Frequently Asked Questions about Sarin (GB)

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Introduction:

Many people have asked me about chemical warfare agents, in particular the nerve agent "Sarin" also known as GB. This paper is an attempt to encapsulate many of these questions that I have been asked.

Notes:

1. Much of this material has been published on the Brown Moses Blog at http://brown-moses.blogspot.co.uk/
2. If something is not common knowledge, I've made efforts to reference the information to a scientific, academic, or government document. All references are by end-note.
3. This paper was revised on 9 September 2013 to add additional information.
4. US English spelling is used, so please don't complain about my lack of UK spelling.
5. I fixed a small error. GA/Tabun is more persistent than Sarin, not less.

Sarin

What is Sarin? Sarin, also commonly known by its old NATO nickname GB, is one of a family of toxic chemicals known as nerve agents. It was invented by German scientists in 1938-1939 who were performing research on organophosphorous pesticides led by Dr. Gerhard Schrader. Sarin was named by the team of researchers who invented it. Sarin is considered to be a "non-persistent" chemical warfare agent because it evaporates quickly.

What are the other nerve agents?

Other nerve agents that have been developed and were in various national arsenals include the following agents:

GA: Tabun
GD: Soman
GF: CycloSarin
VX (no common nickname)

A number of other related chemicals were investigated as well, but this is the list most commonly used. It should be noted that there are several variants and formulations of VX. It should be noted that nerve agents are chemically similar to many pesticides.

What's different about the other nerve agents?

There are many differences, but the general rule of thumb is that all of the other nerve agents are more persistent than GB/Sarin. Here is a brief summary of the principal differences:

GA: Slightly more persistent than Sarin. Least toxic of the nerve agents. Reputed to be most easy to manufacture.

GD: More persistent than Sarin. Easy to thicken. Most difficult to treat, due to various biochemical reasons.

GF: Rarely seen. More expensive and difficult to manufacture. It was used by Saddam Hussein's Iraq.

VX: Very thick, oily liquid. Evaporates very slowly. At cool temperatures primarily a contact hazard. Can contaminate terrain and equipment for weeks or months under correct conditions.

What form does Sarin take?

Sarin (also know as GB) is a liquid at normal temperatures.[1] It has the appearance and general consistency of water. The terms "Sarin gas" or "nerve gas" are misleading. It is not a gas at normal temperatures. (For example, methane is a gas at room temperature.) Sarin is liquid between the temperatures of -56º C and approximately +150º C[2], although it evaporates in proportion to the temperature.

Sarin has a viscosity (how thick the liquid is) slightly higher than water, although my own experience is that you can't tell with the naked eye.

Vapor pressure and volatility. Sarin has a vapor pressure. In other words, it has a tendency to evaporate into a vapor state from liquid state, just like many liquids. Water, alcohol, petrol, acetone, etc. all have vapor pressure. Sarin has a slightly lower vapor pressure than water (2.48 torr at 25º C) In practice, Sarin often evaporates quicker than water at normal temperatures This is because Sarin has a lower "latent heat of vaporization" (the amount of energy required to change from liquid state to vapor state)than water. I've seen a drop of water next to a drop of Sarin on the side of a rifle in a test chamber, and the Sarin will evaporate before the water will.

It should be noted that at high temperatures, Sarin evaporates very quickly. This makes it a "non-persistent" nerve agent. At room temperature or higher, terrain, clothing, equipment, etc. will not remain contaminated for long periods of time as any liquid droplets will evaporate. This is in contrast to so-called "persistent agents" (e.g. GD, VX) which have lower vapor pressures and evaporate much slower. However, Sarin vapors can be trapped in clothing.

Sarin vapor is heavier than air. It has a vapor density of 4.8 (air being 1.0), meaning that Sarin vapor is 4.8 times as dense as air. This means that it will seek low lying areas. Conversely, being upstairs or uphill can provide some degree of protection.

Can it be liquid, gas, powder, etc?

The best way to describe Sarin is that it is a liquid that gives off vapors. It

should be noted that many ways of dispensing Sarin (see weaponization below) cause the formation of an aerosol – a finely divided cloud of droplets. Aerosols behave much like gases and vapors. The phrase "Sarin Gas" is not terribly accurate. Things like methane, hydrogen, chlorine, and phosgene are gases at room temperature.

"Dusty agents"/ Powder[3]: There's no way that I know of to dispense Sarin as a solid or powder, although I can't completely rule out the possibility that someone has developed a "dusty agent" form of Sarin. There is some literature out there on the possibility of "dusty" chemical warfare agents. As far as I know, this was only ever a possibility with really low vapor pressure agents, not fast evaporating agents like Sarin. The only benefit I can think of for making a "dusty Sarin" (in reality, not Sarin as a powder, but small particles impregnated with Sarin) would be to slow down the evaporation time of the Sarin… i.e. increase its persistency. But doing so would decrease the rate at which the agent is dispensed in vapor form, thus reducing its immediate lethality somewhat. And immediate lethality is the point and purpose of Sarin. It would seem to have little utility and an awfully difficult way of engineering some persistency into Sarin. It would be far easier to use a more persistent nerve agent instead. Or it may be possible to thicken Sarin with an additive. The US government applied for a patent to do so in 1969. [4]

Does it have a particular smell or color?

It is colorless. Pure Sarin has no odor.[5] Even if it did have an odor, it would be difficult to tell as a concentration detectable by a human nose is probably a lethal exposure.

How do nerve agents like Sarin affect the human body?

All of the nerve agents affect the human body's nervous system. The human nervous system requires a delicate balance of chemicals to regulate itself. Nerve agents bind to a chemical known as acetylcholinesterase and, in doing so, disrupt the electrochemical reactions required for the body to operate properly. The binding of acetylcholinesterase leads to a build-up of acetylcholine, which then in turn leads to a syndrome called a "cholinergic crisis". In effect, the nervous system starts to over-act and muscles and glands start to work over-time.

What are the medical effects of Sarin or the other nerve agents?[6]

<u>Inhalation of vapor</u>

Rate of Action: Seconds to minutes after exposure

Mild: Miosis (pinpoint pupils), dimness of vision, headache, runny nose, salivation, tightness in chest

Serious: Mild symptoms, plus difficulty breathing, generalized muscle twitching, weakness, paralysis, convulsions, loss of bladder and bowel control

Liquid exposure to skin

Rate of Action: Minutes to hours after exposure

Mild/Moderate: Muscle twitching at site of exposure (fasciculations), sweating, nausea, vomiting, weakness

Serious: Mild symptoms, plus difficulty breathing, generalized muscle twitching, weakness, paralysis, convulsions, loss of bladder and bowel control.

It should be noted that miosis is often a late sign in situations where the victim is exposed only to liquid.

A useful acronym that I learned in training is **SLUDGE**:

Salivation
Lachrymation (tears)
Urination
Defecation
Gastrointestinal distress
Emesis (vomiting)

Remember that Sarin does evaporate quite quickly. In situations where people do not have respiratory protection, liquid exposure to skin will also likely lead very quickly to vapor exposure to the respiratory tract and eyes.

How is Sarin typically weaponized?

By "weaponized" we generally mean "how is this chemical put into a device or munition in order to function effectively on the battlefield. In order to answer this question we must apply the characteristics of the liquid Sarin to the battlefield environment. Because of its physical and toxicological characteristics, the most useful methods of employment for Sarin or any other non-persistent nerve agent are means and devices that rapidly disperse droplets or aerosols in a concentration high enough to cause immediate casualties. Dispersing a payload of Sarin in one load of liquid all in one place (like dumping a bucket) causes a great hazard in one spot, but not wide effects. A device that did this would be less useful than a conventional explosive device of similar size. Likewise, dividing it too finely over a large area will cause it to disperse quickly and not have a concentration adequate to cause incapacitation or death. Again, such a device would have little or no value in comparison to a conventional device of similar size, weight, or shape.

The overall guiding principle for weapon design with Sarin was that is was meant to rapidly cause casualties, and as such, weapons/munitions were designed to detonate/disperse at ground level. (This is different from persistent agents, which were designed to contaminate terrain and equipment, which generally burst/dispense/detonate some meters above

ground level in order to spread a radius of droplets.) During the Cold War, the various superpowers devoted a lot of time, expertise, and money to studying and testing various weapon designs to see how effective different munitions and configurations might be. Rather a lot of this information is now out in the public domain, either directly in form of declassified documents or indirectly, e.g. we can see the types of weapons that were the result of testing and optimization and draw our own conclusions as to what types of weapons work and which ones don't. Drawing on US and Soviet experience, the following are the classic weapons for dispensing Sarin on the battlefield, all fuzed to detonate at surface:

- Artillery shells
- Mortar shells
- Air dropped bombs
- Cluster bombs
- Missile warhead
- Rocket warhead
- Land mine

For purposes of comparison, the following chart shows some old US weapon systems (dating from the 1960s) that had Sarin as a filling.

Designation	Type	Approximate Sarin/GB content (kg)
M360	105mm artillery shell	0.8kg
M121	155mm artillery shell	3.0 kg
M426	8 inch / 203 mm artillery shell	7.2 kg
M55	115 mm rocket	5.0 kg
MC-1	Air-dropped bomb	99.8 kg
MK94	Air dropped bomb	49.9 kg

It should be noted that some types of weapons that aren't so good for Sarin:

- Hand grenade – Very small payload possible. Possibiity of leakage killing soldier handling it. Soldier likely to have to be in protective gear the whole time. Soldiers throwing grenades in protective gear are probably going to be less accurate and achieve less distance.

- Grenade launcher round – same liabilities as hand grenade. And very low payload.

- Aerial spray devices – Unless the helicopter or aircraft is almost at ground level (highly unlikely), the Sarin would be too dispersed to have much effect. Aerial spray devices are better for more viscous persistent agents (like Mustard or VX)

- Anything fuzed for aerial burst. Likely to spread the droplets too thinly for effect at ground level.

- Any explosive dissemination device with too little or much explosive. I won't specify what it is (for obvious reasons) but there is an optimum ratio of charge to agent. Too little leaves a puddle, too much spreads it too thin.

Some notes about types of "agent fills". An "agent fill" is a term that describes exactly how the chemical warfare agent is configured inside. There's three basic kinds of agent fills:

- Unitary: This means the agent is in the weapon in one big pool.

- Binary: Binary fills mean that two separate components are mixed to created the chemical agent. Generally, this is done for the purposes of safely handling the munitions and to avoid having to store chemical weapons or filled munitions. Sarin could be mixed on-site and poured into empty shells/rounds or munitions could be designed to mix two different components in flight. To my knowledge, this was done with GB and VX. A well-made binary weapon would have little or no difference from a unitary fill. A poorly made one would have a high dud rate and would be generally less effective. It is not easy to make an efficient binary weapon. One cannot simply rely on the shock of getting fired to adequately mix the components.

- Submuntions: A highly effective way of dissemination would be a munition that scattered bomblets or submunitions at some height, with the submunitions designed for ground impact detonation. Other factors being equal (…but they often aren't), submunitions are generally considered a more efficient method of dispensing Sarin.

A note about "dud rates." Any class of munition has a dud rate, i.e. the percentage of shells/rockets/etc. that fail to function as intended. Anecdotal evidence is that some older chemical weapons may have quite high dud rates. Even many modern conventional artillery rounds have non-trivial dud rates[7] there's no physical mechanism to explain why chemical rounds would have a radically lower dud rate. This means that if any significant use of chemical warfare happens, there's going to be an unexploded shell out there somewhere, which will be of great intelligence value if it can be safely retrieved. (A task not for amateurs!)

Have you ever heard of Sarin being used in a diluted form, or mixed with other chemical substances to make it less lethal?

There seems to be little point in trying to dilute Sarin to have some kind of non-lethal effect and I have no knowledge of this ever happening. The sub-acute, low-level signs and symptoms of nerve agent poisoning are annoying but not terribly debilitating. Giving a bunch of people a runny noses and pin-point pupils has far less tactical usefulness than using conventional riot control agents or the generally non-lethal vomiting agent adamsite. Such agents can easily cause debilitating effects, whereas with nerve agents,

there's a fine razor's edge, not easily (or at all) controllable between incapacitating dosage and lethal dosage. Why risk the opprobrium of the international community and the possibility of triggering international intervention by using just a wee bit of Sarin? There seems no point.

Sarin is designed to injure and kill. There's not much leeway between the incapacitating doses and lethal doses with Sarin (1000 mg and 1700 mg respectively as the ED_{50} and LD_{50}[8]) and the concentration that would lead to a person absorbing 1000mg Sarin would quickly lead to absorption of a lethal dose of 1700mg[9].

One scenario that could account for Sarin being used in dilute form is inadvertent. A poorly designed binary weapon would not adequately mix the components. Such a device would spread a cocktail consisting of some Sarin and a large quantity of various precursors, some of which are unpleasant materials themselves.

A number of reports have claimed to have proven the use of Sarin through tests on hair, clothing, blood, tissue, and urine samples.

I will address each of these types of samples in turn:

Blood:

Sarin can be directly and indirectly detected in blood samples. Several methods have been studied for detection of Sarin in blood. Several studies have been described in the academic literature.[10] The general consensus is that Sarin hydrolyzes (reacts with water) too quickly to be present in its normal form in blood or blood plasma. There are also indirect methods that detect decomposition products of Sarin or the physiological effects of Sarin.

Experience from the Tokyo subway incident in 1995, documented by the OPCW[11] shows that one of the decomposition products of Sarin is a chemical known as isopropyl methyphosphonic acid (IMPA)is detectable in blood.

Sarin's method of action is to inhibit a substance called acetylcholinesterase, which is used by the human nervous system. At least one study shows that the presence of a nerve agent could be deduced by examining post-mortem blood samples for presence or lack of acetylcholinesterase, up to a week after death.[12] A person who has died from Sarin exposure would have little or no acetylcholinesterase present. It should be noted that this would only indicate the presence of a nerve agent and would not specifically indicate Sarin versus any other nerve agent (or even organophosphate pesticide intoxication) nor would it conclusively indicate nerve agent as a cause of death, as other factors may have killed the victim, such as conventional trauma.

Urine

One of the decomposition products of Sarin in the human body is methylphosphonic acid. A study shows that this substance is detectable in

urine by use of mass spectrometry[13]. This particular substance is not specific to Sarin. (The journal article says it is a decomposition product of cyclosarin, Soman and one type of VX as well.) It should be noted that it can take some time for chemicals absorbed in the human body to end up in urine. An immediate post-exposure sample may not have any evidence of exposure.

Tissue

A study from 2004[14] using guinea pigs indicates that plasma, heart, liver, kidney, and lung samples can indicate the presence of either Sarin or Soman using gas chromatography and mass spectrometry.

Clothing, Skin, or Hair:

Clothing, skin, or hair could get contaminated by droplets of Sarin. I cannot find any literature on the absorption of Sarin into human hair, but common sense would dictate that any water-like liquid could be trapped in hair. Because of the rapid speed at which Sarin evaporates, a sample would need to be collected quickly and kept in a sealed container. A lowered temperature would help. In such a case, the Sarin might actually be most easily identified in vapor form in the headspace of the container, having desorbed from the sample itself.

How would these samples be tested for the presence of Sarin?

First of all, my expertise is not very strong in the laboratory techniques used for such analysis. My expertise is strongest in field detection techniques. To the best of my knowledge, the generally accepted gold-standard analytical technique is the combination of gas chromatography and mass spectrometry (GC/MS) which is widely used by chemists to identify molecules. GC/MS is a sophisticated technique requiring training and expensive equipment mostly found in labs. There are some portable GC/MS devices, but they are generally used in vehicles or mobile labs and aren't handheld devices.

The following are field technologies which also have relevance in laboratory settings, given the appropriate equipment. All have pros and cons.

- FTIR: Fourier transform infrared – Used to analyze a gas, vapor, liquid, or solid sample. Not real time. An identifier, not a surveillance or detection tool.

- Raman: Laser-based identification technique that can identify liquids or solids. Not real time. An identifier, not a surveillance or detection tool.

- Ion Mobility Spectrometry (IMS): Fast acting analysis of gas and vapor. IMS is the backbone of military field electronic nerve agent detectors. Works very quickly and is very sensitive. Some problems with false positives, varying from model to model. Some units will only

detect, others will identify as well (i.e. discriminate VX from Sarin), while others provide a qualitative ("Hi, Med, Low") or quantitative ("25 mg/m^3") measurement.

- Flame ionization: Used by a family of French chemical warfare detectors. Broadly similar to IMS in application.

- Photoionization: Commonly used in civilian HAZMAT detectors. Generically detects toxic gases, but cannot identify chemicals. Would not be able to tell difference between, say, ammonia, acetone, and Sarin. I only mention this because it is so prevalent in civilian fire departments.

- Wet chemistry: A variety of manual chemistry techniques ranging from very sophisticated to very simple. Too many different kits and tools to generalize, other than to state that the cheap tools are easy to use but not very specific, whereas the expensive tools can be good but hard to use. There are some specific nerve agent detection techniques in this category, but they generally have difficulty discriminating between types of nerve agent.

If Sarin was detected in hair and urine wouldn't that suggest small, non-lethal quantities, being ingested over a period of time?

Sarin detected in hair might theoretically be a small droplet that was in the hair as a direct result of a Sarin attack. However, the sample would have to have been collected quickly and sealed up. (See above) I don't know of a biological mechanism that would result in Sarin or byproducts ending up inside human hair through hair growth. I checked the literature and found nothing in this regard.

As far as urine is concerned, I can't find direct literature in my cursory search about how quickly Sarin or decomposition products end up in urine. However, Sarin acts on the bladder and kidneys rather quickly, so this cannot be ruled out. One Japanese Sarin victim of the lesser-publicized Matsumoto incident (previous to the infamous Tokyo incident) had measurable Sarin decomposition products in his urine.[15]

If Sarin was on clothing how hazardous would it be to handle that clothing without correct protection?

Very hazardous. Depending on the amount of contamination, possibly lethal. Full head-to-toe protection would be needed. The fastest acting hazard would be vapor from the clothing.

Is it possible other substances could produce false positives for Sarin?

Yes. Generally, the more sophisticated and expensive the detection technique, the less scope for false positives. The false positives depend

entirely on the detection method. IMS is often fooled by chemicals of the same molecular weight as Sarin. Organophosphate-based pesticides are very similar chemicals to nerve agent chemical weapons, so they may pose a false positive.

After a suspected Sarin attack how should the victims be processed, and what precautions should be taken?

An effort should be made to triage the victims and deal with the most severely affected ones first. Triage and treatment guidelines are available in various resources.[16] The general acronym **ABCDD** can be used to describe the field medical interventions required for nerve agent exposure. This stands for Airway, Breathing, Circulation, Drugs, and Decontamination.

A general broad guideline for dealing with a serious Sarin casualty is as follows:

- Move casualty out of danger. If possible remove contaminated clothing
- Establish and maintain airway, through intubation if necessary
- Control secretions through suction
- Ventilate with oxygen if available, using bag-valve mask if necessary. Regular air is better than nothing if oxygen is not available.
- Monitor pulse, commence compressions if pulse stops
- Administer atropine, pralidoxmine (or other oxime, in accordance with local protocols), and diazepam via intramuscular injection.
- Decontaminate any possible skin exposure. Soap and water are fine, if specialty decontaminants are not available. Even plain water will work in a pinch. Flush eyes with water. Take care to not come into contact with any contaminated water after decontamination.
- Establish IV access to allow further antidote administration. Administer atropine until excess secretions stop. Do not attempt to use miosis as an indicator of effective atropine dose.
- Administer additional antidotes as required
- Move to definitive care
- Constantly reassess airway, breathing, and circulation en route.

If these precautions are not taken what is likely to happen to the people coming in contact with the victims?

If the victim was only exposed to Sarin in vapor form, which is quite possible, then there's sometimes no particular hazard. Vapor can be trapped in clothing for a short period after an acute exposure, however. If a victim has been exposed to droplets or liquid, then persons coming into contact with the victim are likely to be affected if they are unprotected. Due to the rapid rate at which Sarin evaporates, the principle hazard will be respiratory hazard, although contact hazard risk cannot be eliminated. Droplets on skin, hair, and clothing are likely to evaporate and pose a respiratory hazard both to the victim and bystanders/helpers.

How long would it take Sarin to become harmless, or dissipate? In general terms are we talking minutes, hours, weeks?

Minutes to hours, depending on wind and air temperature and the volume of liquid Sarin. Sarin liquid evaporates quickly. Vapor will disperse quickly in the open, but could last a very long time in a combined space.

About the author: Dan Kaszeta is the author of "CBRN and Hazmat Incidents at Major Public Events: Planning and Response" (Wiley, 2012) as well as a number of magazine articles and conference papers. He has 22 years of experience in CBRN, having served as an officer in the US Army Chemical Corps, as CBRN advisor for the White House Military Office, and as a specialist in the US Secret Service. He now runs Strongpoint Security, a London-based CBRN and antiterrorism consultancy and is also a Senior Research Fellow with the International Institute of Nonproliferation Studies.

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[1] All physical values taken from US Army Field Manual 3-11.9, Potential Military Chemical/Biological Agents and Compounds. US Government, January 2005, pp II-18 to II-20.
[2] Some authorities state 158º C as the boiling point.
[3] A good discussion of "dusty agents" is at http://www.nti.org/analysis/articles/dusty-agents-iraqi-chemical-weapons/
[4] The United States of America as represented by the Secretary of the Army (Washington, DC), application no. 855078, September 2, 1969
[5] Welchman, R.M.A., *Preliminary Report on the Potential Value of Nerve Gases as C.W. Agents*, Porton Report No. 2747 (PR 2747), Chemical Defence Experimental Establishment, Porton, England, January 1947, UNCLASSIFIED Report.
[6] *Field Management of Chemical Casualties Handbook*, US Army Medical Research Institute for Chemical Defense. See also: http://www.ecbc.army.mil/downloads/mirp/ECBC_firefighter_quick_ref_01.pdf
[7] See http://www.landmineaction.org/resources/Cluster_Bombs.pdf for an exhaustive discussion of failure rates of cluster munitions.
[8] FM 3-11.9, op cit. p II-20
[9] It should be noted that all toxicology figures for Sarin are approximate and based on animal studies, some of which occurred far in the past with poorer methods and instrumentation than today.
[10] One example of many is Vandine R, Babu UM, Condon P, Mendez A, Sambursky R. A 10-minute point of care assay for detection of blood protein adducts resulting from low level exposure to organophosphate nerve agents. Chemical and Biological Interactions, 25 March 2013.
[11] See http://www.opcw.org/news/article/the-Sarin-gas-attack-in-japan-and-the-related-forensic-investigation/ for a discussion of forensics after the 1995 Tokyo incident.
[12] Klette KL, Levine B, Dreka C, Smith ML, Goldberger BA. Cholinesterase activity in postmortem blood as a screening test for organophosphate/chemical weapon exposure. Journal of Forensic Science, July 1993.
[13] Zydel F, Smith JR, Pagnotti VS, Lawrence RJ, McEwen CN, Capacio BR. Rapid screening of chemical warfare nerve agent metabolites in urine by atmospheric solids analysis probe mass spectroscopy. Drug Testing and Analysis. Mar-Apr 2012.
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[15] Nakajima, T. et al. Urinary metabolites of Sarin in a patient of the Matsumoto Sarin incident. Archives of Toxicology. September 1998.
[16] United States Army Medical Research Institute of Chemical Defense. Medical Management of Chemical Casualties Handbook, 4th ed. Edgewood (MD): United States government 2007.