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Why are Nerve Agents so Difficult to Make?

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Nerve agents, both in the form of Sarin in Syria and in the form of the so-called Novichok A-234 in the UK, continue to claim both victims and headlines. A recurring theme, aired early on in the Syrian chemical war, and oft-repeated, is that somehow nerve agents are easy to make. Many conspiracy theories and “alternative narratives” rely on the fact that someone other than the Syrian or Russian state made the nerve

agents in question. These theories, in turn, need Sarin or Novichoks to be easy to manufacture in order for there to be a remote chance of their being true.

None of the chemical warfare agents in the nerve agent category are easy to manufacture, and none of them lend themselves to a small improvised process. The idea that there is such a thing as “kitchen Sarin” is laughable to those of us familiar with how Sarin has actually been made in the real world. Manufacturing Sarin or other nerve agents is difficult for many reasons. It is not merely a matter of chemistry. It is also a matter of chemical engineering and management.

For the majority of this article, I use the example of Sarin. I do this because, for better or for worse, the Sarin production processes are those which are the most documented in the public domain. A handful of the nerve agents are easier to make than Sarin, although they tend to be ones that are less deadly and less useful as weapons. Most of the nerve agents are more difficult than Sarin. One that is easier than Sarin is Tabun, the original German nerve agent first manufactured in the late 1930s. Making Sarin is not the logical entry point into nerve agent manufacture. Manufacture of Tabun is somewhat easier. This point is relevant when investigating claims of improvised manufacture of Sarin or Novichoks – the question of “why didn’t he/they make Tabun?” is a useful exercise. VX is a bit easier than Sarin, so there’s always that question as well.

Ingredients

You do not just run down to the shop to get what you need to make Sarin or other nerve agents. The majority of the precursors are either not commercially made at all or are “scheduled” substances that are controlled by arms control treaties, particularly the Chemical Weapons Convention and relevant laws.

As an example, let us look at Sarin. There’s only two ways to make a Sarin moleucle. One is by reacting the critical precursor methylphosphonyl difluoride (DF) with isopropyl alcohol. This yields a mix of Sarin and hydrogen fluoride (HF), a potent acid. The other way is by the so-called “di di” reaction, which reacts equal amounts of DF and methylphosphonyl dichloride (DC), which yields Sarin and hydrogen chloride (HCl), also a powerful acid. DC is the direct precursor to DF. You need to have DC to make DF. It is difficult to obtain DC in any useful quantity without raising alarms. One must usually undertake to manufacture DC. There are number of production pathways to get to DC, but all of them require sourcing ingredients. Given the likely wastage and yields, it is difficult to envisage a Sarin production scheme that uses less than 9 kg of input ingredients for every kg of Sarin produced. If you compile the various chemical inputs needed for Sarin, or any of the other nerve agents, it comprises a list of substances, only a handful of which can be readily procured. The rest have to be made as part of an overall production process.

Process

A key mistake made by amateurs is thinking that, somehow, an ingredient list is the same thing as an industrial process. Nobody would consider a list of culinary ingredients as the same thing as a recipe. The next most common mistake is thinking that a list of basic steps or a notional block diagram is an adequate description of the chemical engineering needed. Many of the processes required are simple in their application of chemistry but extremely difficult to execute in any type of quantity or

quality in terms of chemical engineering. Some of them need to be done remotely and/or under an inert atmosphere in order to be done effectively. Other processes involve the handling of corrosive, toxic, and/or flammable ingredients. Some, like “DF”, are in themselves mild nerve agents. Most of the processes and procedures do not like gratuitous contact with air or moisture. Again, there is the example of DF, one of the Sarin precursors. It is highly reactive with water. Many precursors are solids and need to be turned to liquid for reactions. A high percentage of the intermediate steps produce heat, which are likely to need cooling.

The G-series of nerve agents (the family originally developed by the Germans, which includes Tabun, Sarin, and Soman) require handling of extremely dangerous substances under precise combinations of high temperature and pressure. For Sarin and Soman, this includes handling HF, which is extremely dangerous. Another example from the manufacture of G-agents is the problematic alkylation step. This particular process adds a methyl group or an ethyl group to the central phosphorous to form a P-C bond. This is necessary to create the nerve agents, but this is a rarely used step elsewhere in industry. Historically, there was much difficulty in getting this step right, and that knowledge base is either lost to history. Much of it remains classified. Most of the practical knowledge of technique and process is lost to us. This is because much of this knowledge was in the heads of people now dead. Some of it was in notebooks that are largely destroyed or permanently sequestered in classified archives.

Trial and Error

It should be noted that every single manufacturing process for nerve agents has been the subject of significant trial and error. In some cases, the trial and error took years and took a toll on personnel and expensive equipment. As a benchmark for comparison, it took 7 years for the US to get viable large scale production facilities for making Sarin up and running after the Second World War. The war in Europe ended in May 1945. The US and UK had the scientists who invented Sarin, samples, and significant documentation. There’s a series of documents called the British Intelligence Operations Sub-Committee reports, which report the systematic debriefing of the German nerve agent scientists. It is clear from reading these documents that the West quite quickly understood the science. They just did not understand the engineering to put it into operation. The US military threw many millions of dollars and many hundreds, if not thousands, of personnel at the problem of Sarin production. Yet the first actual large scale production run of Sarin did not begin until July 1952. This first batch took 13 months to get right. They did not start the second batch until 1954. As another example, the Japanese cult Aum Shinrikyo, whose manufacturing effort was very large, had to make a number of attempts to make Sarin. Their first effort only yielded 20 grams of Sarin. It took them another year before they could make enough for their Matsumoto attack.

The idea that some people somewhere in a shed will get it right on the first try is risible.

Purity of the inputs

The various odd discussion groups online, and the half-dozen or so strange books that purport to contain nerve agent processes, rarely if ever measure cleanliness and purity. They usually blithely assume that each step of the process starts with pure laboratory grade materials. Such sources do not account for purifying the base

ingredients or the intermediate products. If you are going to make nerve agents in an efficient manner, the ingredients used need to be pure. Various impurities and contaminants, even such commonplace ones as moisture, will throw off a production step, reduce the purity of the product being made for the next step, contaminate the batch with by-products, cause an unsafe reaction to occur, or possibly ruin the whole batch and make the whole process more difficult. If you just go from Step 1 to Step 7, your impurities from the previous steps just build up along the way and you may end up with useless soup, not a batch of Sarin. It is not a Step 1, Step 2… process. It is a Step 1, purify the results of step 1, check the purity of step 1, then Step 2, purify, check, etc. All the way along the line. If you don't, some of the steps will get very interesting very quickly in some of the usual processes. Indeed, if corners are cut and base ingredients are bought that are less than pure, some work needs to be done prior to the early steps. For example, isopropyl alcohol, needed for Sarin, commonly has other alcohols in it, such as 1-propanol or butanol.

Purity of the outputs

Regardless of the agent produced, very few processes and pathways yield a relatively pure agent. There are byproducts, even when the purest ingredients are used. For example, the purest possible inputs to make Sarin do not get you a pure output. For every molecule of Sarin you make, you get a molecule of acid. It's inevitable and cannot be helped. The process also yields an inevitable impurity called DIMP. Even the best high-quality US Sarin had significant amounts of DIMP that had to be removed. The Tokyo Sarin was riddled with the stuff, as well as another byproduct, DFP.

With residual acids, such as the HF or HCl that is inevitably in Sarin, these acids must be removed if you want the final product to have any kind of shelf life at all. Some sort of acid removal strategy is critical for a variety of reasons. Residual acids will degrade the nerve agents very quickly, and will wreak havoc on any kind of storage vessel or chemical munition. Historically, both physical and chemical means have been tried. Distillation is one approach, but it proved highly problematic with residual HF. Removing residual HF was so difficult in the US Sarin programme that they decided not to do it, and re-engineered the whole process, ending up with the "di di" process mentioned above. This process ended up with residual HCl instead. The HCl could be removed by a very lengthy and expensive distillation process. The USSR appears to have used a similar approach, if old East German military chemistry texts can be believed. Even so, many lots of the Sarin had to be repeatedly re-distilled in order to purify it. The difficulty of this step should not be underestimated. Saddam's Iraq could not be bothered and made Sarin with very short shelf life.

The other approach is to add chemicals to absorb the residual acids. This requires different infrastructure than distillation and has proven more affordable for some producers. Chemicals from the amine family have a long history as nerve agent additives, particular as acid scavengers. (Full essay here.) The Assad regime in Syria makes Sarin with residual HF. This is dealt with by addition of the chemical hexamine. A single molecule of hexamine can attach to up to four molecules of HF. This particular method, no doubt, took a fair bit of experimentation to work out. These processes are exothermic, creating much heat, so this must be taken into account for most applications and planned for in the development of processes and procurement of equipment. An interesting point to be made here is that additives, residual impurities, and byproducts give a lot of clues to how a nerve agent was made. These can serve to match a producer to an incident. The exact mix can serve as a chemical fingerprint.

Equipment

All of the above-referenced issues mean that specialty equipment is required. Although much of the equipment needed is commercially available, there is a bit of a chicken-and-egg issue at work. Until you work out for yourself which process is needed, you won't know which equipment you will need. But you will need equipment to get started. Different equipment, configurations, and settings will need to be tried out. Various important bits of kit may be damaged or destroyed. Because of the dangerous nature of many of the chemicals used in the various processes, the operational lifespan of many components may be short. The Nazis used slave labour to repeatedly change valves and pipes in their Tabun factory.

The equipment for handling and controlling high pressure high temperature corrosive gases is highly specialized and expensive. The original Tabun factory in Nazi Germany used pipes made from silver. In addition, not every item needed is commercially available. Various pieces, parts, and vessels will have to be specially fabricated. None of this is particularly advanced or difficult, but serves to greatly increase the overall logistical footprint, time, labour, and expense of the project.

Furthermore, the above-mentioned purity requirements will require a fair bit of analytical instrumentation to test the characteristics of the various inputs and outputs. It's all well and good to have a process to purify a substance, but it's not likely you can tell just by looking. So analytical methods and instrumentation will be needed to tell how clean a particular part of a manufacturing process is. Likewise, how do you know if your end product is actually what it is meant to be? The nerve agents are largely undistinguished in their appearance.

Quantity, Size, and Space

Once you start adding up the weight and volume of the various pieces and parts you need to make a nerve agent, it quickly becomes apparent that a process for all but the smallest quantities needs more than a garden shed full of kit. The Aum Shinkrikyo facility was called Satyan 7 and was not small. It was a substantial facility and it never operated in a way to mass produce Sarin. Even with the Aum cult's significant effort, their ability to produce Sarin was limited to batches that never exceeded 20 kg in size. This was due to a variety of engineering and management issues. 20kg may sound like a lot of Sarin but it wasn't, and resulted in only a small number of dead victims. (A full description of the Aum effort is here.) Military attacks with nerve agents are likely to take tens or hundreds of kilograms of agent. My own calculations show that perhaps a ton of chemical agent was used in the August 2013 attack in Ghouta, Syria.

Handling and storage of materials is an issue. With Sarin, the most economical pathway takes something like 8 or 9 kg of various inputs to end up with 1 kg of Sarin at the end of the process. The ratios are not exactly economical with other nerve agents. Also, there is this thing called conservation of mass. If you make 1 kg of Sarin starting from 9 kg of inputs, the other 8 kg does not disappear. You still have to deal with it in the form of waste. All of this waste material needs to be dealt with and some of it is extremely nasty. Some of it is in the form of highly dangerous gases and vapours that somehow must be vented somewhere. The large volumes of waste are one way to find a chemical weapons manufacturing site.

Cost

None of this is free. Very little of this is low-cost. In 1995, the Canadian government admitted that its costs for laboratory-grade ingredients for the small quantities of Sarin they produced for testing and evaluation were between 100 and 500 Canadian dollars per gram of Sarin produced. That is just for ingredients and does not account for facilities, equipment, or labour. The Aum cult spent many millions of dollars to make its relatively small amounts of Sarin. There's very much a question of cost efficiency when it comes to nerve agents. Given the cost, time, and difficulty, is it really worth it? Surely other forms of killing are far more economical.

Safety

Finally, a bit of a note about safety. People died while developing the manufacturing processes for nerve agents. Some of them were well-equipped and well-trained scientists or engineers. All of the nerve agents are unsafe to handle, and particularly so by under-trained ill-equipped people. Many of the possible stages or processes are highly dangerous and are best done remotely. Some steps pose fire or explosion hazards. Small mistakes can be fatal or causing destruction of facilities. Protective clothing and respirators that will protect you from nerve agent exposure are not adequate for protection from many of the other industrial hazards. Exhaust will need to be specially scrubbed, lest the authorities take notice of birds falling out of the sky or similar phenomena. Expensive specialty glove boxes will be needed. Filters will need to be exchanged and somehow disposed of. The safety processes, even for someone with a cavalier attitude, will not be trivial.

Conclusion

The development and manufacture of nerve agents, particular in any kind of "useful" quantity, is a difficult and nasty undertaking. It is not cheap or easy or fast.

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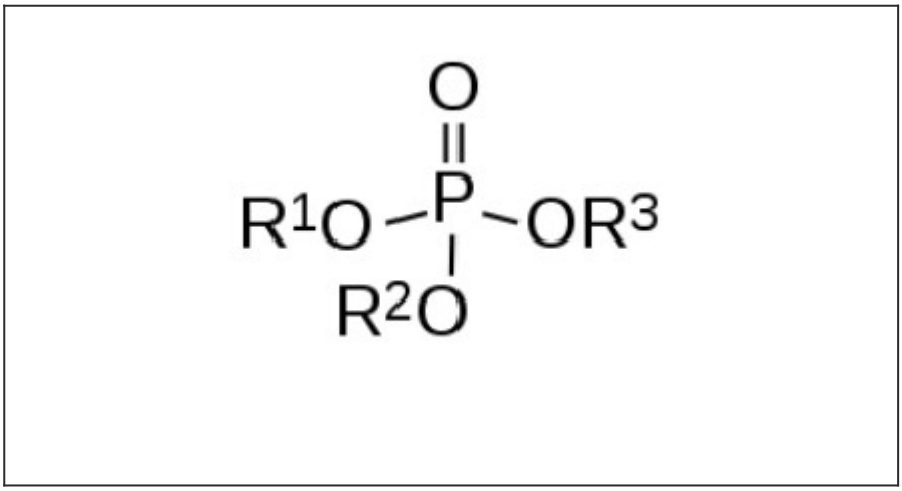

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