# Osmium Tetroxide: A New Kind of Weapon

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**Key words:** osmium tetroxide, terror, exposure, health effects

*IMAJ 2007;9:750–752*

Osmium tetroxide is a non-combustible, colorless to pale yellow solid that has a disagreeable chlorine-like odor [1]. It slowly develops when powdered osmium metal is exposed to air. $OsO_4$ is fairly soluble in water and in several organic solvents, but reacts as an oxidant with many of them. The substance is used in organic syntheses, mainly to oxidize unsaturated carbon-carbon bonds to dihydroxy compounds (glycols). Its most common usage is as a staining agent and a "fixant" in transmission electron microscopy. This chemical sublimes at room temperature, having a remarkable vapor pressure of about 7 mmHg at 20ºC (more typical for a liquid compound than for a solid), as compared to 17 mmHg for water, 2 mmHg for the nerve agent sarin, or 0.07 mmHg for the blistering agent sulfur mustard under the same conditions. It is highly poisonous, even at very low concentrations, and must be handled according to the appropriate precautions. Hours may pass between exposure and the appearance of noticeable symptoms.

*Symptoms may not be noticeable until several hours after the exposure – an appealing feature for a terrorist*

Being an expensive chemical, available commercially only in small amounts, it is still considered a serious toxic compound for small-scale terrorist devices. On 6 April 2004, news agencies reported that the British police foiled a plot by members of El-Qaeda to prepare and detonate a bomb containing $OsO_4$ in London [2].

$OsO_4$ = osmium tetroxide
$LCt_{50}$ = often used to denote the vapor or aerosol exposure ($Ct$) necessary to cause death in 50% of the population exposed
ppm = parts per million

In this short review we discuss the properties of $OsO_4$ and its health effects, with the aim of increasing the knowledge of medical teams who may in the future confront the consequences of this kind of threat [3,4].

## Dangerous concentrations

$OsO_4$ has an odor threshold of 0.0019 parts/million [5]. Its lethal concentration time ($LCt_{50}$) is considered to be 1316 mg/min/m$^3$, similar to that for sulfur mustard [5]. Humans may tolerate a maximal concentration of 0.1 ppm in air for 1.5 hours or 0.0001 ppm for 6 hours without harmful effects [6]. McLaughlin and co-authors [7] reported that workers exposed to 0.01–0.53 ppm (0.1–0.6 mg/m$^3$) suffered from lacrimation, conjunctivitis, vision disturbances, headaches and cough.

$OsO_4$ can be compared to chemical warfare agents in terms of toxicity. Exposure to even low doses can be lethal. In addition, both $OsO_4$ and chemical warfare agents share similar physiological effects. The first appearance of a physiological effect, also known as the threshold effect, is observed at a lower concentration for osmium tetroxide vapor than for chemical warfare agents such as phosgene, sulfur mustard or even the nerve agent sarin. The various $LCt_{50}$ values are summarized in Table 1. As mentioned before, the $LCt_{50}$ of $OsO_4$ is comparable to that of sulfur mustard, but since sulfur mustard has a much lower vapor pressure $OsO_4$ can pose a greater inhalational threat. Under the same environmental conditions there will be much more $OsO_4$ vapor in a closed space than sulfur mustard vapor [2].

**Table 1.** $LCt_{50}$ values of chemical warfare agents compared to $OsO_4$

| Substance | $LCt_{50}$ (mg/min/m$_3$) | Threshold effects (mg/ml) |
|---|---|---|
| Sarin (GB) | 70 | 2 |
| Sulfur mustard (HD) | 1500 | 12–500 |
| Phosgene (CG) | 3200 | 2 |
| $OsO_4$ | 1316 | 0.1–0.6 |

See refs. 7,14-16.

## Health effects

Osmium tetroxide is a rapid, indiscriminative oxidizer that does not distinguish between organic tissue and inorganic materials. An inhalational toxicity study with rabbits proved futile, because of the rapid reduction of $OsO_4$ by the skin, hair, mucous membranes, etc., as well as by the chamber walls [8]. Inhalation, ingestion, contact with skin and with mucous membranes may all result in severe consequences. Due to its high vapor pressure, most exposures are to vapor. These can cause severe chemical burns to the eyes, skin and respiratory tract [9]. Very short-term contact with the vapor may cause lacrimation, accompanied by cough, headaches and dizziness. $OsO_4$ may cause irreversible blindness by turning the cornea black. Symptoms may not be noticeable until several hours after the exposure, which may be an appealing feature for terrorists. Affected people may not realize immediately the extent of its toxic effects. Another severe delayed effect following inhalational exposure is acute lung injury, which may be followed by non-cardiogenic pulmonary edema [2]. Direct contact with osmium tetroxide solution will turn the skin black (severe chemical burns due to strong oxidizing properties). Painful burns or contact dermatitis may result, depending on the concentration. $OsO_4$ is not considered a carcinogen [2]. Major human health effects are summarized in Table 2. Death is mainly the result of complications due to the exposure.

## Immediate and general medical care

Neutralization of the chemical on surfaces can be conveniently achieved by covering it with unsaturated oil (vegetable oil) [2]. Osmium tetroxide does not have a medical antidote; therefore the treatment is supportive and symptomatic, depending on the route of exposure. Initial treatment should focus on preventing further exposure. Victims should be removed from the contaminated area, undressed, and decontaminated by running water as soon as possible.

**Table 2.** Major clinical effects on humans following acute exposure to $OsO_4$

| System | Acute effects | Chronic effects |
|---|---|---|
| Eyes | Irritation, lacrimation, photophobia, blepharospasm, blindness | Keratitis, conjunctival edema, corneal destruction |
| Skin | Irritation, discoloration, severe pain, burns, ulceration, necrosis | Dermatitis |
| Respiratory tract | Irritation of the nose, throat and bronchial tree, burning sensation, coryza, cough, wheezing, chest tightness, dyspnea, acute lung injury, pulmonary edema | Bronchitis, bronchial spasms and breathing difficulties, asthma |
| Gastrointestinal tract | Irritation, severe burning pain in the mouth, metallic taste in the mouth and pharynx, vomiting, diarrhea, abdominal cramps | Liver degeneration, fatty renal and adrenal degeneration |
| Central nervous system | Frontal headaches, dizziness | CNS depression |

See refs. 1,9,11,12,17,18.

### Inhalational exposure

The exposed person should be moved to fresh air. If breathing has stopped, resuscitation should be initiated immediatly. The victim should be kept warm and at rest [1]. Intubation should be considered early in the course of treatment due to possible upper airway obstruction. Humidified inhalations and antitussive drugs may heal inhalational injuries in the upper airways. Severe inhalational injuries may require mechanical ventilation, including positive end-expiratory pressure. Diuretics (e.g., furosemide) and aerosolized bronchodilators may be useful for managing pulmonary edema and bronchoconstriction [5]. Although we found no data on the role of corticosteroids and nitric oxide in the treatment of acute lung injury following exposure to $OsO_4$, we presume that they might be beneficial based on their effect in other cases of exposure to irritant volatile compounds [10].

### Ocular exposure

Eyes should be lavaged with copious amounts of normal saline or water for at least 15 minutes [5], while lifting lower and upper eyelids periodically. An ophthalmologist should be involved in the management of these patients at an early stage.

### Skin exposure

All clothing should be removed immediately, and the skin should be washed thoroughly with soap and water. Necrotic tissue should be excised [11]. Further evaluation should be conducted by a dermatologist and a plastic surgeon.

### Gastrointestinal exposure

Administering large amounts of water in case of ingestion should be guided not only by the victim's state of consciousness but also by the presence of airway obstruction or imminent obstruction and the time elapsed from exposure. Nothing should be given by mouth to someone who is unconscious [1]. Gastric lavage and activated charcoal may be used while protecting the airways [11].

### Laboratory tests

Complete blood count, electrolytes, urinalysis, and liver and renal functions should be monitored following significant exposure. If respiratory tract irritation or respiratory depression is evident, arterial blood gases, chest X-ray, and pulmonary function tests should be monitored [12]. Spirometry may be used in the emergency room to obtain further information on the condition of the victim.

### Case studies

Osmium tetroxide is a chemical used mainly in industry and research facilities. Below is a list of several cases involving accidental exposures as well as a terror attempt.

- USA, 1874: A worker accidentally inhaled an unknown amount of $OsO_4$. The vapors caused capillary leakage and bronchitis, which brought about his death [12].

- USA, 1946: Osmium tetroxide concentrations in the air of a precious metal refining plant were found to be in the range of 0.01–0.53 ppm. The workers in the plant suffered from lacrimation and vision disturbances, described as a "gritty feeling in the eyes" and the "appearance of rings around lights." Some employees complained of headaches, conjunctivitis and cough [7,12].

*$OsO_4$ may cause irreversible blindness by turning the cornea black*

- USA, 1974: A laboratory worker suffered from ocular pain, blepharospasm, photophobia, epiphora, and ocular hyperemia following exposure to $OsO_4$ vapors that were formed from heating osmium. His visual acuity was reduced for an unknown period [12].

- USA, 2001: A lab technician accidentally broke a vial containing 4% $OsO_4$ solution that spilled onto him, creating a skin lesion. Electron microscopy and energy-dispersive X-ray spectroscopy confirmed the presence of osmium in a tissue sample taken from the lesion. The lesion was treated by simple excision. There are no data available regarding the nature of the damage caused to the tissue [13].

- London, UK, 2004: A terrorist plot involving osmium tetroxide was prevented by the British police. Those involved were allegedly connected to El-Qaeda and were planning to target Gatwick airport, the London subway, or other major traffic areas [2]. They were planning to construct a chemical bomb that would release toxic $OsO_4$ fumes, but were intercepted before they were able to obtain a sufficient amount of the chemical [2].

## Summary

$OsO_4$ is a powerful oxidizer. It affects mainly the skin and mucous membranes. Although unsuitable for a large-scale terrorist attack, mainly due to its scarcity, it could be used in small-scale attacks.

The small quantity contained in a vial would cause irritation to the eyes, nose, throat and skin. Combining the agent with an explosive material will probably destroy most of it, chemically. Thus, releasing the chemical without using explosives may be considerably more dangerous.

Medical management is mainly symptomatic. As soon as the chemical enters the body, it rapidly reacts with the tissues in contact. Medical personnel should be aware of its poisonous effects and be equally familiar with the necessary self-protection measures and the treatment protocols.

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*For all sad words of tongue and pen, the saddest are these: "It might have been"*

John Greenleaf Whittier (1807-1892), American Quaker poet and forceful advocate of the abolition of slavery in the United States