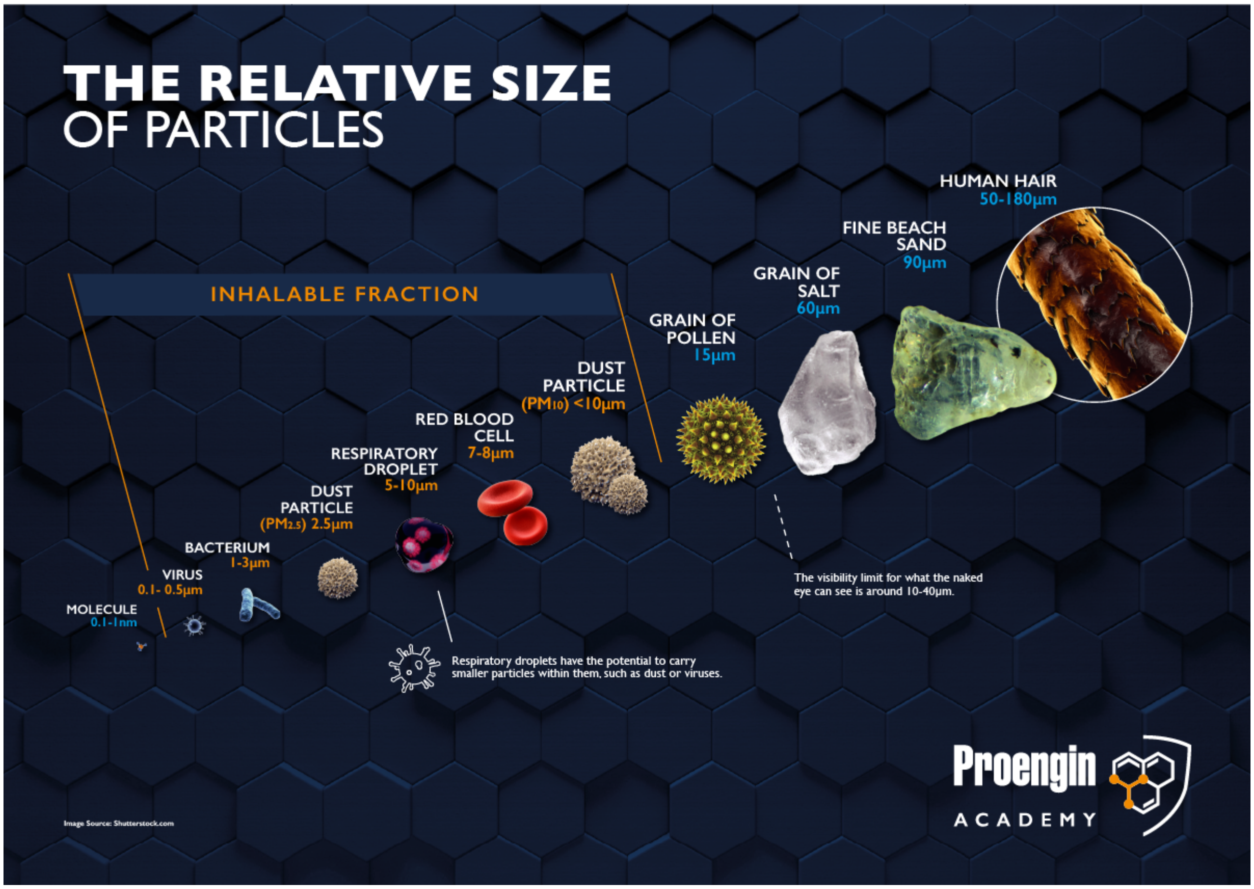


Figure 1: Formation and origin of secondary aerosols



The visibility limit for what the naked eye can see is around 10-40µm.

Respiratory droplets have the potential to carry smaller particles within them, such as dust or viruses.

Image Source: Shutterstock.com

Figure 2: Comparison of the size of aerosols with known and easily measurable objects

Aerosol Size

Generally, it is accepted that the size of the aerosols is between 0.02 and 100 µm. The smallest detail visible to the human eye is around 50µm. It is therefore difficult to get a representation of the size of an aerosol, the easiest way is to compare it to known things (see below).

Aerosols are divided into distinct groups according to their size, because their chemical compositions and their origins are very different:

- Ultrafine particles whose aerodynamic diameter is less than 100 nm

- Fine particles whose aerodynamic diameter is between 100 nm and 2.5 µm,

- Coarse particles with an aerodynamic diameter greater than 2.5 µm.

In the literature, we speak of particulate matter (PM: Particulate Matter). PM2.5 includes fine particles, whose aerodynamic diameter is less than or equal to 2.5 µm. PM10 includes these fine particles as well as coarse ones, whose diameter can reach 10 µm.

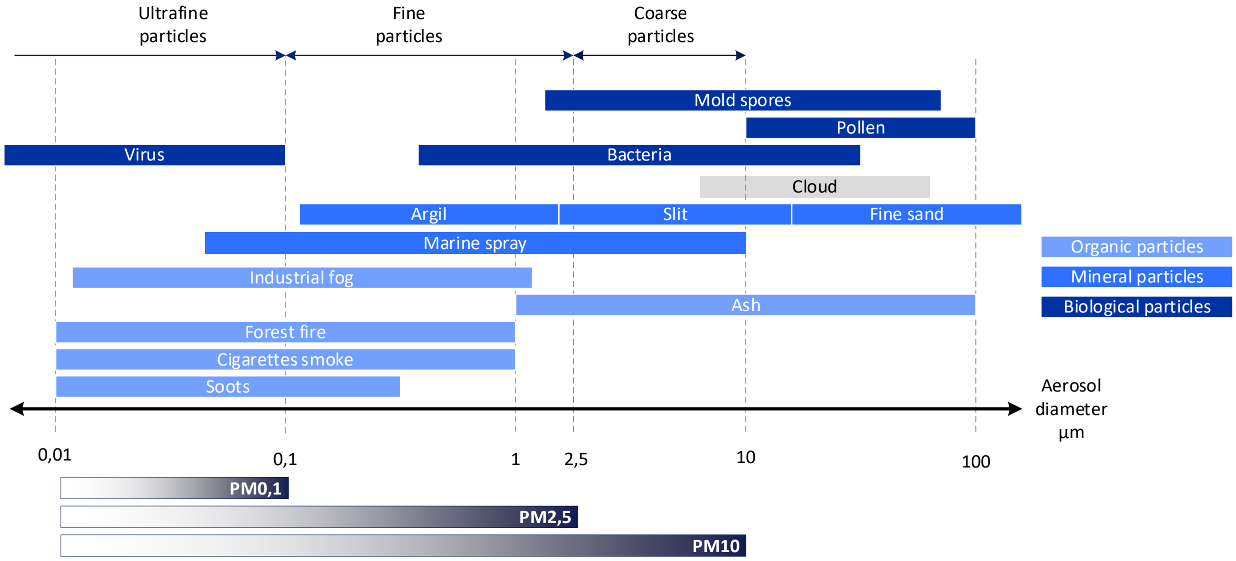


Figure 3: Particle sizes according to their type or origin

Their composition

The particles suspended in the atmosphere are made up of a variety of substances with the most varied chemical and physical properties. They have various forms, compositions and states of aggregation and come from many natural or anthropogenic sources (result of human activity).

There are two categories of particle population:

- Primers are particles that end up as such in the atmosphere, following combustion, abrasion or re-suspension processes (soot, ash, salt crystals, mineral particles, etc.).
- The secondaries that are formed in the atmosphere during chemical reactions caused by the emission of precursors such as nitrogen oxides (NOx), sulfur dioxide (SO2), volatile organic compounds (VOC) and l ammonia (NH3).

Among the primary aerosols, there are those from natural sources such as:

- Mineral particles (e.g. desert),
- The salts produced by the agitation of the sea (spray),
- Volcanic ash,
- Ashes from biomass fires (forest fires),
- Primary biological aerosols (PBAP: Primary Biological Aerosol Particles) or bioaerosols.
- And aerosols from anthropogenic sources (human activity) such as:
- Those produced by transport (brake, tire, engine, etc.)
- Or by industrial activity.

What is a PBAP?

Primary biological aerosol particles (PBAPs, also known as "bioaerosols") are emitted directly from the Earth's surface by various mechanisms, in a wide range of sizes from tens of nanometers for viruses to hundreds of micrometers for viruses. plant fragments. According to J. M. Hirst, PBAPs are aerosols comprising particles of biological origin (or resulting from biological activity) and risking poisoning living beings through infections, allergies, poisoning or other processes.

There is a distinction between active organisms and inactive organisms. From a chemical composition point of view, it is difficult to differentiate between the two. If the dead microbes do not present a pathogenic risk for humans, it has been shown that the presence of 1% of living organisms allows them to be cultured. A small number of living bioaerosols can lead to infecting an entire population.

It would be risky to want to make an exhaustive description of all the bioaerosols, however we can report the most commonly cited in the literature:

- Viruses (0.02 µm – 0.3 µm),
- Bacteria (0.5 µm – 30 µm),
- Mushrooms (0.5 µm – 30 µm),
- Pollens (10 µm – 100 µm).

What is the “inhalable fraction”?

Aerosols enter the human body through the respiratory system which, to defend itself against the invasion of foreign bodies, behaves like a filter. The fraction of inhaled particles will travel through the entire respiratory system starting with the nose or mouth to the pulmonary alveoli. Some particles will settle along their journey, others will pass through and be exhaled. The deeper the particles enter our respiratory system the more they pose a risk to our health. Indeed, the particles that will impact each other can be absorbed by the body and cause pathogenic effects.

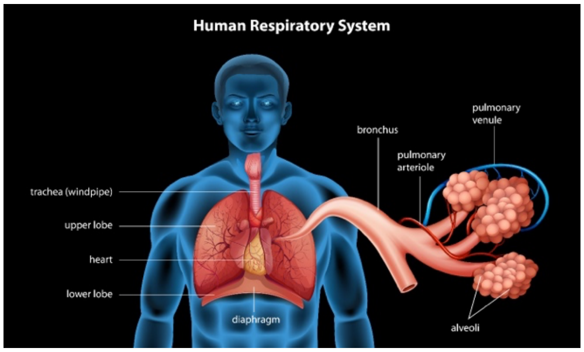


Figure 1 : Human respiratory system[1].

It is therefore important to define which particle size will reach which part of the respiratory system. The ISO 7708 standard is used to overcome the variations that exist in individuals, it defines the penetration of risk particles into the human respiratory system according to their size. The standard presents several conventions for the fraction of particles likely to affect our respiratory system more or less deeply; the inhalable fraction, the thoracic fraction and the alveolar fraction (Figure 4).

The fraction that interests us the most is the alveolar fraction. The particles of this fraction can pass the barrier of the nose and reach the bronchi and the alveoli of the lungs. The respirable fraction is often misnamed the inhalable fraction. The alveoli are very small porous air sacs, whose wall is thin but richly vascularized. Their total area is approximately 75m^2. The particles that will get into them represent a real health hazard because:

1- The exchange surface is very important there, and therefore this increases their probability of deposit,

2- They can quickly enter the body via this route given the low thickness of the wall and the large number of blood vessels,

3- Finally, these particles being lighter, they will therefore sediment less quickly (fall) and therefore have a longer lifespan in the atmosphere.

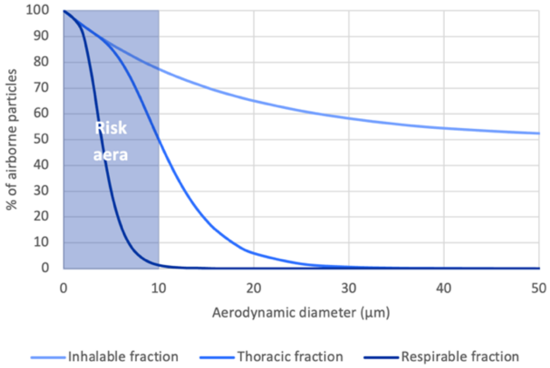


Figure 5: Convention of the fractions of particles entering our respiratory system according to their aerodynamic diameter.

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[1] https://www.vecteezy.com/vector-art/365769-respiratory-system

What are the threats?

The Center for Disease Control and Prevention in the United States indicates on its website that there are 7 biological agents in category A. These agents are classified A for the following reasons:

1. They are easily spread or transmitted from person to person,
2. They have a high level of mortality,
3. Their use may cause panic in the civilian population,
4. They require preparedness actions from the public health system.

These officers are:

- Anthrax (Bacillus anthracis)
- Botulism (Clostridium botulinum toxin)
- Plague (Yersinia pestis)
- Smallpox
- Tularemia (Francisella tularensis)
- Hemorrhagic fevers:
  o Filoviruses (Ebola, Marburg)
  o Arenaviruses (Lassa, Machupo)

In order to understand why biological risk is a risk in the form of aerosols, we will treat as an example that of anthrax.

Anthrax is a gram-positive sporulating bacterium. It causes an acute infectious disease, anthrax. It is an anthropozoonosis (an infection that is transmitted naturally from vertebrate animals to humans). When its environment is unfavorable, the vegetative bacterium sporulates. The anthrax spore is extremely resistant to high temperatures, even in humid conditions, to desiccation, to radiation, to extreme pH. The anthrax spore has an ovoid shape whose diameter is between 0.81µm and 0.86µm and the length is between 1.26µm and 1.67µm.

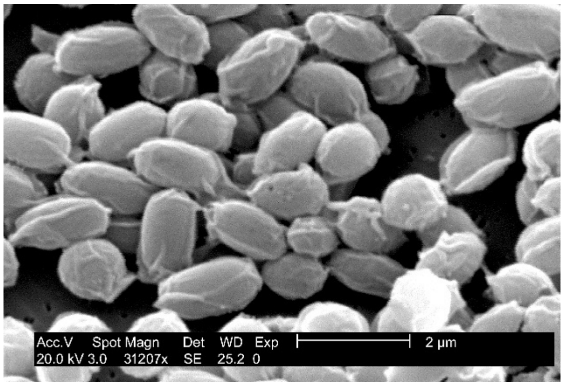

Figure 6: Image of Bacillus Anthracis spores obtained by scanning electron microscope

If we take anthrax as an example as a biological threat, this bacterium can infect humans in three ways; either through a skin wound; either through the gastrointestinal tract; either by air via the respiratory system.

The cutaneous form results from contact between spores and a wound. In 80% of cases, the infected wound heals without complications. Only 5% to 20% of the remaining cases (20%) lead to complications and require treatment to avoid death. We can therefore see that anthrax infection through the skin causes very few deaths and that this mode of infection is not of interest for terrorist acts or during conflicts.

The gastrointestinal form is triggered by the consumption of meat containing endospores. The development of the infection leads to between 25% and 60% of deaths depending on the speed of treatment. The disease caused by anthrax during an intestinal infection is much more virulent than that caused by a skin infection. However, this form of infection is of no interest for military applications because potential victims must agree to ingest products that are unfit for consumption.

The respiratory form is considered the most serious. Infection is caused by inhaling spores of the bacteria that are suspended in the atmosphere. They will be deposited in the pulmonary alveoli and they end up being transported by the lymphatic system. The incubation time is 2 to 6 days, but it can be up to 60 days. The first symptoms of the disease resemble the flu. If treatment is not promptly administered, the mortality rate is 90% to 100%. Rapid support with modern treatment lowers the rate to 50%.

We see that this mode of contamination is very effective.

In conclusion, the anthrax bacterium is a bacterium that has the ability to sporulate. During this phase, it reduces its cellular activity and it becomes very resistant. Its reduced size between 1µm and 2µm makes it an excellent candidate for dispersion which can easily be transported in the air in the form of an aerosol invisible to the naked eye. When victims inhale the airborne spores, they will unknowingly become infected.

How can we detect this threat with FPD?

The principle of a detector using hydrogen flame photometry is as follows:

1. The device continuously samples an atmospheric fraction. It is burned in a hydrogen flame (the oxygen in the air reacts with the hydrogen to form a flame). The molecules or particles are decomposed by the heat of the flame and the atoms which constitute them will produce light. Each atom emits a characteristic color
2. This light produced in the burner is collected and then separated by color by an optical system,
3. The signals thus collected are processed with an electronic card and embedded software,

Finally, a Man-Machine interface informs the user of the level of risk

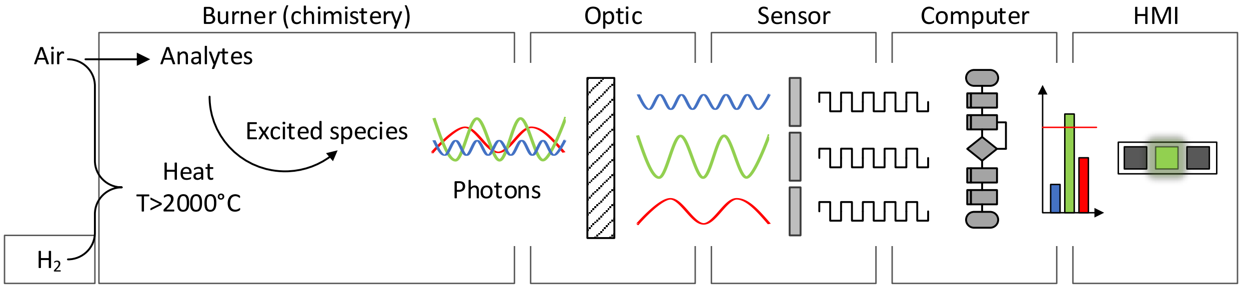

Figure 7: Operating principle of the HFPD (Hydrogen Flame Photometry Detector)

Biological organisms contain a wide variety of inorganic elements such as calcium (Ca), manganese (Mg), phosphorus (P), sodium (Na) and potassium (K). These elements are detectable and quantifiable by flame spectrometry because when they burn in the flame, they each produce a characteristic and intense light.

It is very difficult to precisely measure the quantity of these elements contained in the microorganisms. First, because they are living entities that will interact with their environment. Their composition will therefore vary according to their culture medium and the elements surrounding them. Then, there are very many species of microorganisms with different strains, so it is almost impossible to build a library of spectra for all microorganisms.

On the other hand, what we do know is that the following three elements: sodium, potassium and calcium are found in sufficient quantities to be detected in biological aerosols of the threat and with FPD, we have demonstrated that it is possible to detect those three elements in a single bioaerosol whose size is between 2 and 10 µm. Each time a microorganism burns in the flame, it will emit a spectrum (see Figure 8).

Tests were carried out in the laboratory with two strains of deactivated *Bacillus Anthracis* (7700 and 7702) diluted at 1:1000 in Millipore water. From this solution, bioaerosols of about 2µm were generated and dispersed in a closed enclosure. An FPD detector (MAB) placed in the enclosure demonstrate its ability to detect at least two elements contained in the biological particles. Other field trials and tests carried out on military grounds with simulating bioaerosols have shown that the FPD detects the arrival of a cloud at the same moment as the impactor on agar plates (slit samplers) did and there is a good correlation between those two measures[2].

If the frequency of analysis is fast enough and the density of aerosols is not too high, we do not have a coincidence (two particles which burn at the same time, therefore an addition of their emission spectra). Real-time analysis and classification of the spectra emitted by each aerosol allow monitoring of the atmospheric background. An appropriate treatment based on the frequency of appearance of the aerosols, on the line ratios and on their intensities makes it possible to identify an anthropogenic dispersion.

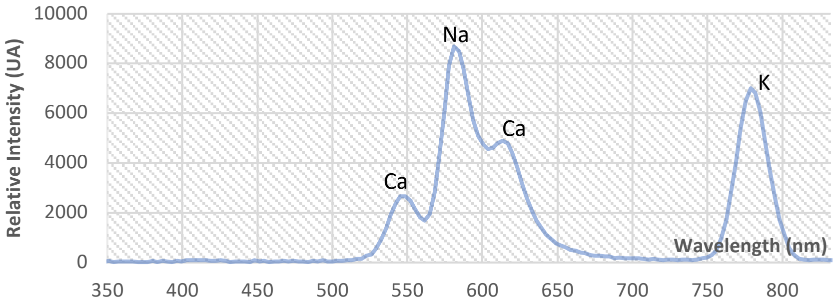

Figure 8 : Bioaerosol spectrum on FPD sensor

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[2] G. Olofsson and T. Tjärnhage, Biological Alarm Monitor Results from the Biodetection Field Trials in Sweden March 2005, FOI-R-- 1938 –SE, March 2006

About the Author

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During his time with the company, Henri has been involved in all major development projects contributing to the current portfolio. His extensive experience in the industry, has allowed him to foster strong partnerships with key global CBRN laboratories including India, Finland, and The Netherlands.

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Proengin designs, produces and maintains chemical and biological agent detection solutions for the military and civilian markets, based on the unique performance of flame spectrophotometry technology. This detection technology, which analyses the light spectrum through a hydrogen flame, has two major advantages: its universality and its sensitivity. Its universality allows it to detect in real time, all chemical agents containing molecules of phosphorus, sulphur, arsenic and nitrogen, whatever their state (gaseous, solid, liquid, aerosol). Its extreme sensitivity allows it to detect the presence of a dangerous chemical agent, at a concentration up to 500 times lower than its lethal dose.

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If you want to know more about Proengin offerings or if you want to have access to more white papers and application notes on CBRN related topics, please visit www.proengin.com and follow us on social media.

Application Note

Chemical Aerosol Threat

What are aerosols?

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1. Their origin
2. Their composition
3. Their size
4. Their number per unit volume

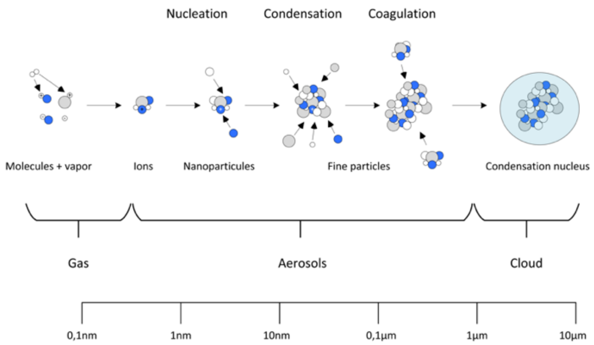
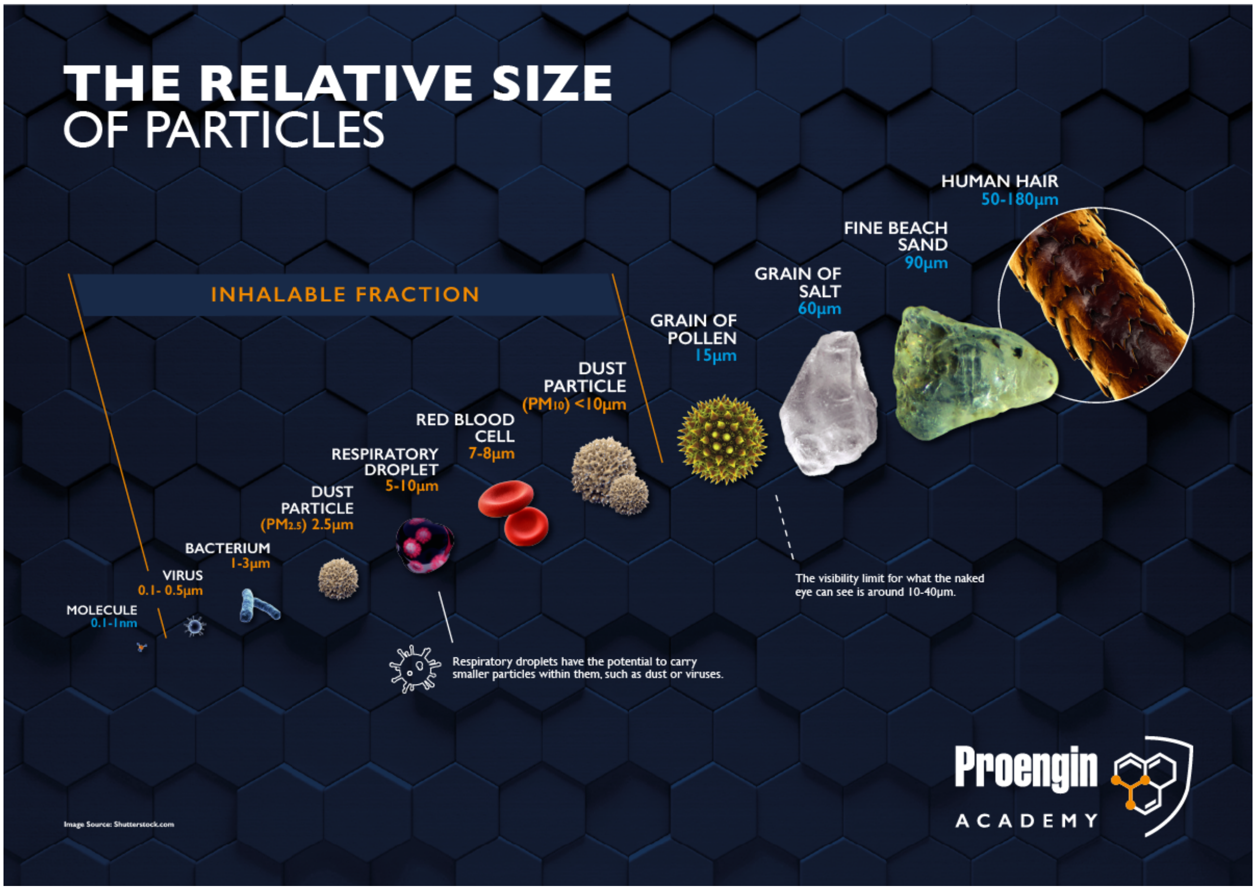


Figure 1: Formation & Origin of secondary aerosols



The visibility limit for what the naked eye can see is around 10-40µm.

Respiratory droplets have the potential to carry smaller particles within them, such as dust or viruses.

Image Source: Shutterstock.com

Figure 2: Comparison of the size of aerosols with known and easily measurable objects

Aerosol Size

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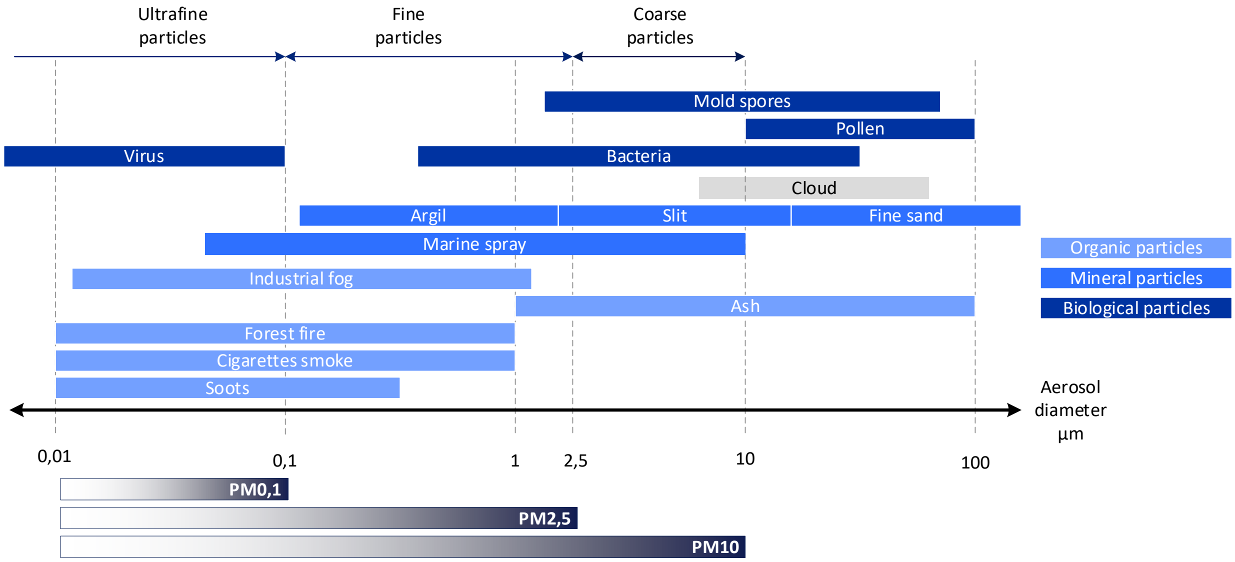

Figure 3: Particle sizes according to their type or origin

What is the “inhalable fraction”?

Aerosols enter the human body through the respiratory system which, to defend itself against the invasion of foreign bodies, behaves like a filter. The fraction of inhaled particles will travel through the entire respiratory system starting with the nose or mouth to the pulmonary alveoli. Some particles will settle along their journey, others will pass through and be exhaled. The deeper the particles enter our respiratory system the more they pose a risk to our health. The particles that will impact each other can be absorbed by the body and cause pathogenic effects.

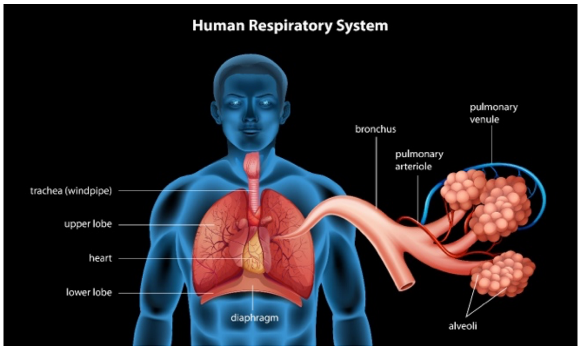

Figure 4 : Human respiratory system[1]

It is therefore important to define which particle size will reach which part of the respiratory system. The ISO 7708 standard is used to overcome the variations that exist in individuals, it defines the penetration of risk particles into the human respiratory system according to their size. The standard presents several conventions for the fraction of particles likely to affect our respiratory system more or less deeply; the inhalable fraction, the thoracic fraction and the alveolar fraction (Figure 5).

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1- The exchange surface is very important there, and therefore this increases their probability of deposit,

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3- The particles being lighter, will sediment less quickly (fall) and therefore have a longer lifespan in the atmosphere.

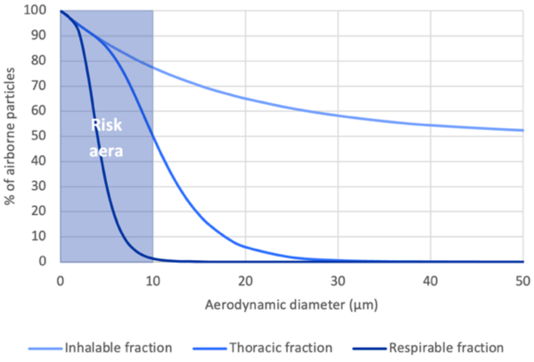

Figure 5: Convention of the fractions of particles entering our respiratory system according to their aerodynamic diameter.

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[1] https://www.vecteezy.com/vector-art/365769-respiratory-system

Aerosols as a Threat

At atmospheric pressure (760 mmHg) and room temperature (20°C), chemical warfare products (CWA) are found in three forms: gaseous, liquid and solid. On the following graph, we have indicated the percentage distribution of the products according to their condition under at atmospheric pressure and room temperature (see Figure 6). The majority of products are liquids and, among these liquids, most have a sufficient vapor pressure (see “4th generation threats”) to be detectable as gases. When the threat is solid or liquid, it can be dispersed as an aerosol. It is then suspended in the atmosphere and the people present can inhale it and be intoxicated.

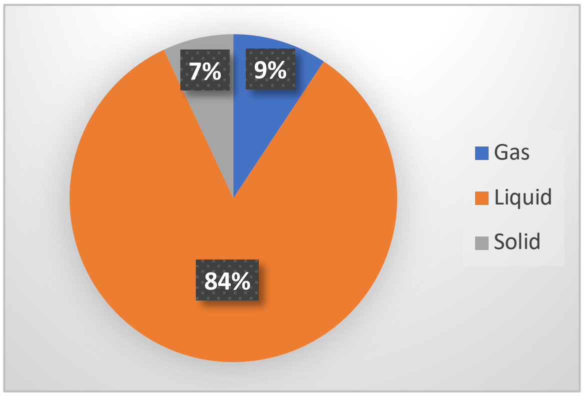

Figure 6: State repartition of CWA @ atmospheric pressure & room temperature

What chemical threats could be used as aerosols?

There is little or no publication on the conditions of dispersion of the chemical threat in the form of aerosols. Chemical aerosols can be dispersed in two ways:

- Either from a very fine powder which can be solid particles on which are impregnated liquid agents or solid agents at room temperature (PBA family),
- Either from a liquid which can be the liquid agent at room temperature (like VX) or a liquid containing a solvent in which a solid or liquid product is dissolved,

In any case, to be effective, the aerosols generated must be in the alveolar fraction in order to reach the lungs of the targeted people (see previous Chapter “What is the inhalable fraction”?).

Why is FPD suitable for aerosol detection?

The principle of a detector using hydrogen flame photometry is as follows:

1. The device continuously samples an atmospheric fraction. It is burned in a hydrogen
2. flame (the oxygen in the air reacts with the hydrogen to form a flame). The molecules or particles are decomposed by the heat of the flame and the atoms which constitute them will produce light. Each atom emits a characteristic color.
3. This light produced in the burner is collected and color separated by an optical system.
4. It is transformed into an electrical signal with a sensor and then digitized with a converter.
5. The signals collected are processed with an electronic card and embedded software.
6. A man-machine interface informs the user of the level of risk

The AP4C's Flame Photometric Detector (FPD) technology uses pure hydrogen mixed with continuously sampled atmospheric air. Air naturally contains oxygen (20.95%), nitrogen (78.08%) and other gases. If you generate a spark in the air/hydrogen mixture, you induce a reaction between the two molecules which produce heat and water.

The written reaction is as follows:

$$\cdot\frac{1}{2}O_2 + H_2 \rightarrow H_2O + heat \text{ (618 kJ·mol}^{-1}\text{)}$$

The dissociation and recombination reaction is much more complex than it appears in the formula and produces different short-lived intermediate reaction species (OH*, H*). The temperature reached in this type of confined flame is at least 2000°C. If you pick up particles with the air, they will first be vaporized by the high temperature of the flame. Then the bonds of the molecules constituting it will be broken and it will be broken down into simple elements which will recombine in the flame. The nitrogen (N2) contained in the air will not be dissociated because the energy of the flame is not sufficient to break the nitrogenous triple bond, this molecule is therefore invisible on the spectrum of the flame.

All other bonds have a dissociation energy lower than the energy produced by the recombination of hydrogen and oxygen.

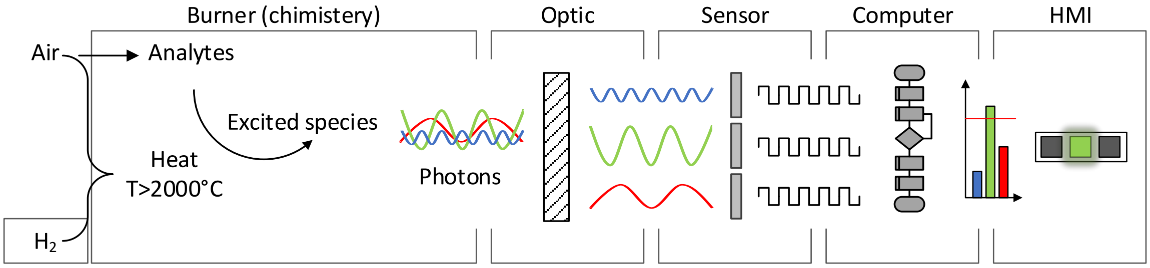

Figure 7: Operating principle of the HFPD (Hydrogen Flame Photometry Detector

We can consider that the burner is a reactor, the atoms recombine there to form intermediate species (OH, HNO, NO, CH, CO) and simple elements (Na, K, H, O). Excited by the thermal energy of the flame, these species will produce photons (grains of light) whose wavelength (color) is a characteristic fingerprint of their identity. The atoms will emit a few fine lines and the simple intermediate reaction species (HNO, S2, POH, etc.) will produce wider bands with many more lines (Figure 8). Many elements are detectable with this technology (P, S, As, N, Na, K, Ca, etc.), including when they are carried by particles.

Bond[2]	Energy (kJ·mol^{-1})
N≡N	945
O=O	502
H-H	435
C-H	414
C-O	351
C-C	347
N-H	390
C-N	293

Table 1: Bond dissociation energy

Can aerosol threat be detected with FPD?

When the particles are captured by an AP4C, they will follow the airflow entering the burner. After a few minutes of operation of an AP4C, its burner is at thermal equilibrium and the heat of the flame has diffused to the gold capillary. All the way to the flame, the particle will heat up and its most volatile components (water, solvent, etc.) will evaporate. Arrived at the flame (temperature of approximately 2200°C), the other components of the particle evaporate, the molecules decompose and the elements emit light whose color (wavelength) is characteristic of the element (see previous chapter about FPD technology principle).

The AP4C detects the presence of gases in the atmosphere but also of aerosols. However, it will not differentiate between the two states. It will identify the presence of the threat through its specific emissions (P, S, As, HNO).

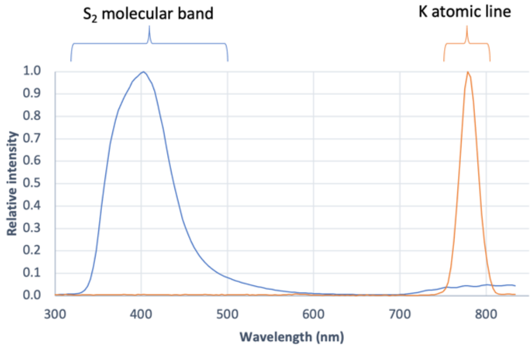

Figure 8: Example of the atomic narrow atomic emission line (K: potassium) and molecular wide band emission (S2: disulfur)

It will identify the presence of the threat without indicating whether it is a gaseous threat and a threat in the form of an aerosol.

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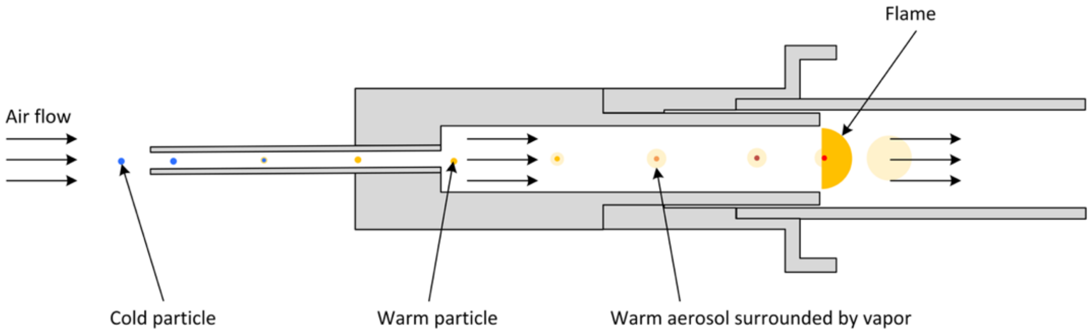
[2] http://www.geocities.ws/profmokeur/chimie/energie.htm



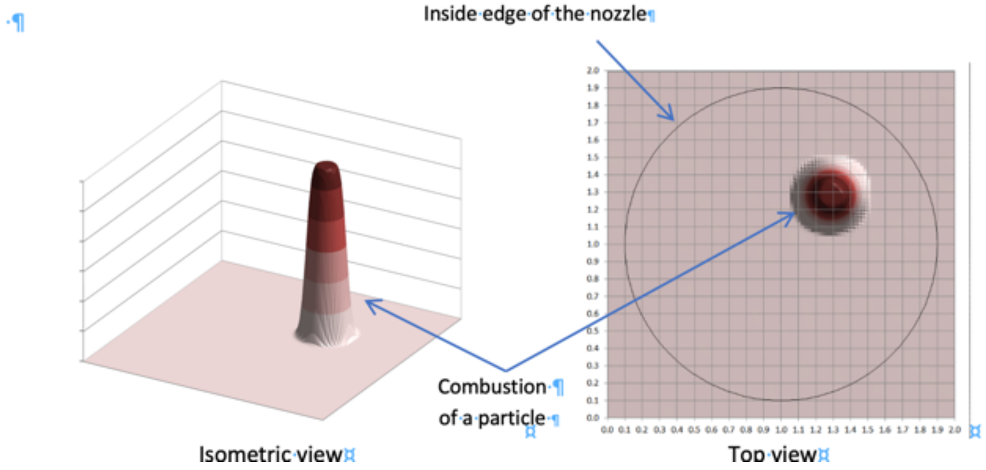


Figure 9: Example of a non-point particle emission model

For a liquid spherical aerosol of VX whose diameter would be 2 µm, the mass of VX contained in this particle is approximately 4.2 pg. When this particle burns in an air/hydrogen flame, it will vaporize and the elements composing it will emit. For a hemispherical flame such as that of an FPD detector, the volume is approximately 17mm^3. The volume concentration of VX in the flame is then around 260 µg/m^3; which is 15 times higher than the detection threshold of AP4C.

This demonstrates that this technology is not only capable of detecting chemical aerosols but that it can do so in real-time without having to perform a sampling or sample preparation operation.

About the Author

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Proengin designs, produces and maintains chemical and biological agent detection solutions for the military and civilian markets, based on the unique performance of flame spectrophotometry technology. This detection technology, which analyses the light spectrum through a hydrogen flame, has two major advantages: its universality and its sensitivity. Its universality allows it to detect in real time, all chemical agents containing molecules of phosphorus, sulphur, arsenic and nitrogen, whatever their state (gaseous, solid, liquid, aerosol). Its extreme sensitivity allows it to detect the presence of a dangerous chemical agent, at a concentration up to 500 times lower than its lethal dose.

Proengin's solutions respond to the current context of growing threats, the return of high-intensity conflicts and growing industrial risks, with increasingly numerous and diversified chemical agents (4th generation chemical agents, pharmaceutical derivatives, etc.). For many years, Proengin solutions have been used in all areas of military operations by teams dedicated to CBRN threats, as well as first responder teams (hazmat, EMS, law enforcement) responding to industrial incidents such as the Lubrizol industrial chemical disaster in 2019 (France). Proengin system solutions also protect critical and sensitive infrastructure, such as the new Frégate de défense et d'intervention (FDI) and European Council headquarters.

If you want to know more about Proengin offerings or if you want to have access to more white papers and application notes on CBRN related topics, please visit www.proengin.com and follow us on social media.