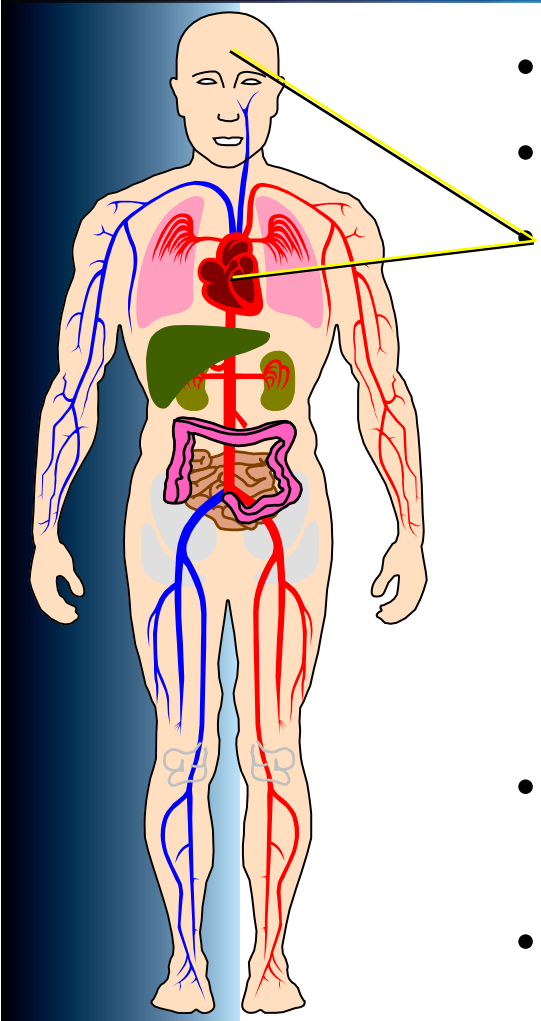
Science and Technology

Chemical Weapons Part 2

By

Mark Bishop

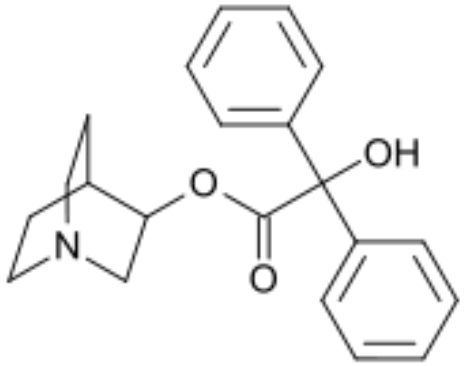
Psychochemical Incapacitants

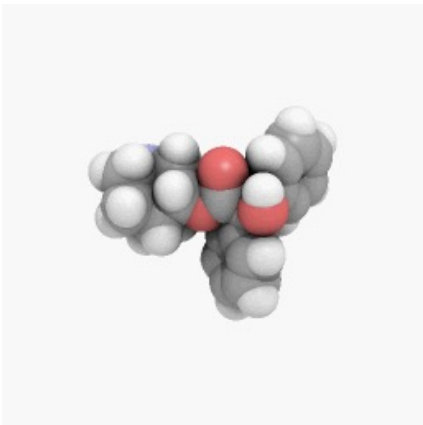


- BZ (3-3-quinuclidinyl benzilate)
- Modes of action: inhalation, ingestion, injection
- Physiological effects
  - Potent anti-cholinergic compound (similar to atropine)
  - Dose <1 mg induces hallucinations and delirium
  - Mild effects within an hour, peak at 8 hours, and decline over next 48-72 hours
- Form when disseminated: aerosolized solid, possibly in solvent
- Required defensive dear: protective mask, suits

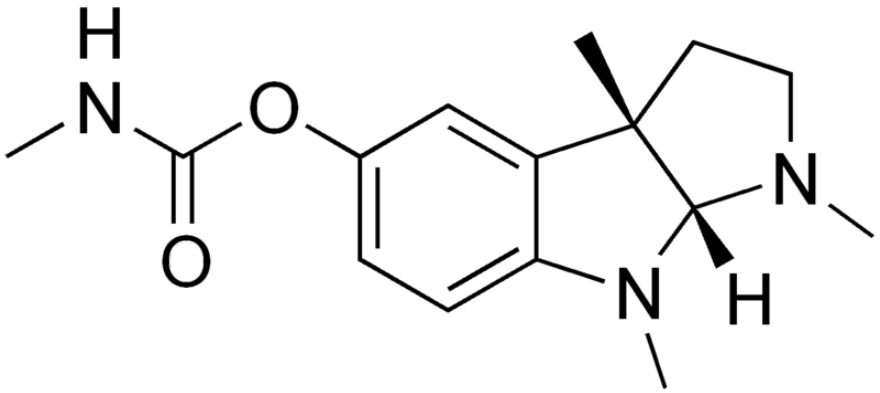
BZ

- **3-Quinuclidinyl benzilate** (BZ) - military incapacitating agent.
- Related to atropine
- Competitive inhibitor of acetylcholine at receptor sites in smooth muscle, exocrine glands, autonomic ganglia, and the brain
- Decreases the effective concentration of acetylcholine seen by receptors at these sites.
- Opposite of effects in nerve agent poisoning.
- Effects include stupor, confusion, and hallucinations.
- Schedule 2 of the Chemical Weapons Convention





Physostigmine - BZ Antidote



- Anticholinesterase, which temporarily raises acetylcholine concentrations by binding ***reversibly*** to acetylcholinesterase, the enzyme responsible for the breakdown of acetylcholine in the synaptic gap.

Toxins

- A **toxin** is a poisonous substance produced within living cells or organisms.
- Because toxins are chemicals produced by biological organisms, they can be considered chemical or biological weapons, the use of which would be a violation of both the CWC and the BWC (Biological Weapons Convention).
- As modern chemistry can synthesize an ever-growing number of toxins, they fall under the purview of the CWC.
- Two toxins, ricin and saxitoxin, are listed on Schedule 1 of the CWC.

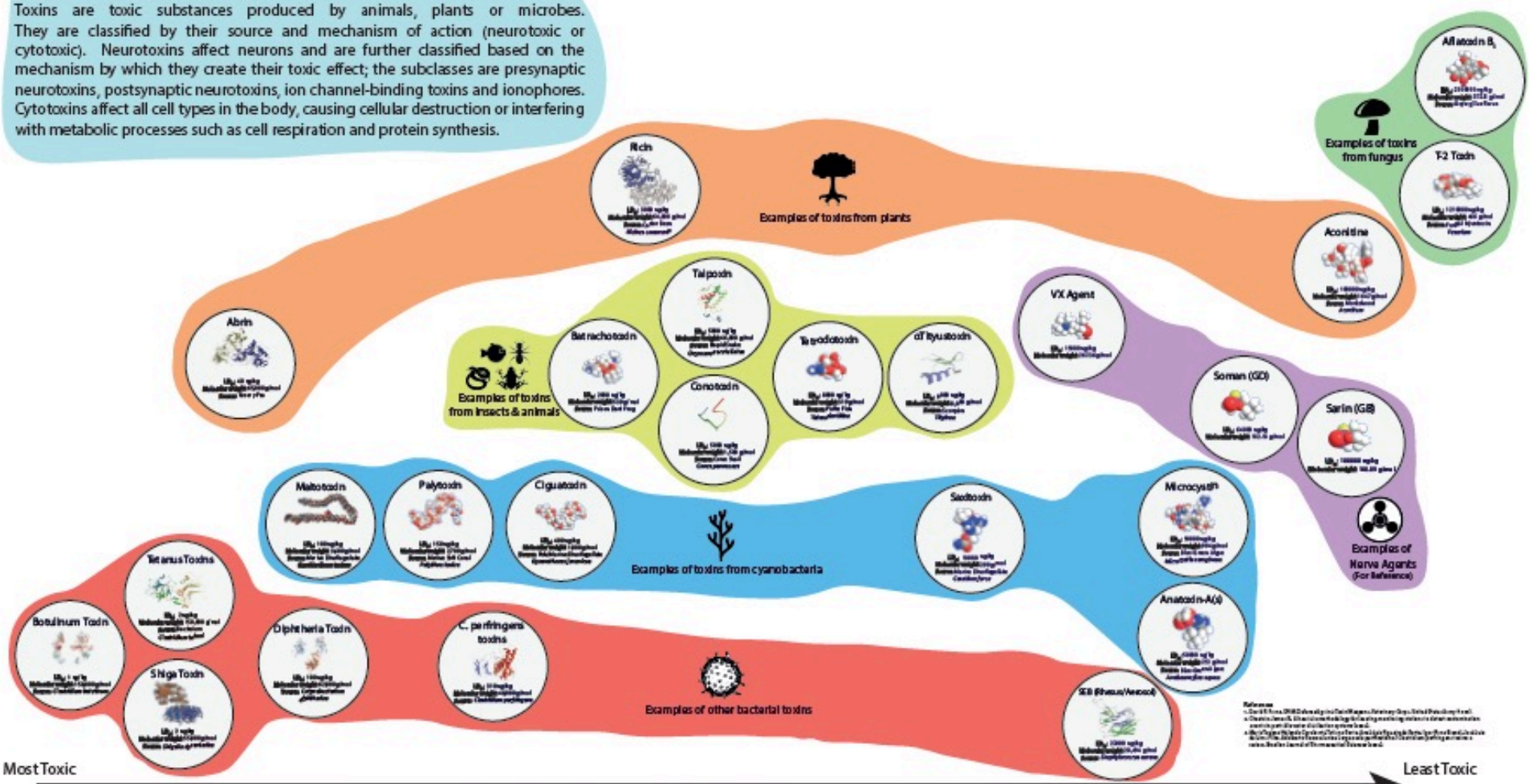
ORGANISATION FOR THE PROHIBITION OF CHEMICAL WEAPONS

Working Together for a World Free of Chemical Weapons

Biological Toxins and their Relative Toxicity

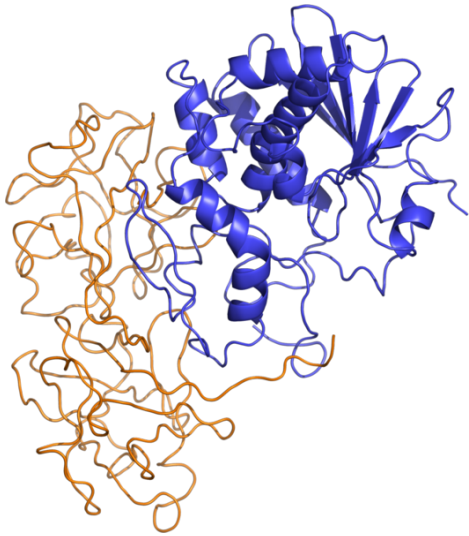
What are Toxins?

Toxins are toxic substances produced by animals, plants or microbes. They are classified by their source and mechanism of action (neurotoxic or cytotoxic). Neurotoxins affect neurons and are further classified based on the mechanism by which they create their toxic effect; the subclasses are presynaptic neurotoxins, postsynaptic neurotoxins, ion channel-binding toxins and ionophores. Cytotoxins affect all cell types in the body, causing cellular destruction or interfering with metabolic processes such as cell respiration and protein synthesis.



Ricin

- Naturally occurring protein.
- Can be extracted from castor beans
- The LD_{50} of ricin is around 22 micrograms per kilogram in humans if exposure is from injection or inhalation.
- Oral lethal dose is 20–30 milligrams per kilogram.
- The major reason ricin is a public health threat is that it is easy to obtain. (More than 1 million metric tons of castor beans are processed each year.)
- Low thermal stability makes it useless in munitions.
- Ricin is listed as a Schedule 1 controlled substance in the CWC.



http://en.wikipedia.org/wiki/Ricin

https://www.google.com/patents/US3060165

Ricin Physiological Effects

- Ribosomes, which are the site of protein synthesis in cells, are about 60% ribosomal RNA (rRNA) and 40% ribosomal protein.
- Ricin reacts with rRNA, deactivating the ribosome, and disrupting protein synthesis.
- Because proteins have wide-ranging functions, including as enzymes, ricin causes wide-ranging, detrimental effects on the body.
- Symptoms may take anywhere from hours to days to appear. Death typically occurs within 3–5 days of exposure.
- Antidotes are being developed but are not available yet.
- A vaccine has been developed and tested.

Ricin Symptoms

- **Symptoms from inhalation**: respiratory distress (difficulty breathing), fever, cough, nausea, and tightness in the chest. Heavy sweating may follow as well as fluid building up in the lungs (pulmonary edema). Finally, low blood pressure and respiratory failure may occur, leading to death.
- **Symptoms from ingestion**: vomiting and diarrhea that may become bloody. Severe dehydration, followed by low blood pressure….hallucinations, seizures, and blood in the urine. Within several days, the person's liver, spleen, and kidneys might stop working, and the person could die.

Ricin and the United States

- During World War I, the U.S. investigated ricin for its military potential as a toxic dust and as a coating for bullets and shrapnel.
  - The dust cloud concept could not be adequately developed, and the coated bullet/shrapnel concept would violate the Hague Convention of 1899, "...it is especially prohibited...[t]o employ poison or poisoned arms".
  - World War I ended before the U.S. weaponized ricin.
- During World War II, the US and Canada considered ricin to arm cluster bombs.
  - Conclusion - it was no more economical than using phosgene.
  - Interest in ricin stopped when the U.S. Army Chemical Corps began a program to weaponize sarin.

Ricin and the Soviet Union

- The Soviet Union possessed ricin.
- Georgi Ivanov Markov - Bulgarian dissident writer
  - 1969 - defected from Bulgaria
  - Broadcaster and journalist for the BBC World Service, the US-funded Radio Free Europe, and Germany's Deutsche Welle.
  - Criticized the Bulgarian regime.
  - Died in London when a pellet containing ricin was fired by compressed gas into his leg from an umbrella wielded by someone associated with the Bulgarian secret police.
  - It is believed that the Soviet KGB supplied the ricin pellet.

Ricin as Chemical Weapon

- Ian Davison, a British white supremacist and neo-Nazi, was arrested in 2009 for planning terrorist attacks involving ricin.
- In 2011 the United States government discovered information that terrorist groups were attempting to obtain large amounts of castor beans for weaponized ricin use.

  Eric Schmitt and Thom Shanker (2011-08-13). "Al Qaeda trying to harness toxin for bombs, U.S. officials fear". The New York Times.

- On November 1, 2011, the FBI arrested four North Georgia men and charged them in plots to manufacture ricin from castor beans to assassinate state officials.

http://www.fbi.gov/atlanta/press-releases/2011/north-georgia-men-arrested-charged-in-plots-to-purchase-explosives-silencer-and-to-manufacture-a-biological-toxin

Ricin as Chemical Weapon

- According to a NY Times report, Al-Qaida's Yemeni branch is trying to stockpile the lethal toxin ricin for aerial dispersal in the United States.
  - U.S. insiders said they saw no signs of an impending ricin strike.
  - Yemen's climate is not conducive to ricin retaining its potency

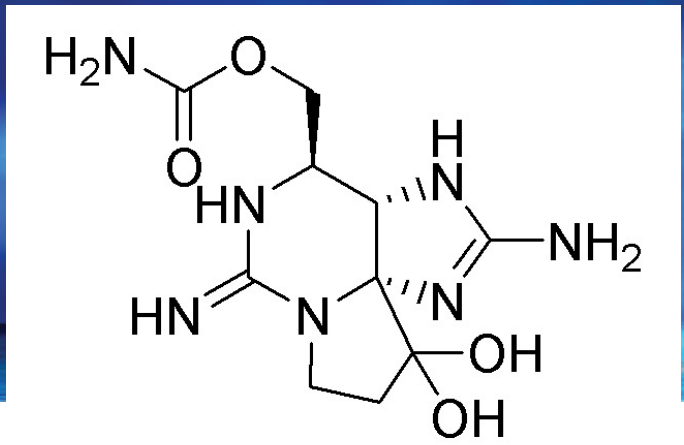
http://www.nytimes.com/2011/08/13/world/middleeast/13terror.html?pagewanted=all&_r=0

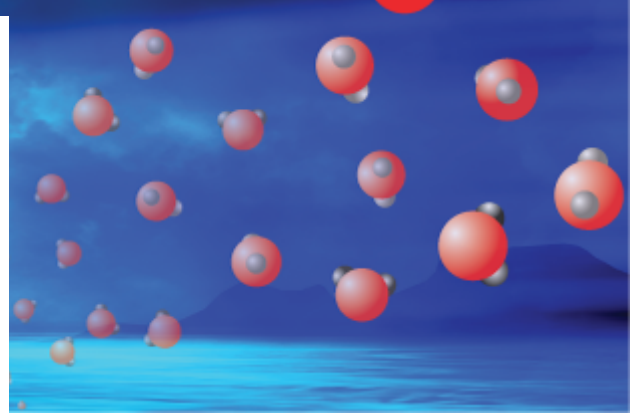
Ricin and ISIS

- Some indications that ISIS has pursued the production of ricin.
- *"The laptop of Muhammed S., a Tunisian chemistry and physics student who joined the Islamic State, contains an eclectic mix of speeches by jihadi leaders, neo-Nazi screeds, and U.S. Army manuals on specific aspects of warfare".*
- *Includes "…instructions for how to obtain the deadly toxin ricin from castor beans."*

http://foreignpolicy.com/2014/09/09/recipes-from-the-islamic-states-laptop-of-doom/

Saxitoxin





- **Saxitoxin** (**STX**) is the most well-known paralytic shellfish toxin (PST)
- STX has been found in at least 12 marine puffer fish species.
- Saxitoxin is a neurotoxin that acts as a selective sodium channel blocker. It acts on the voltage-gated sodium channels of nerve cells, preventing normal cellular function and leading to paralysis.
- Can potentially be produced in a chemical laboratory.
- The oral LD_{50} for humans is 5.7 µg/kg, therefore approximately 0.5 mg of saxitoxin is lethal if ingested and the lethal dose by injection is about one-tenth of the oral dose.

http://en.wikipedia.org/wiki/Saxitoxin

Saxitoxin

- Saxitoxin is about 1,000 times more toxic than the nerve agent sarin.
- The United States military isolated saxitoxin and assigned it the chemical weapon designation TZ.
- U-2 pilot Francis Gary Powers was issued with a hollow silver dollar containing a tiny, saxitoxin-impregnated needle, to be used to commit suicide in case of capture by enemy forces.
- Saxitoxin is listed in Schedule 1 of the CWC.
- Although there are other ways to obtain saxitoxin, it takes 8 tons of clams to extract 1 gram of toxin.

http://en.wikipedia.org/wiki/Saxitoxin

Comparison of Toxins and Chemical Agents

Toxins	Chemical Agents
Natural Origin	Human-made
Difficult, small-scale production	Large-scale industrial production
None volatile	Many volatile
Many are more toxic	Less toxic than many toxins
Mostly not dermally active	Can be dermally active
Legitimate medical use	Almost no medical uses
Odorless and tasteless	Noticeable odor or taste
Diverse toxic effects	Fewer types of effects
Many are effective immunogens	Poor immunogens
Aerosol delivery	Mist/droplet/aerosol delivery

1925 Geneva Protocol

- Protocol on the Prohibition of the Use in War of Asphyxiating, Poisonous or Other Gases, and of Bacteriological Methods of Warfare
- **Banned first use of chemical and biological weapons but not their production and stockpiling**
- Adopted by the League of Nations
- Within ten years, it was ratified by forty countries, including most of the major powers except the U.S. and Japan.
- U.S. signed with reservations 50 years later (General Fries lobbied against it, aided by a coalition of veterans' groups, the chemical industry, and the American Chemical Society.)
- A number of countries reserved the right to retaliate and therefore stockpiled chemical weapons.

U.S. Chemical Warfare Service (CWS)

- Formed in 1918
- Headquartered at Edgewood Arsenal
- Headed by General Amos Fries
- Later became the U.S. Army Chemical Corps

When properly safe-guarded with masks and other safety devices, [chemical weapons give] the most scientific and most ingenious people an advantage over the less scientific and less ingenious…It is just as sportsman-like to fight with chemical warfare material as it is to fight with machine guns.

General Fries

Chemical Weapons Convention (CWC)

- **A disarmament agreement that bans the production, stockpiling, transferring, and use of chemical weapons.**
- Approved by the U.N. General Assembly in November, 1992.
- Open for signature in 1993
- The U.S. ratified CWC in 1997.

http://www.cwc.gov/

http://www.opcw.org/chemical-weapons-convention//

http://www.opcw.org/news-publications/publications/history-of-the-chemical-weapons-convention/

CWC General Obligations

1. Each State Party to this Convention undertakes never under any circumstances:

(a) To develop, produce, otherwise acquire, stockpile or retain chemical weapons, or transfer, directly or indirectly, chemical weapons to anyone;

(b) To use chemical weapons;

(c) To engage in any military preparations to use chemical weapons;

(d) To assist, encourage or induce, in any way, anyone to engage in any activity prohibited to a State Party under this Convention.

CWC General Obligations (cont.)

2. Each State Party undertakes to **destroy chemical weapons it owns or possesses**, or that are located in any place under its jurisdiction or control, in accordance with the provisions of this Convention.

3. Each State Party undertakes to **destroy all chemical weapons it abandoned** on the territory of another State Party, in accordance with the provisions of this Convention.

4. Each State Party undertakes to **destroy any chemical weapons production facilities** it owns or possesses, or that are located in any place under its jurisdiction or control, in accordance with the provisions of this Convention.

5. Each State Party undertakes not to use riot control agents as a method of warfare.

Organisation for the Prohibition of Chemical Weapons (OPCW)

- Model of multilateralism - 193 member states that contain 98% of the world's population.
- 4 nonmember states
  - Signatory states that have not ratified the CWC
    - Israel
  - States that have neither signed nor ratified the CWC
    - Egypt
    - North Korea
    - South Sudan ("has all but concluded the process of joining the Organisation for the Prohibition of Chemical Weapons" 12/1/17)

States Outside CWC

- Israel
  - Analysts believe that Israel initiated a CW program between mid-1950s and mid-1980s.
  - Refuses to ratify CWC until there's more regional participation.
  - Israel's chemical industry is advanced and diverse.
  - Although Israel is capable of creating CW weapons, there is insufficient information available to reconstruct their CW program.

http://www.nti.org/country-profiles/israel/

States Outside CWC

- Egypt
  - Used CW in North Yemen
  - Thought to have inherited mustard agent and phosgene from British forces when they withdrew in 1954
  - May have nerve agents
  - Refuses to join CWC until Israel joins the Nuclear Nonproliferation Treaty (NPT)
  - Thought to have helped Iraq get CW production capabilities

http://www.nti.org/e_research/profiles/Egypt/Chemical/index.html

States Outside CWC

- North Korea
  - Thought to have 2500-5000 metric tons of phosgene, hydrogen cyanide, mustard agent, and sarin
  - Has capable but aging chemical industry

http://www.nti.org/country-profiles/north-korea/

Organisation for the Prohibition of Chemical Weapons (OPCW)

- Intergovernmental organization located in The Hague, Netherlands
- *"…implementing body of the [CWC]…given the mandate to achieve the object and purpose of the Convention, to ensure the implementation of its provisions, including those for international verification of compliance with it, and to provide a forum for consultation and cooperation among States Parties."*

http://www.opcw.org/about-opcw/
http://www.opcw.org/

OPCW Tasks

- Bring all States into the CWC
- Verifying the destruction of declared chemical weapons, including those in abandoned CW weapons
  - The CWC is unique among disarmament treaties in having a verification regime.
- Verifying the destruction or conversion of CW plants
- Monitoring future compliance with CWC

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www.opcw.org/fileadmin/OPCW/Science_Technology/Diplomats_Programme/Science_for_Diplomats_at_the_OPCW_2014_2015.pdf

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ENVIRONMENTAL SAMPLING

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CHAIN OF CUSTODY!

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www.opcw.org/fileadmin/OPCW/Science_Technology/Diplomats_Programme/Science_for_Diplomats_at_the_OPCW_2014_2015.pdf

OPCW Fact Finding Missions

- Collection of evidence
  - Environmental samples
  - Biomedical samples
  - Chain-of custody
  - Interviews
  - Photos, video
- On-site detectors, on-site analysis
- Samples transferred to OPCW designated laboratory network for confirmation

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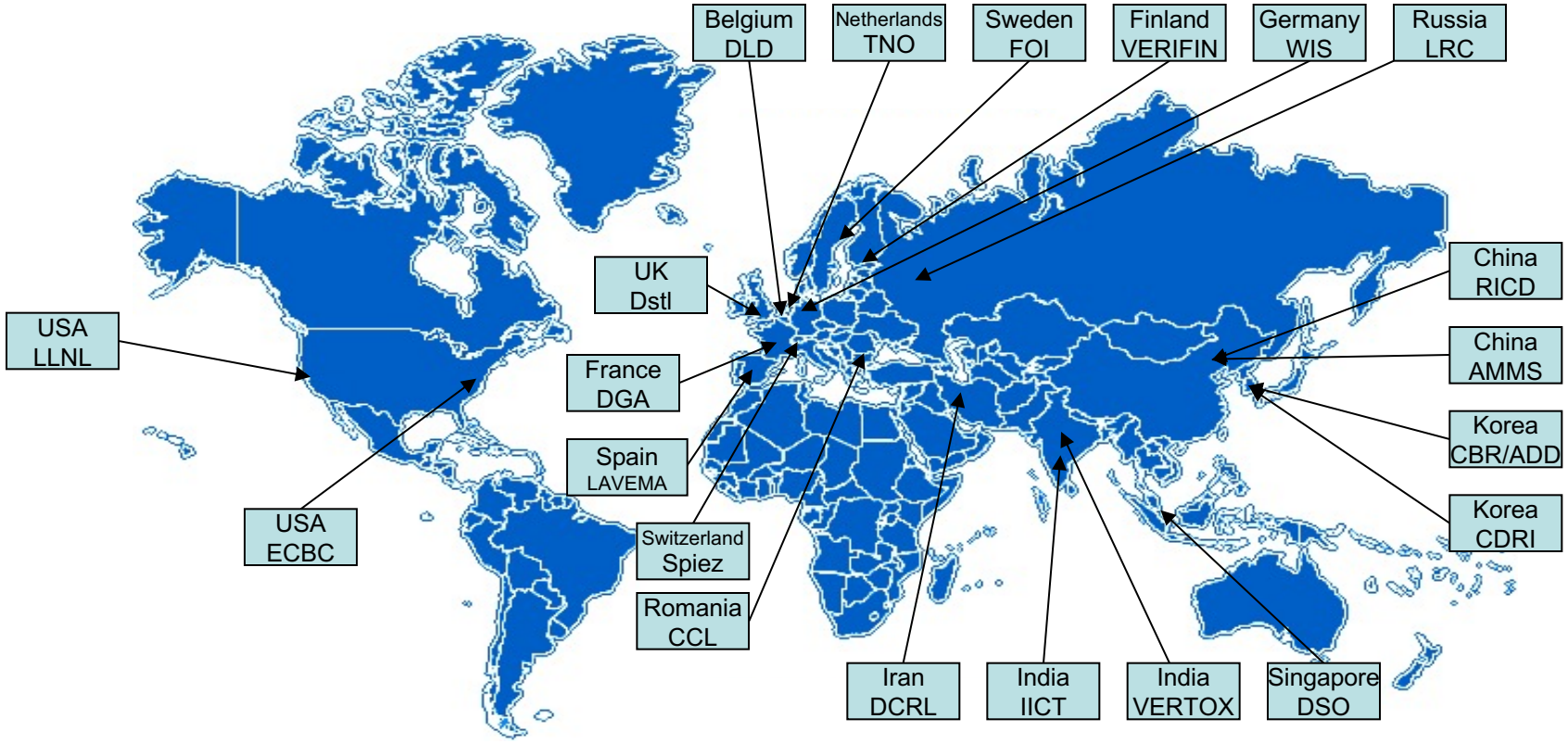
OPCW Designated Laboratories (as of May 2014)



21 Designated Laboratories in 17 countries

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www.opcw.org/fileadmin/OPCW/Science_Technology/Diplomats_Programme/Science_for_Diplomats_at_the_OPCW_2014_2015.pdf

Sample Types and Assumed Concentrations

- Environmental samples
  - “Neat” agent from a reactor or bomb
  - Residue from a reaction or waste container
  - Contaminated clothing, hair, soil, water, etc.
  - Concentrations usually expected >1 µg/g (ppm)
  - Survey analysis is possible
- Biomedical samples
  - Urine, blood, plasma, tissue, etc.
  - Intact chemical agent likely not present (degradation/reaction product or metabolite)
  - Concentration levels quite low, < 5 ng/g (ppb)
  - Survey analysis not possible; must use targeted analysis

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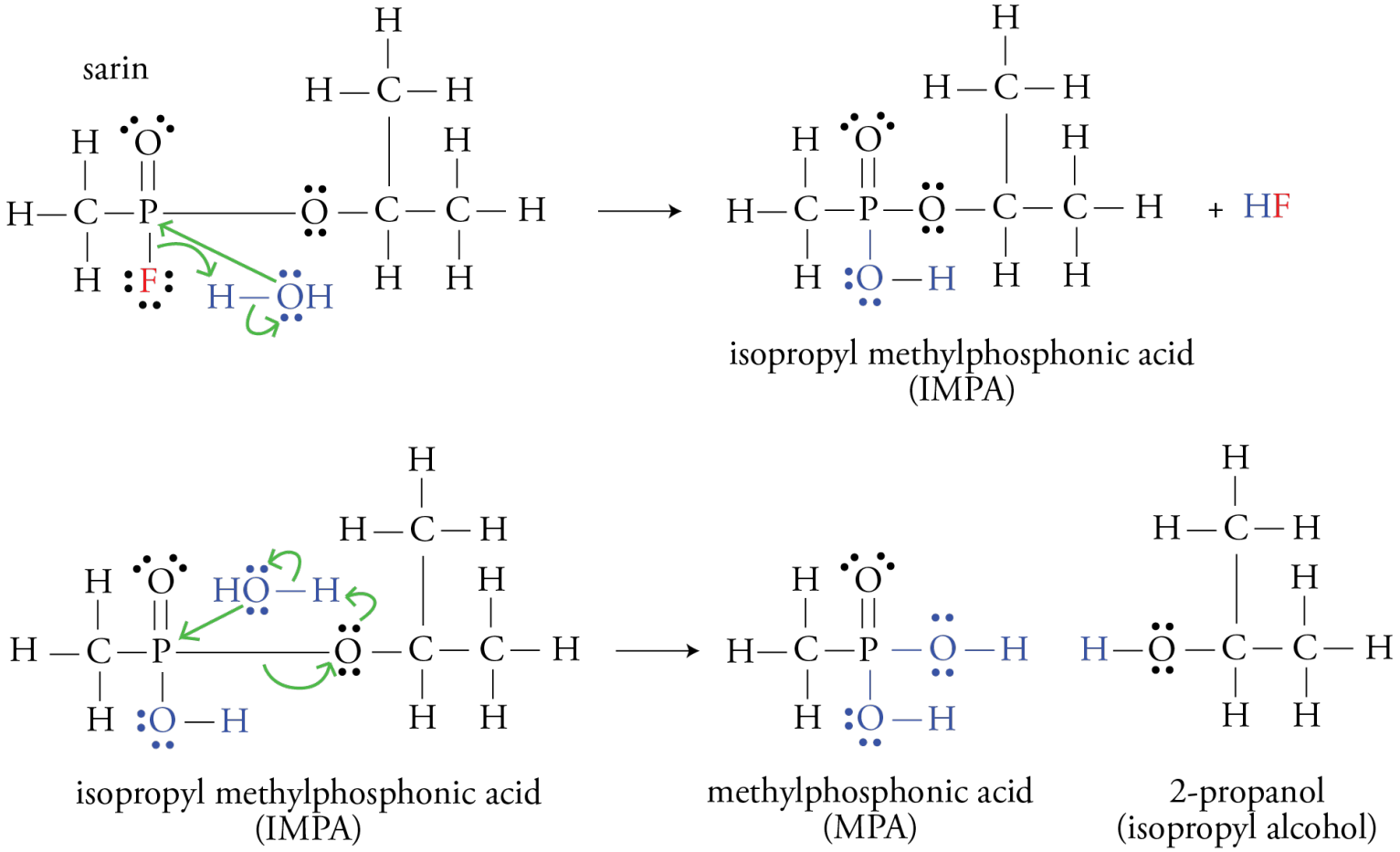
Hydrolysis of Sarin

Each arrow represents the movement of a pair of electrons as covalent bonds are broken and made.



Detection of Sarin Use

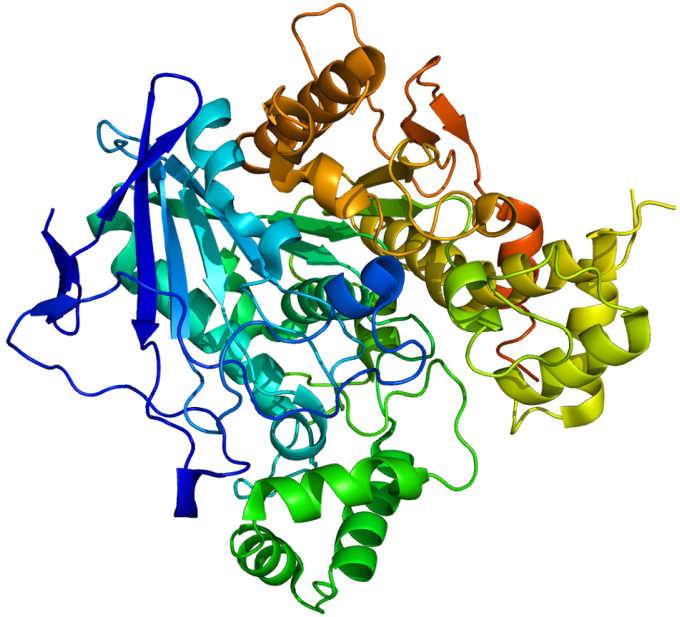
- The product of the first step in the hydrolysis of sarin, isopropyl methylphosphonic acid (IMPA), is a chemical that is not commonly found in nature, so if it is found at the site of a chemical weapons attack, it's an indication of the use of sarin.
- IMPA was detected in 20 of 42 reported environmental samples taken by the OPCW team in Ghouta, Syria.
- The final products of the hydrolysis of sarin are formed from the hydrolysis of other organophoshates.

Detection of Sarin Use in Biomedical Samples

- Urine or blood samples taken from exposed persons are more difficult than environmental samples to analyze because the chemical agent, its adducts, and metabolites degrade and are excreted from the body, giving a limited time window to collect and analyze samples.
- Concentration levels in these samples are likely to be in the parts per billion range, requiring a targeted rather than a survey approach to the analysis.
- Can look for IMPA and protein adducts, including sarin-AChE or sarin-BChE (butyrylcholinesterase), which may persist for several weeks.
- Unlike the sarin-AChE adduct, sarin-BChE is found in blood serum.

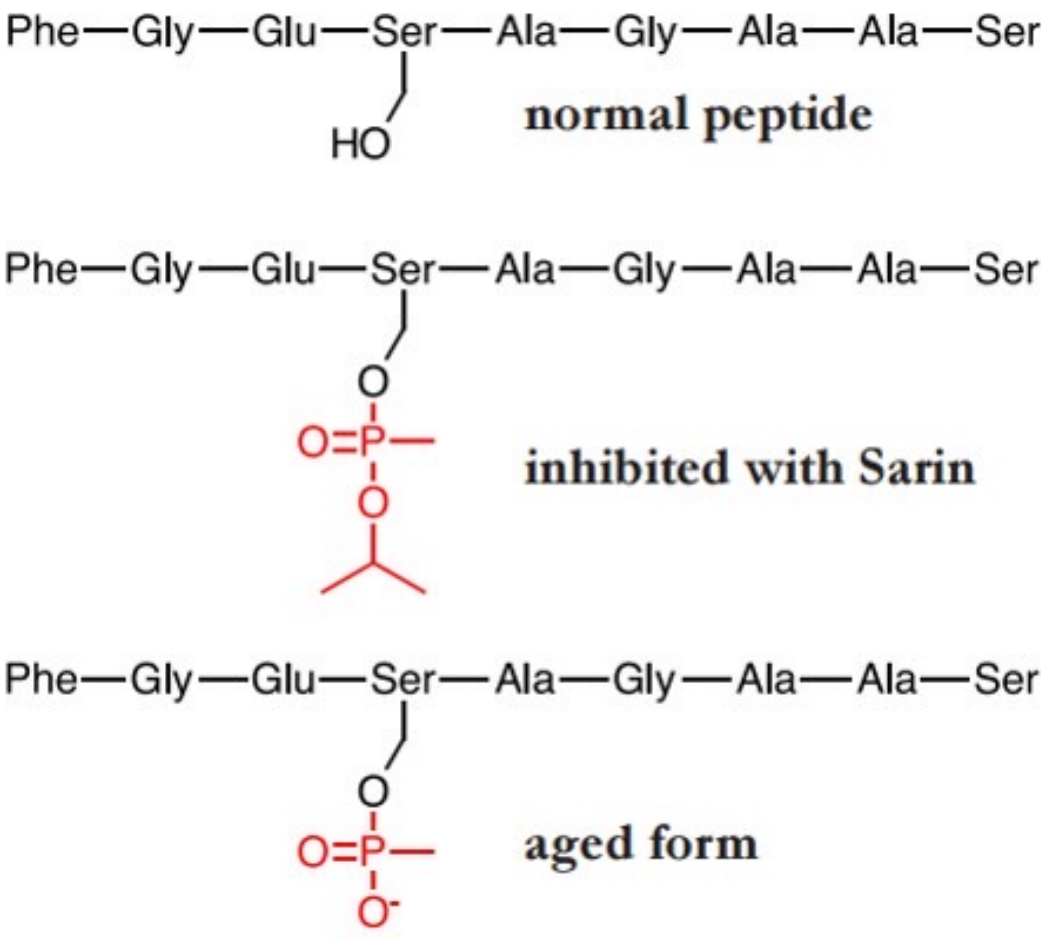
Butylcholinesterase (BChE)

- Similar to acetylcholinesterase (AChE).
- Hydrolyzes many different choline-based esters
- In blood serum
- Can be used as a prophylactic countermeasure for nerve agents



Detection of Sarin Use in Biomedical Samples

- Can look for protein fragments that come from the partial digestion of the sarin-BChE in blood serum.
- These fragments can be in the sarin-fragment form or the aged form.



How does a GC/MS work?

(1) Autosampler:
Injects a small amount (1 µL) of sample into the Gas Chromatograph

(2) Gas Chromatograph:
Separates chemical species and creates a chromatogram of all the species in the sample.

(3) Mass Spectrometer:
Creates a spectrum or "fingerprint" of each compound as it comes from the GC

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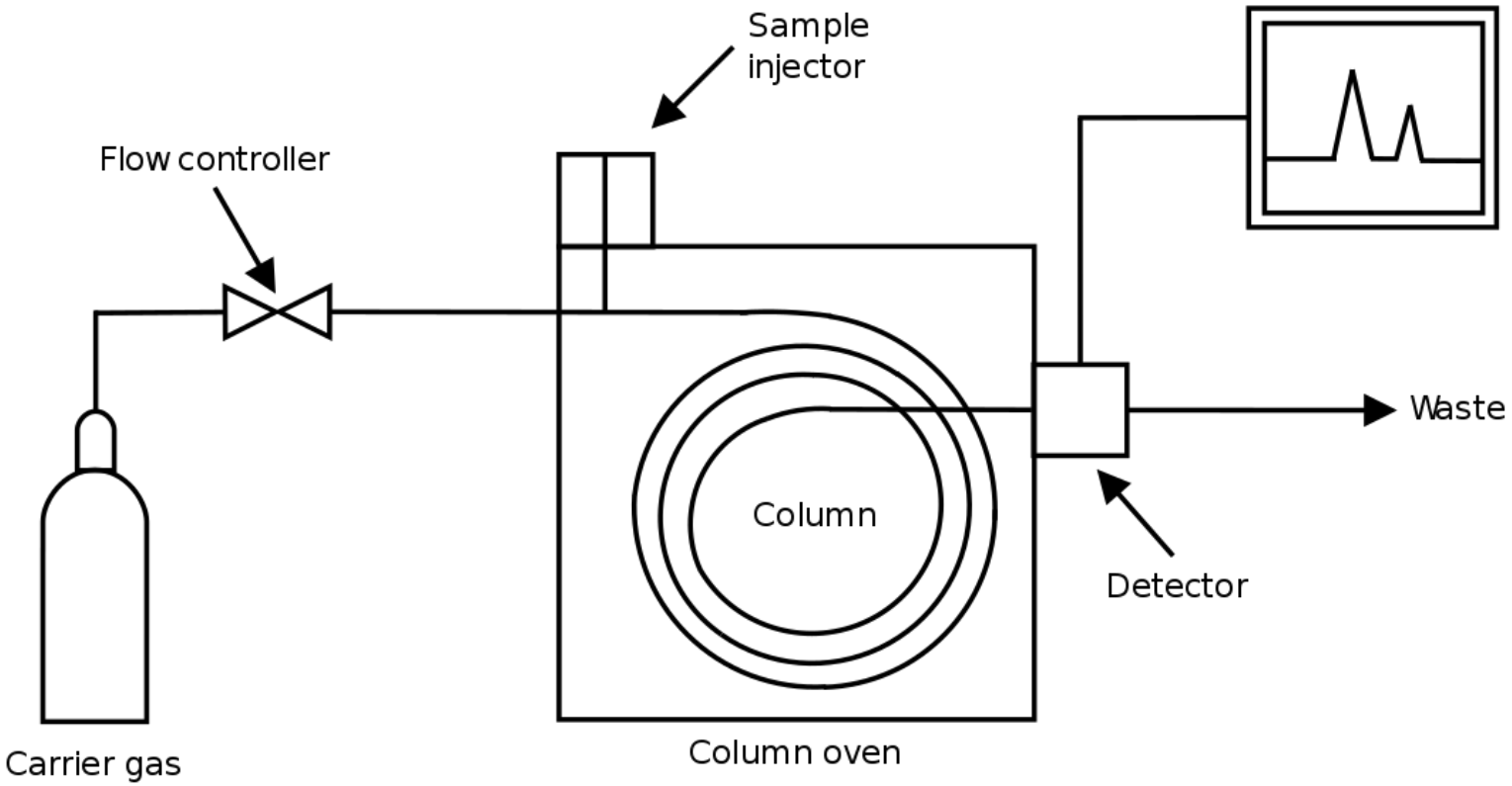
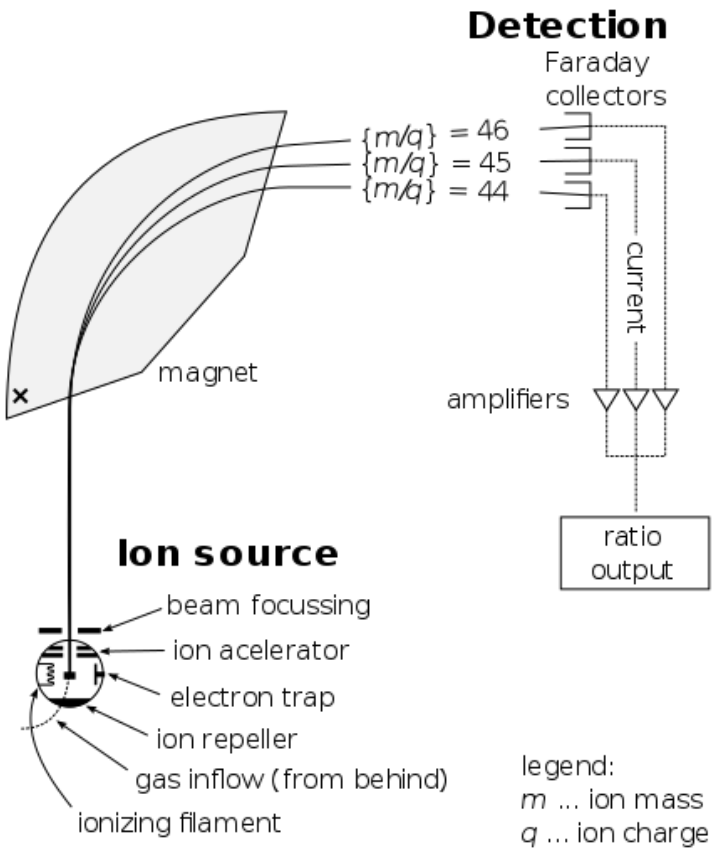
Gas Chromatograph



Gas Chromatograph

- Volatile sample injected.
- Carried by an inert or unreactive gas (e.g. helium or nitrogen) through column with solid coated with thin layer of liquid or a polymer.
- Substances move back and forth between moving in the gas and stationary on liquid or polymer.
- Different substances have different volatilities and different attractions to liquid or polymer, so they spend different amounts of time moving in gas.
- Substances are separated because they come out of the column at different times

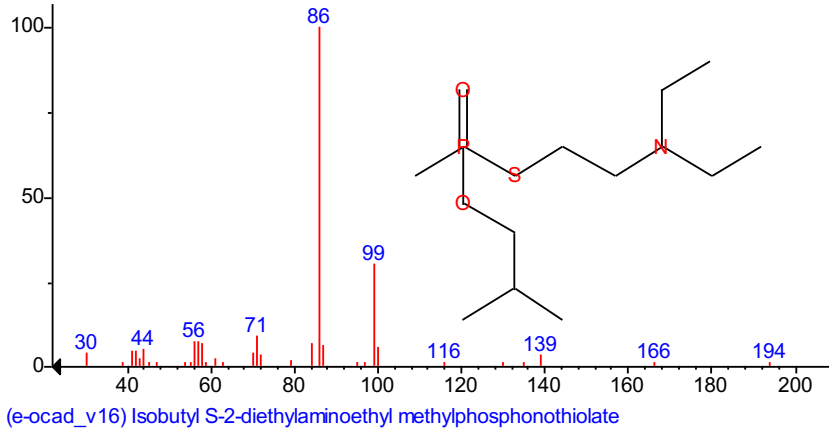
Mass Spectrometer



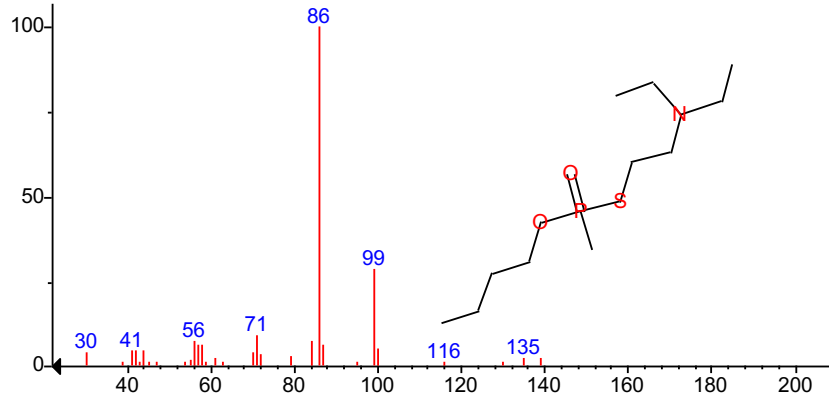
Mass Spectrometer

- Substances is ionized and broken into fragments by an electron beam.
- Ions are accelerated through a velocity selector that only allows fragments with a particular velocity to move into a magnetic field.
- Moving ions create a magnetic field that interacts with the external magnetic field, causing the ions to be deflected.
- The more massive the particle is, the more difficult it is to deflect it, so the less it is deflected.
- Detector finds the ions at different positions, and a mass spectrum is created based on the amount of deflection and the intensity of the ion beam at different degrees of deflection.
- Each substance yields a unique mass spectrum, and comparison of a mass spectrum to mass spectrums of known substances can be done to identify substances.

GC/MS Results: Spectra Match to Library



(e-ocad_v16) Isobutyl S-2-diethylaminoethyl methylphosphonothiolate



(e-ocad_v16) Butyl S-2-diethylaminoethyl methylphosphonothiolate

- Small differences in mass spectra indicate different structures
- Both are V-agents

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OPCW Member State Obligations

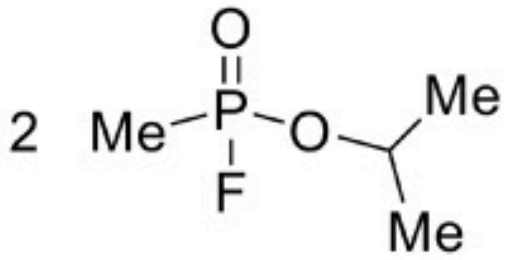
- *Each country that belongs to the OPCW must:*
  - *destroy all chemical weapons it owns or possesses;*
  - *destroy all chemical weapons it may have abandoned in another country; and*
  - *destroy facilities it owns or possesses which were involved in the production of chemical weapons.*

https://www.opcw.org/our-work/demilitarisation/destruction-of-chemical-weapons/

Three Ways of Disposing of Chemical Weapons

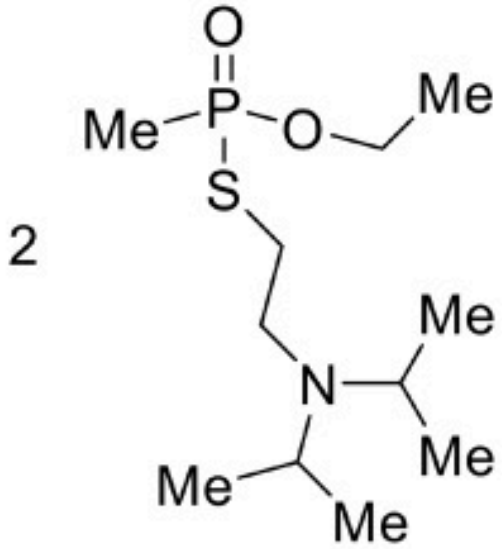
- Ocean dumping (no longer done)
- Incineration
- Hydrolysis (chemical neutralization) followed by various further treatments (now favored)

Incineration of Sarin and VX



GB (Sarin)

$$\xrightarrow[1480\ ^{o}C]{13\ O_2} P_2O_5 + 8\ CO_2 + 9\ H_2O + 2\ HF$$

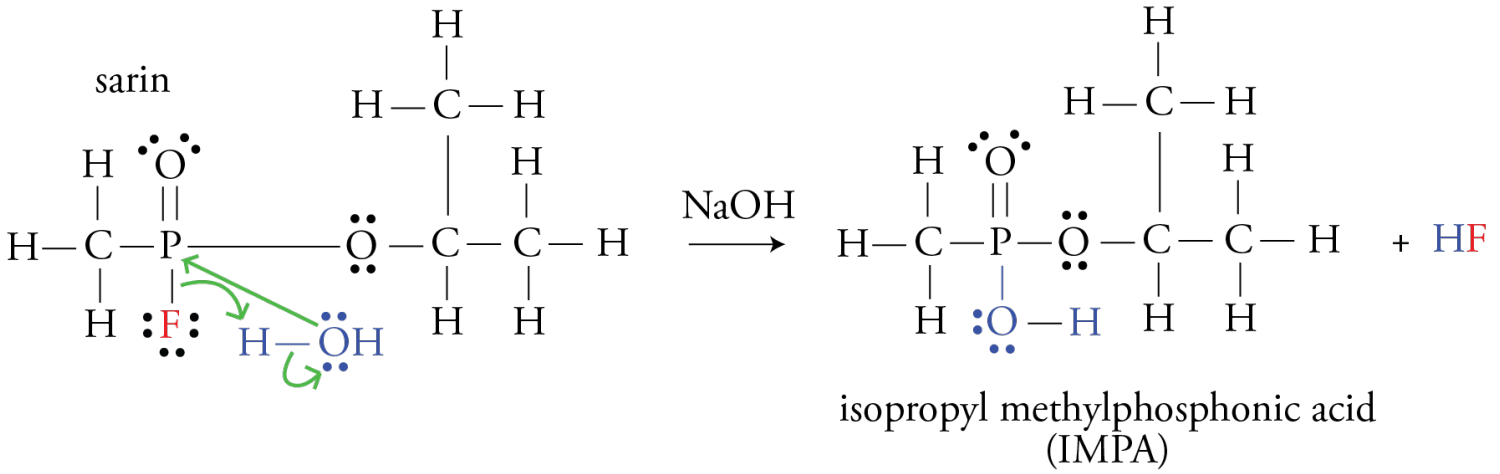


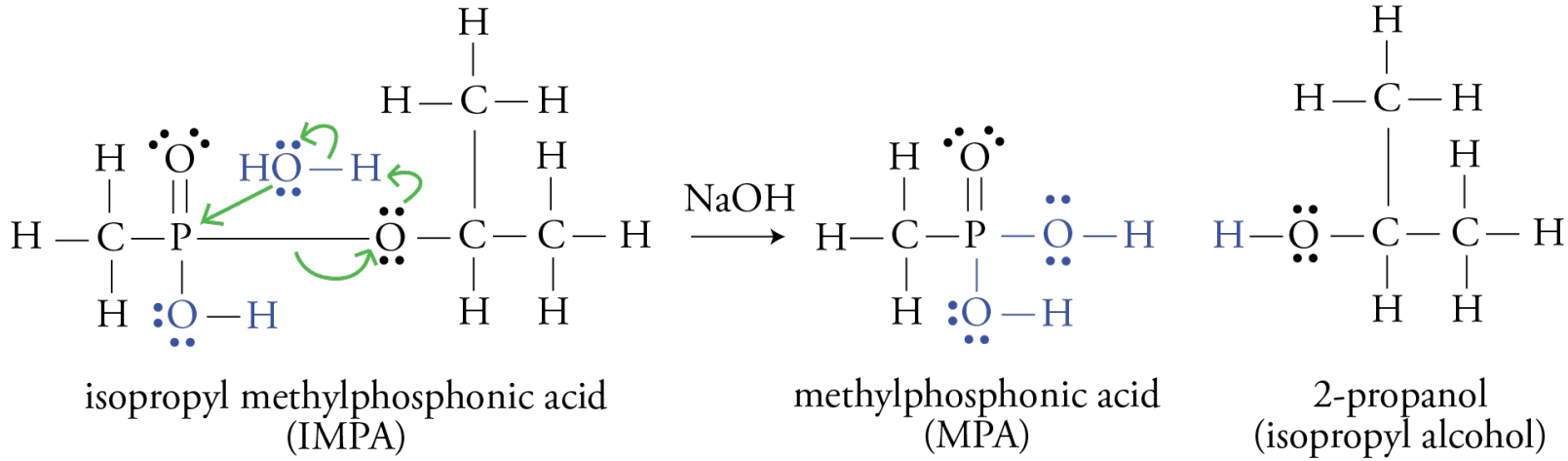
VX

$$\xrightarrow[1480\ ^{o}C]{38.5\ O_2} P_2O_5 + 22\ CO_2 + 26\ H_2O + 2\ SO_2 + 2\ NO$$

Hydrolysis of Sarin

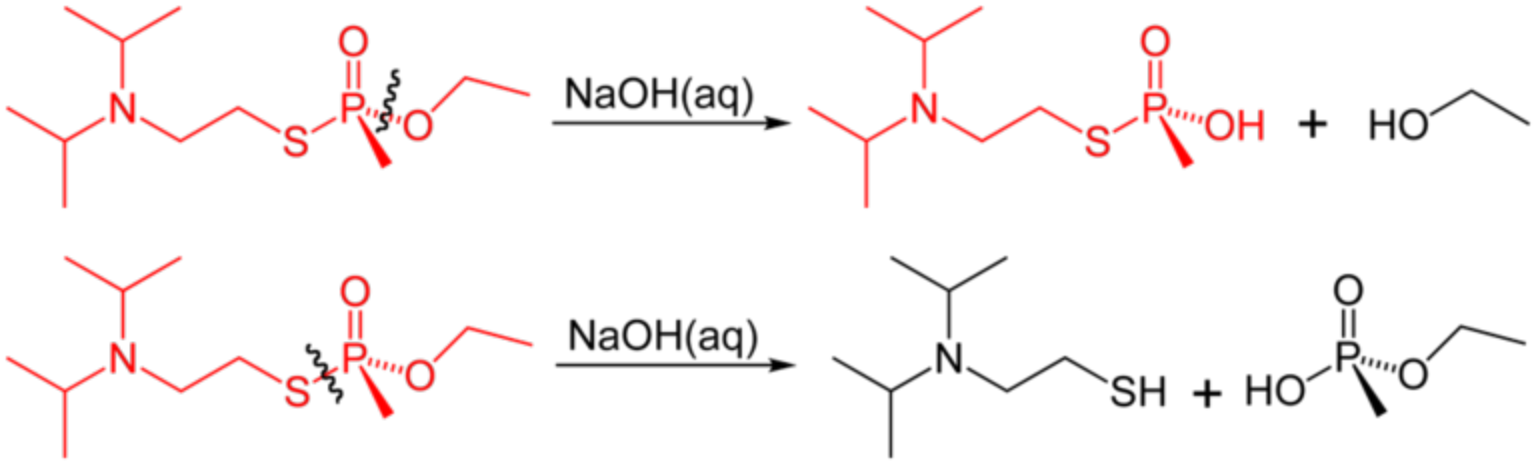
Each arrow represents the movement of a pair of electrons as covalent bonds are broken and made.





Chemical Neutralization of VX

- VX can be converted into safer substances by combining it with a concentrated solution of sodium hydroxide, NaOH.
- The reaction is called hydrolysis, in which water, H_2O, divides into H, which combines with one part of a molecule, and OH, which combines with another part of the molecule, splitting the molecule into two parts.

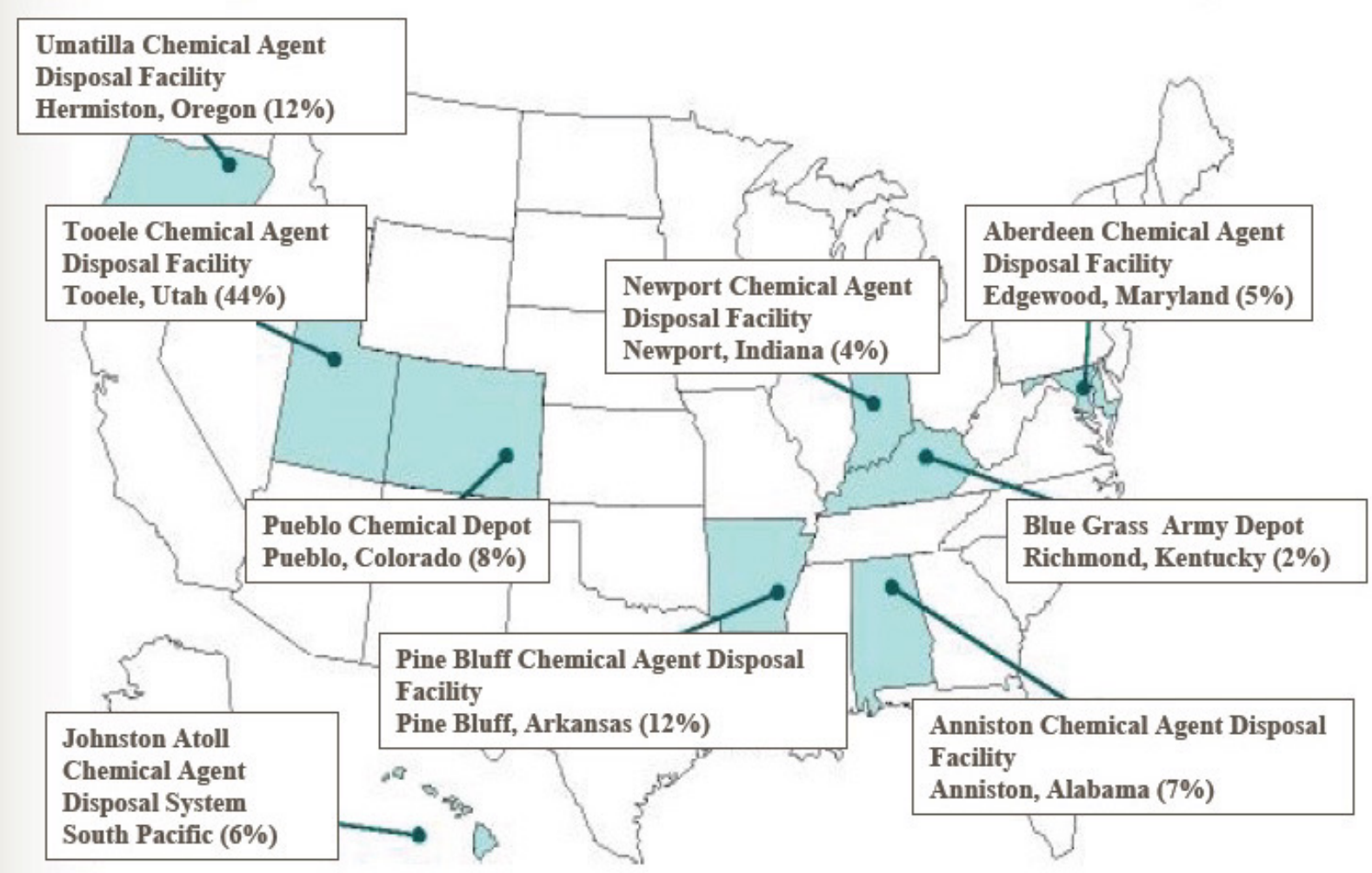


U.S. Army's Chemical Materials Agency (CMA)

- The CMA stores and destroys the U.S. chemical weapons.
  http://www.cma.army.mil/

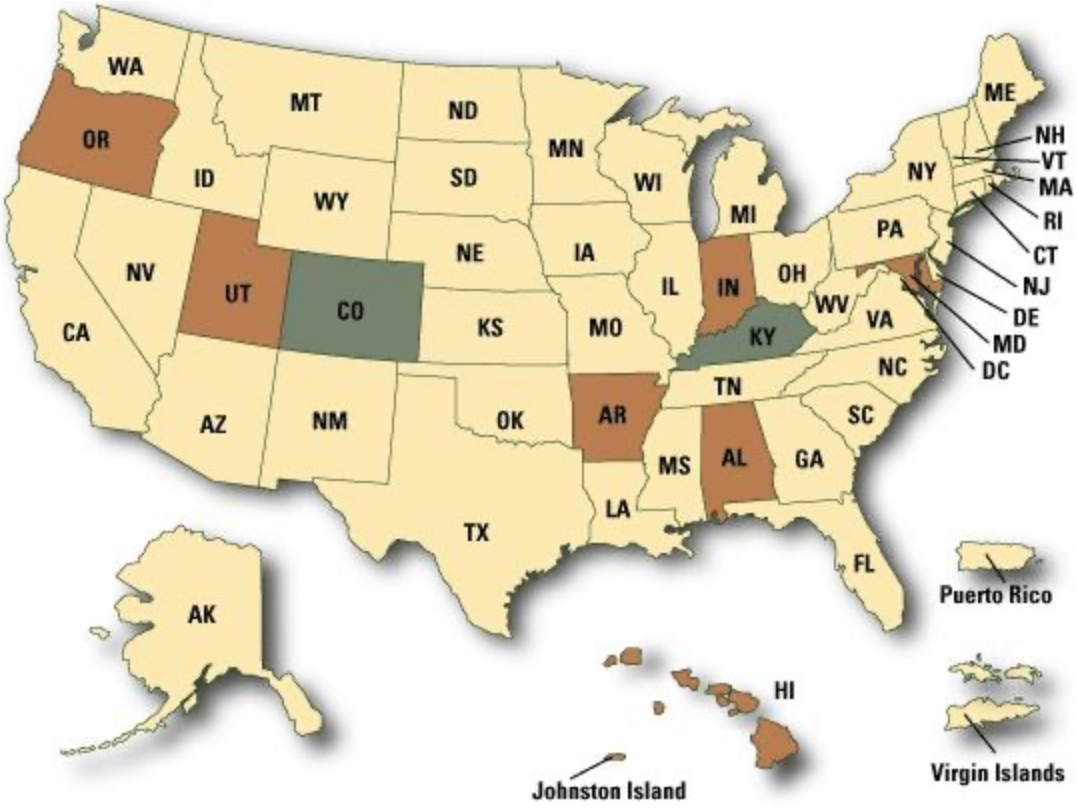
A student fully encapsulated in a protective suit at the Chemical Demilitarization Training Facility at Aberdeen Proving Ground, Md., rolls a simulated waste barrel in the Demilitarization Equipment Room.

United States CW Disposal Facilities



Status of CW Disposal Facilities

Green - States and Regions with Chemical Weapons Stockpiles
Yellow - States and Regions without Chemical Weapons Stockpiles
Brown - States and Regions that had Chemical Weapons Stockpiles



http://www.cma.army.mil/map.aspx

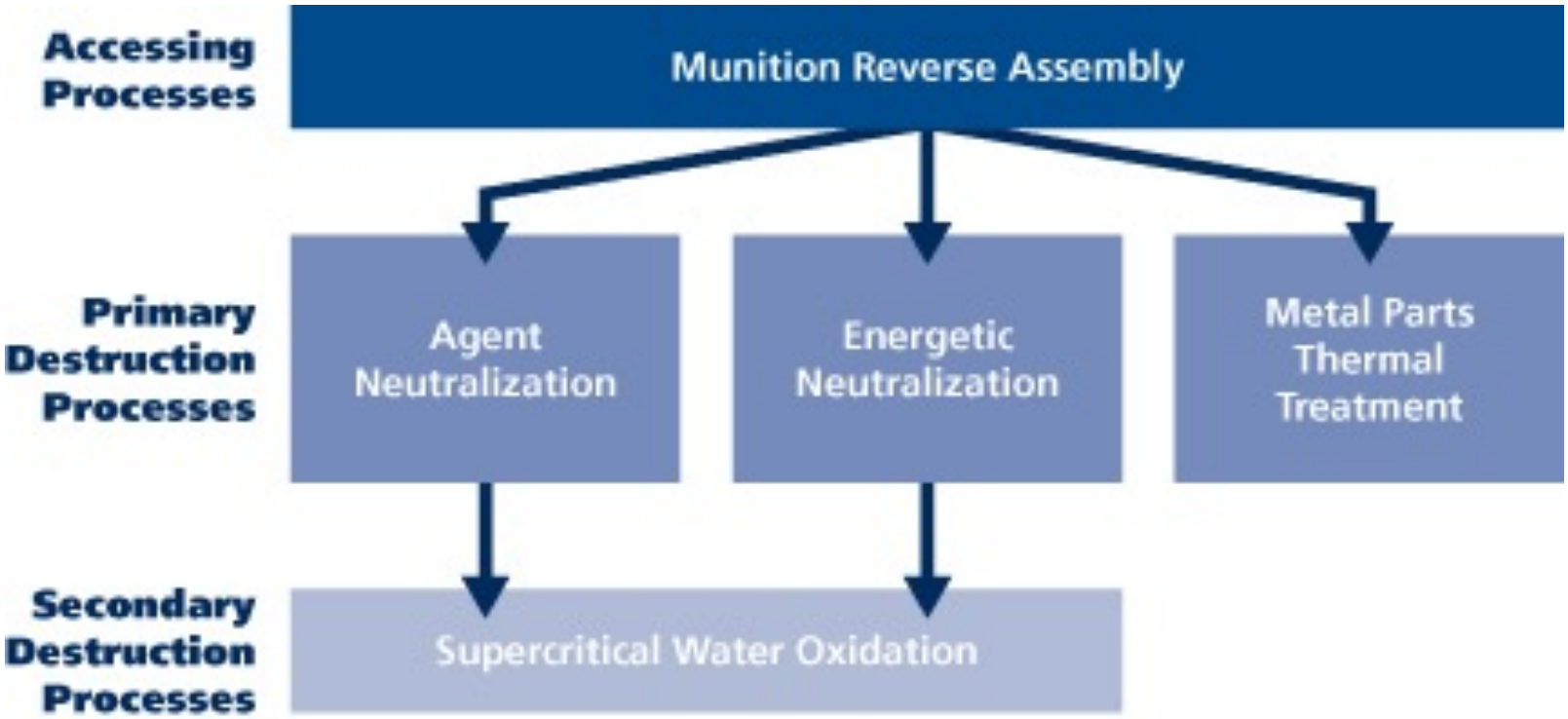
United States Remaining Chemical Weapons

- Blue Grass Army Depot - Richmond, Kentucky
  - 523 tons of sarin, VX, and mustard agent in projectiles, warheads and rockets will be destroyed by chemical neutralization followed by supercritical water oxidation.
  - 169.8 tons (or 32.45%) destroyed as of 9/27/2021.

https://www.cma.army.mil/bluegrass/

https://www.peoacwa.army.mil/bgcapp/

Supercritical Water Oxidation (SCWO)



Supercritical Water Oxidation (SCWO)

- The chemical agent and energetics are separated.
- Hydrolysis of chemical agent and energetics
- The hydrolysis products are separately fed to the supercritical water oxidation units to destroy the organic materials.
  - SCWO subjects the hydrolysis products to very high temperatures and pressures, breaking them down into carbon dioxide, water and salts.
- Metal parts are thermally decontaminated by high-pressure water washout and heating to 1,000 degrees Fahrenheit for a minimum of 15 minutes.
- Gases are filtered through a series of filters before being released to the atmosphere.
- Water is recycled into the pilot plant facility and reused as part of the destruction process.

http://www.peoacwa.army.mil/bgcapp/bgcapp-destruction-technology/

United States Remaining Chemical Weapons

- Pueblo, Colorado
  - Will destroy 2,600 tons of mustard agent in approximately 780,000 munitions by neutralization.
  - 2040.4 tons (or 78.08%) destroyed as of 9/27/2021.
  - Started March 2015

https://www.cma.army.mil/pcd/

https://www.peoacwa.army.mil/pcapp/

Steps for Neutralization Followed by Biotreatment

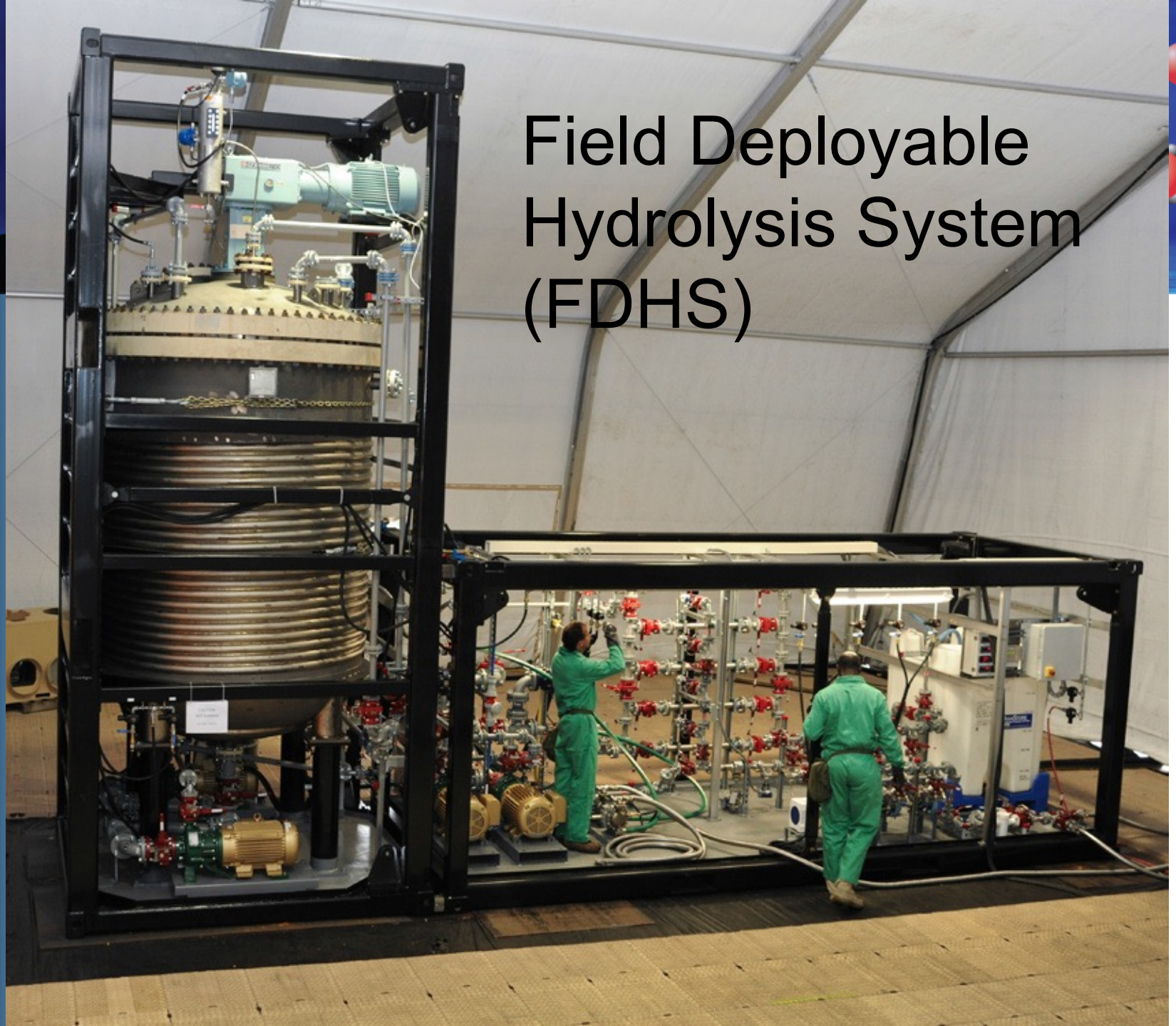
- Robatically removing the energetics, including the fuse and burster
- Robatically removing the mustard agent
- Hydrolysis of mustard agent
- Biotreatment of remaining organics (mostly thiodiglycol) with microbes (ordinary sewage treatment bacteria)
- Disposal of metal parts after heating to high temperature to complete the decontamination

http://www.peoacwa.army.mil/media-toolkit/facts-pages/facts-page-neutralization-followed-by-biotreatment/

Field Deployable Hydrolysis System (FDHS)

- *Transportable, high-throughput modular demilitarization system designed to render chemical warfare materiel into compounds not usable as weapons.*
- *The system uses neutralization technology to destroy bulk chemical warfare agents and their precursors by heating and mixing with reagents, such as water, sodium hydroxide and sodium hypochlorite to facilitate chemical degradation resulting in a destruction efficiency of 99.9 percent.*

Field Deployable Hydrolysis System (FDHS)



Common CW Precursors

- Most precursors have legitimate commercial uses.
- Dual-use nature impedes detection of CW programs.
- Trade in precursors is monitored and controlled.

Chmical Compound	***Commercial Uses***	***CW Agent***
Thiodiglycol	plastics, textile dyes, ink	Mustard agent
Phosphorus trichloride	plasticizers, insecticides	Sarin
Sodium cyanide	dyes & pigments, nylon, metal hardening	HCN
Methylphosphonic difluoride	organic synthesis	Sarin, VX
Phosphorus pentasulfide	insecticides, lubricants, pyrotechnics	VX

Australia Group

- Established 1985
- *"The Australia Group (AG) is an informal forum of countries which, through the harmonisation of export controls, seeks to ensure that exports do not contribute to the development of chemical or biological weapons. Coordination of national export control measures assists Australia Group participants to fulfill their obligations under the Chemical Weapons Convention and the Biological and Toxin Weapons Convention to the fullest extent possible."*

http://www.australiagroup.net/en/index.html

Australia Group

- *"The principal objective of Australia Group participants' is to use licensing measures to ensure that exports of certain chemicals, biological agents, and dual-use chemical and biological manufacturing facilities and equipment, do not contribute to the spread of CBW. The Group achieves this by harmonising participating countries' national export licensing measures. The Group's activities are especially important given that the international chemical and biotechnology industries are a target for proliferators as a source of materials for CBW programs."*
- Some of the controlled chemicals are not listed in the CWC.

http://www.australiagroup.net/en/objectives.html

Australia Group
43 Participants

- European Union (1985), Germany (1985), United States (1985), United Kingdom (1985), Italy (1985), Japan (1985), France (1985), Spain (1985), Sweden (1991), Poland (1994), Switzerland (1987), Netherlands (1985), Argentina (1993), Republic of Korea (1996), Australia (1985), Latvia (2004), Austria (1989), Lithuania (2004), Belgium (1985), Luxembourg (1985), Bulgaria (2001), Malta (2004), Canada (1985), Mexico (2013), Croatia (2007), New Zealand (1985), Republic of Cyprus (2000), Norway (1986), Czech Republic (1994), Denmark (1985), Portugal (1985), Estonia (2004), Romania (1995), Slovak Republic (1994), Finland (1991), Slovenia (2004), Greece (1985), Hungary (1993), Republic of Turkey (2000), Iceland (1993), Ukraine (2005), Ireland (1985), India (2018)

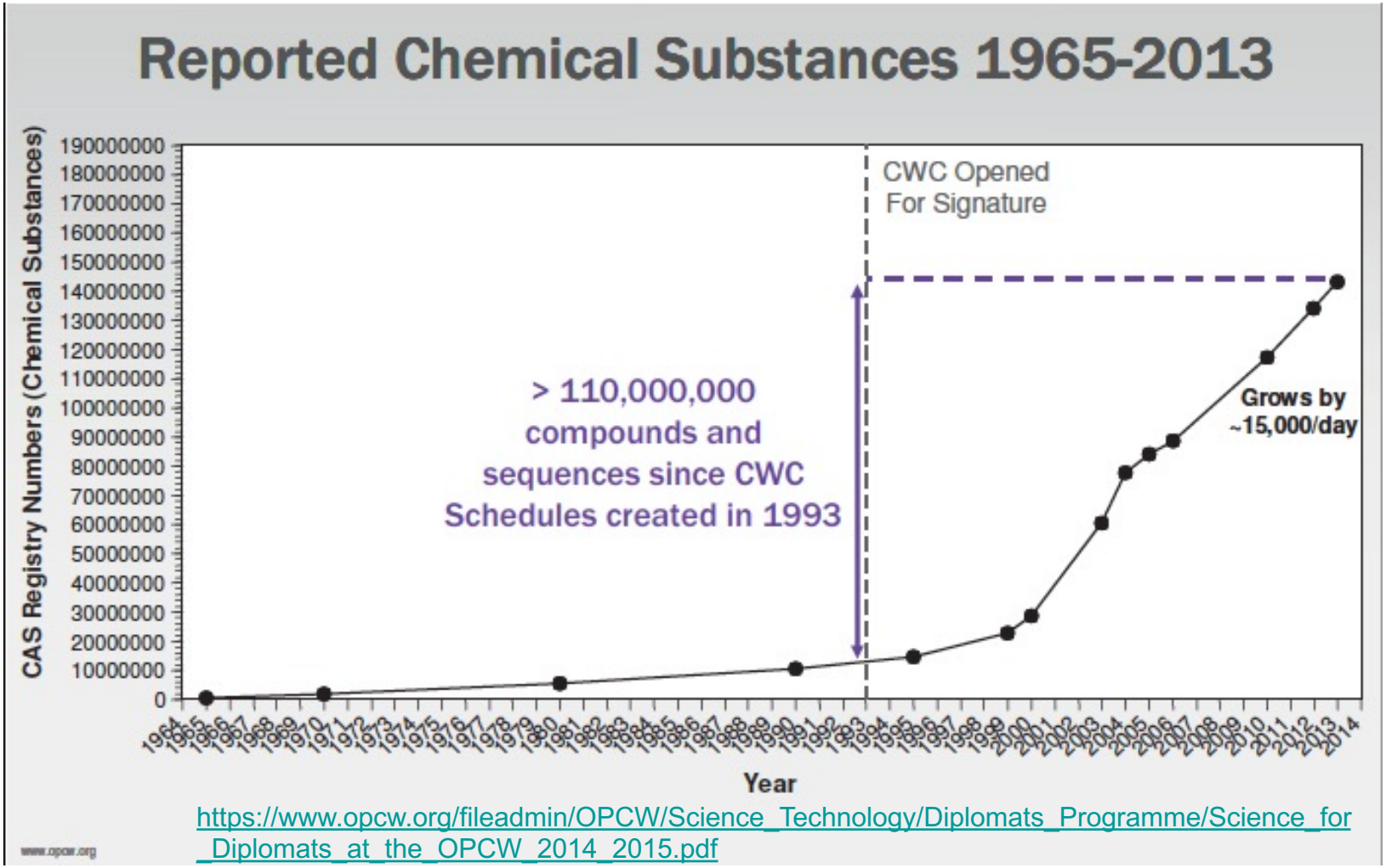
http://www.australiagroup.net/en/participants.html

Top 10 Chemical-Producing Countries

- In Australia Group:
  - 1. USA
  - 2. Germany
  - 5. Japan
  - 6. United Kingdom
  - 7. Italy
  - 8. France
  - 9. India
- Not in Australia Group:
  - 3. Russia
  - 4. China
  - 10. Brazil

http://www.australiagroup.net/en/participants.html

Many New Substances Created



https://www.opcw.org/fileadmin/OPCW/Science_Technology/Diplomats_Programme/Science_for_Diplomats_at_the_OPCW_2014_2015.pdf

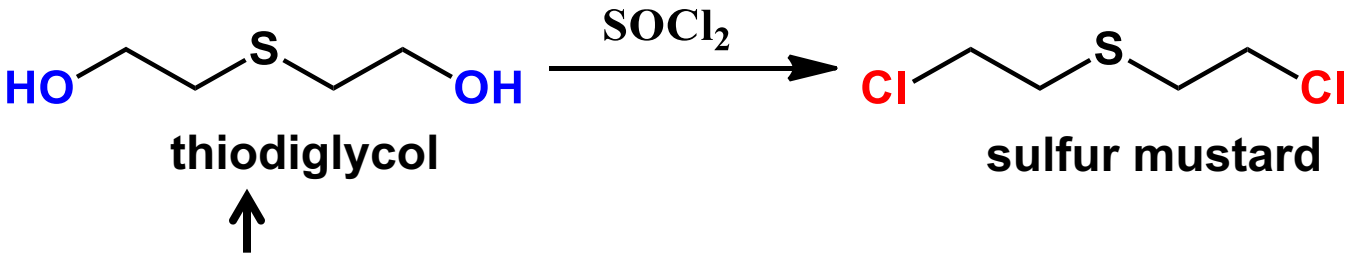
Ways to Circumvent Export Controls on Precursors

- Substitute uncontrolled chemical for controlled one.
- Purchase relatively small quantities from multiple sources
- Produce precursors from simpler, uncontrolled substances.
  - There are at least 9 ways to make sulfur mustard documented in the chemical literature, and some of these involve uncontrolled substances.

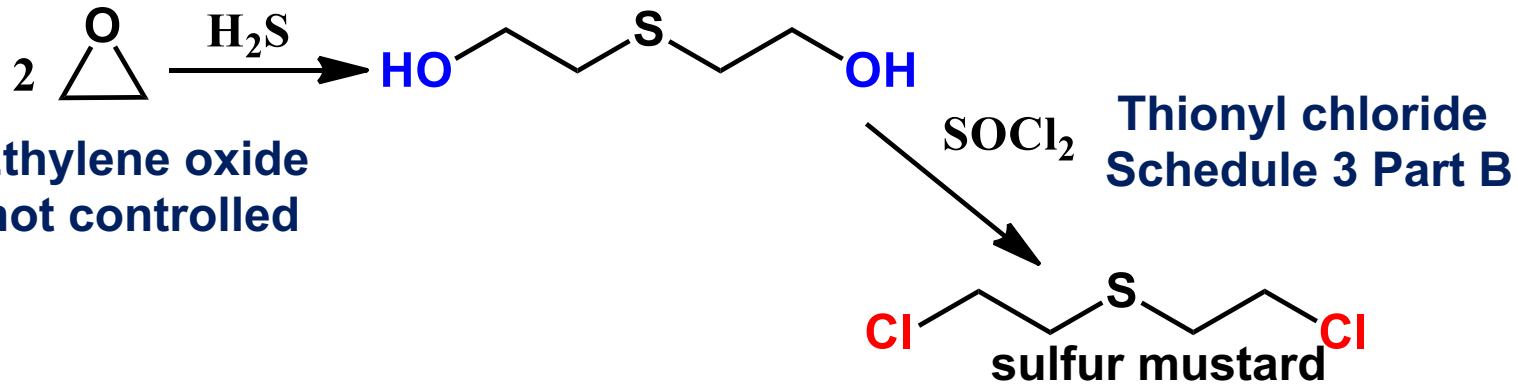
http://www.cwc2013.info/RG2013-by-doc/6/AG-precursors.pdf

Iraqi Mustard Program

Back-Integration = synthesizing precursor compounds from simpler ones that are not export controlled or are available from domestic sources

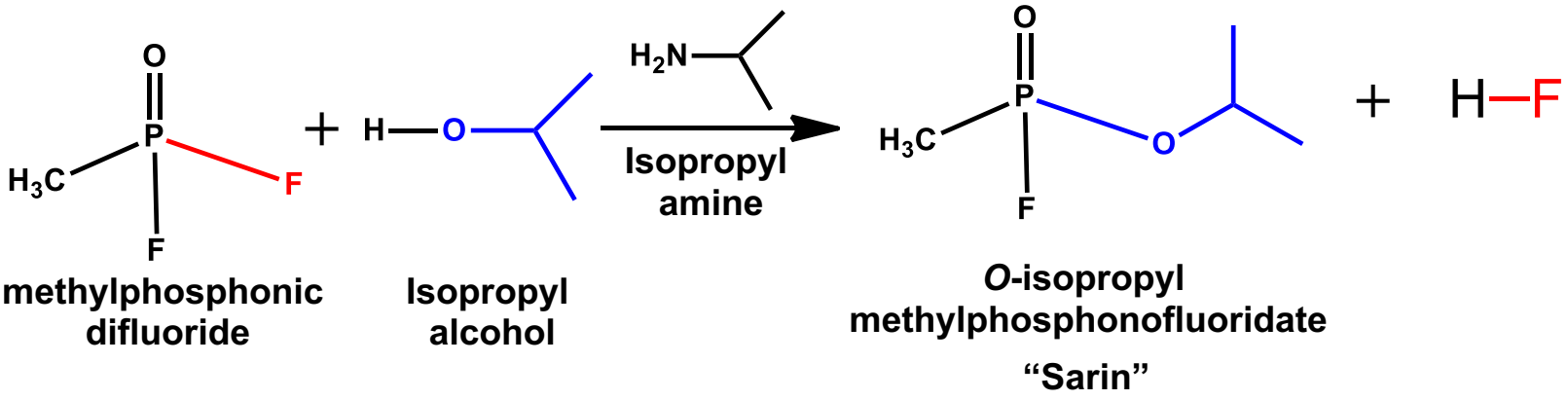


Embargo placed on this by Western Countries in early 80's



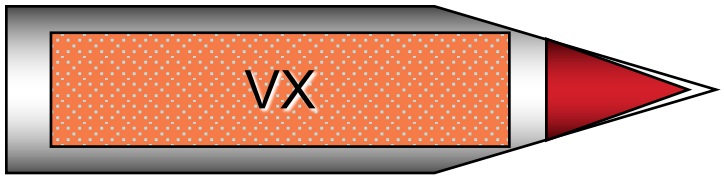
Binary Chemical Weapons

- In order to minimize the dangers associated with the handling and storage of a nerve agent, the last step in its production can take place after a projectile is launched.



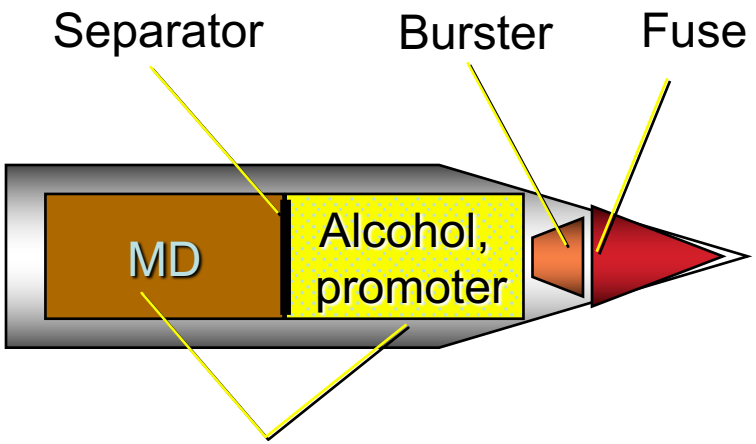
Common CW Munition Types

Unitary Munitions



- Easier to produce
- More dangerous to store, handle & transport

Binary Munitions (sarin)



Two non-lethal compounds

- Firing, spin flight & detonation mix compounds to form agent
- Relatively safer to handle & store
- Munition challenging to manufacture
- Methylphosphonyl difluoride + 72% isopropanol and 28% isopropylamine

Binary Munitions

- Reactants mixed immediately before firing or mixed in flight
- U.S. - three binary munitions
  - A 155 mm artillery shell to deliver sarin (liquid isopropyl alcohol and liquid methylphosphonic difluoride, DF)
  - BIGEYE spray bomb to deliver VX (solid sulfur and liquid precursor QL)
  - Warhead for Multiple Launch Rocket System (MLRS)