The Science of Destruction: Terrorism and Technology in the Nineteenth Century
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"Today, the importance of explosives as an instrument for carrying out revolutions oriented to social justice is obvious. Anyone can see that these materials will be the decisive factor in the next period of world history. It therefore makes sense for revolutionaries in all countries to acquire explosives and to learn the skills needed to use them in real situations."[1] The radical socialist publisher Johann Most, writing in his *Science of Revolutionary Warfare* in 1885, called his comrades' attention to a wide range of explosive technologies developed by chemists working for the state and military in recent decades. The full title of his book, published after Most emigrated from Europe to the USA in 1882, listed some of these compositions, including "Nitroglycerine, Dynamite, Gun-Cotton, Fulminating Mercury, Bombs, [and] Fuses", not to mention the more traditional knives, pistols, rifles, and poisons. Clockwork mechanisms were also used to explode 'infernal machines' of various kinds. He insisted, however, that the book was not what today would be called an 'anarchist cookbook'. In his introduction, Most claimed that although many people had tried to produce these explosives in clandestine workshops, few had succeeded. Revolutionaries would be much better off using ready-made combustibles. "Imperial, royal and republican (government) arsenals have had to do the providing… [and] it would be stupid to consider amateur dynamite production."[2] The legitimate enterprises of the state should thus be the main provider of explosive weapons, but "for the sake of completeness" Most proposed to describe the methods of making explosives in addition to his principal concern, how to use them.[3] To understand the material culture of terrorism in the nineteenth century, then, we must consider the improvised bombs and explosives of anarchists, rebels, revolutionaries, and radicals as part of a broader history of the development of new explosives by state, industrial, and university scientists. The first part of this essay will provide a survey of this broader history of explosives science and technology.

Johann Most supposed revolutionaries should depend on new technologies developed by legitimate enterprises. Often the historiography of terrorism has followed the same argument. A recent study of technology and terrorism proposes, "The terrorist, by and large, is more imitative and habitual than technically imaginative."[4] It is often said that terrorist activities in the nineteenth century were transformed by the invention of dynamite and the application of science to the creation of novel explosives.[5] After Alfred Nobel succeeded in making nitro-glycerin relatively safe to handle in the form of dynamite, it was only a matter of time before illicit bomb-makers deployed the handy new explosive to serve their political causes. But while it is undoubtedly true that many anarchists, radicals, and revolutionaries exploited scientific innovations in explosives in the nineteenth century, it would be an exaggeration to see the case of dynamite as representative, or to assume that terrorists lacked ingenuity. The second part of this essay will suggest that the history of the development of new explosives and terror techniques in the nineteenth century entailed innovation by and traffic between both the state and its revolutionary enemies. This argument is illustrated by the career of incendiary rockets as devices of terror for both the state and its opponents in the early nineteenth century. Both the state and revolutionaries innovated, did so using scientific and technical expertise, and then copied each others' techniques. While revolutionary warfare relied on the technical innovations of the state, the state also learned from revolutionaries.

A third section sets the style of terrorist science within broader currents in nineteenth-century scientific culture and considers the 'modernity' of the terrorist use of scientific practices to produce bombs. Again, it is often assumed that one difference between legitimate and illegitimate bomb-making in the nineteenth century is that official science took place in well-organized, well-funded laboratories while terrorists operated in clandestine, make-shift kitchens and sheds. Scientists operated with dedicated instruments, tools, and methods, while anarchists and revolutionaries 'made do' adapting everyday materials and objects to terrorist uses. This is a fair picture but it ignores two key points. First, both the professional status of science and its use of dedicated and specialized instruments emerged gradually over the nineteenth century, and arose partly as a way to distinguish certain classes of science as legitimate and authoritative. Second, insofar as they championed science and technological innovation, radicals and revolutionaries participated in a much broader public enthusiasm for science, brought about in part by growing efforts to popularize science through new venues and publications. To this extent, radicals were not revolutionary in their attitudes to science but embraced the status quo as it was promoted by scientists of the time.

1. Science and the Development of Explosives in the Nineteenth Century

David Edgerton has argued in *The Shock of the Old* that histories of technology are all too often focused on the innovation period in the career of a technology, ignoring the long-term use of technologies and processes of maintaining and repairing them.[6] Histories of terrorism have typically followed this approach, and while I shall recount the origins of a number of terrorist technologies here, it should be kept in mind that while new technologies were being invented – dynamite most obviously – the old remained a significant element in terrorist attacks. The knife, for example, was used throughout the nineteenth century, and being simple, easy to obtain and use, it remained an effective and efficient tool in the hands of assassins and anarchists. Indeed, the first tool of terror was a blade – the guillotine devised by Joseph-Ignace Guillotin in the autumn of 1789 and used throughout the Reign of Terror during the French Revolution.[7]

With this caveat in mind, we may now turn to the history of explosives in the nineteenth century, which constituted certainly the most dramatic and memorable weapon in the terrorist arsenal if not the most effective. Until the mid-nineteenth century, all explosives were made using black powder, or gunpowder, consisting of saltpetre, sulphur, and charcoal. The process of making gunpowder and bombs did not involve scientists (or 'natural philosophers' as they were known prior to the mid-nineteenth century). Expert artisans made gunpowder and state artillery officers and laborers used it to produce shells, bombs, and pyrotechnics. Gunpowder was also used for blasting rock and coal in mines and engineering projects.[8]

Scientific involvement with bomb-making and pyrotechnics began in the late eighteenth century through the work of French chemist Antoine Lavoisier, appointed to reform the Paris Gunpowder Administration (*Régie des poudres*) in 1775. In England, Lavoisier's counterpart General William Congreve employed London chemists to assist him in similar reforms.[9] Both men sought to improve, via experimental investigations, the manufacture and efficiency of gunpowder. Lavoisier increased saltpetre production, devised tests for the quality of black powder, and rationalized the administration of production. Congreve nationalized the gunpowder industry and also introduced quality tests and experimental trials to the manufacturing process.

The potential to increase radically the explosive strength of gunpowder grew in this period, partly through Lavoisier's investigations and particularly after another French chemist, Lavoisier's colleague Claude Louis Berthollet, discovered potassium chlorate, or what he called 'superoxygenated potassium muriate', in 1786. Gunpowder explodes independently of the oxygen in the atmosphere, because one of its ingredients, saltpetre or potassium nitrate (KNO_3), supplies the oxygen needed for combustion. When this takes place, gases are released at a tremendous speed producing an explosion. Potassium chlorate could also serve this role of oxidizer, and Berthollet found that it provided a more violent explosion than saltpetre. He proposed using it to manufacture gunpowder in 1788, but when Berthollet and Lavoisier began experiments at the gunpowder factory of Essonne in October that year, a devastating explosion led to two deaths. Lavoisier was determined to continue the experiments, however, refusing to ask if "discoveries of this sort are more harmful than advantageous to humanity."[10] Nevertheless, the volatility of potassium chlorate stopped it from being widely used in the nineteenth century though it was an ingredient in some explosives.[11]

Institutionalized scientific research remained a presence in the state's development of explosives from the late eighteenth century onwards. Arsenals typically maintained laboratories or employed chemists to investigate and make improvements in explosives and artillery. The Royal Arsenal in Woolwich, London, for example, employed no less than Michael Faraday to give chemical lectures to artillery students from 1830 to 1851, following which the chemist Frederick W. Abel was appointed to the post and made Scientific Adviser to the War Office in 1854.[12] Universities also increasingly included chemistry laboratories and appointed professors to conduct experimental chemical researches.[13]

Although potassium chlorate was too volatile for use in explosives, scientists continued to seek out better or more powerful alternatives to gunpowder in the nineteenth century. The stability of black powder made it relatively safe to manufacture and use, but the products of its combustion being about half solids, gunpowder produced a large amount of smoke. Smoke obscured the battlefield and gave away the position of snipers, leading to calls for an alternative. Gun-cotton (nitrocellulose) ultimately provided such a 'smokeless' explosive, though it did not achieve widespread use before the closing decades of the nineteenth century.[14] It was first produced in 1845-46 by the Basel chemistry professor Christian Friedrich Schönbein following experiments by Théophile-Jules Pelouze in Paris on treating cotton with nitric acid in 1838.[15] Schönbein devised a process of immersing cotton into a mixture of nitric and sulphuric acid for two minutes, before removing, washing and drying the product. The sulphuric acid decomposed the nitric acid, allowing the latter to combine with the cotton. This form of ‘gun-cotton’ was found to produce a more powerful effect than normal gunpowder, and Schönbein spent many years trying to sell his secret to several European governments. Like Lavoisier and Berthollet, Schönbein found that accidents hindered the take-up of his discovery. In 1846 he traveled to Woolwich, London, where he partnered with one John Hall to manufacture gun-cotton at the gunpowder works in Faversham, Surrey. But an explosion in July 1847 ended this project in England, and it was another decade before new works were established by Schönbein’s successor, the Austrian artillery officer Baron Wilhelm von Lenk, first in Austria, and then, in the 1860s in France, America and England.

Von Lenk made gun-cotton manufacture more reliable, steeping rovings of cotton in nitric and sulphuric acid for two days, before cleaning the product for three weeks in running water before drying. Nevertheless, further explosions led patrons to question the stability of gun-cotton and its suitability as a replacement for gunpowder. To answer this, in 1863, Frederick Abel at Woolwich began a detailed investigation of gun-cotton, whose explosive properties were thought to rely on the degree of nitration of the cellulose in the cotton. Abel thought that Von Lenk’s product entailed three units of nitration of cellulose to produce trinitrocellulose, the most explosive form. While French chemists challenged this view, Abel determined that the instability of gun-cotton was owing to the decomposition of impurities in the cotton, and he developed methods such as the pulping of cotton in an alkaline solution to remove these impurities, making gun-cotton more stable, and so safer to use as an explosive. His methods were used for the remainder of the nineteenth century, but Abel's gun-cotton did not replace gunpowder. Gun-cotton was mainly used for blasting in quarries and mines, exploded with a detonator containing fulminate of mercury in the same manner as dynamite.[16] It was also used by terrorists. Recipes were included in anarchist journals such as the *Alarm* and Johann Most's *Science of Revolutionary Warfare*.[17] The latter claimed, "gun cotton is not to be underestimated. The layman finds it easier to make than dynamite, and… it looks an innocent enough material… It is possible to stuff old sofas, cushions, or mattresses with gun cotton, and transport it under the noses of the police."[18]

Only in the 1880s was a true, workable smokeless alternative to gunpowder devised – the so-called *Poudre B* of Paul Vieille. Vieille was an engineer and graduate of the *Ecole polytechnique*, and after the Franco-Prussian War collaborated on investigations of explosives for the French state with the chemists Marcellin Berthelot and Emile Sarrau.[19] Working at the *Depôt central des Poudres et Salpêtres*, Vieille invented important new instruments for the study of explosions, such as the bomb calorimeter in 1878, measuring the heat and pressure of combustion in explosions to a high precision. Using this instrument revealed to Vieille how the fibrous structure of nitrocellulose correlated with its extremely rapid combustion when exploding.[20] Controlling this structure should then render the speed of the combustion manageable. Vieille used a dissolvant to "gelatinize" gun-cotton, generating thin plates whose speed of combustion depended on their degree of thickness. After pressing and drying the plates could be broken into flakes for use in guns. Three times more powerful than traditional black powder, *Poudre B* was quickly adopted by the French army in 1886. Alfred Nobel developed another version of the same process a year later and his smokeless powder, named Ballistite, was adopted by the German army a decade later. In 1891, the British army adopted another version, named Cordite by its inventors Frederick Abel and James Dewar.[21] In Russia, the chemist Dmitri Mendeleev contributed to the introduction of smokeless powders.[22]

Gun-cotton's rise coincided with that of the most famous terrorist explosive, dynamite. Dynamite was "the weapon with which the "revolution" has armed itself for its assault upon society."[23] It was first used for terrorist actions in Russia by the radical group *The People's Will* in 1879 and remained in use there through the end of the century, by which time dynamite was the weapon of choice for terrorists across the world.[24] Nikolai Ivanovich Kibalchich oversaw the preparation of explosives for *The People's Will*, having studied their chemistry and practiced their use as a student of the Alexander I Institute of Transport Engineers in St. Petersburg.[25] In September 1879, Kibalchich arranged dynamite production in a house on Nevskii Prospect, in three large rooms on the fifth floor. Accidents were common.[26] He collaborated with student sympathizer and chief fireworks organizer for the city, Aleksandr Alekseevich Filippov. From Filippov he gained access to St. Petersburg's Okhtenskii factory, and samples of dynamite from the factories of the Swedish chemist Alfred Nobel.

A stick of dynamite consisted of a container holding a medium, such as sawdust or the infusorial earth kieselguhr, into which was absorbed a highly explosive liquid, nitroglycerin. A fuse connected the mixture to a detonating cap, which was used to ignite the explosion.[27] The key ingredient, nitroglycerin, was first synthesized in 1846 by Ascanio Sobrero, a student of Pelouze in Paris at the time of his experiments with nitration and gun-cotton.[28] Sobrero nitrated glycerol with nitric and sulphuric acid in a cooled container to avoid detonation. He made no subsequent use of the substance, which he called pyro-glycerine on account of its extreme volatility – the slightest vibrations could lead to a dangerous explosion.

A decade passed before Nobel (another student of Pelouze) began investigating the potential of nitroglycerin as a commercial explosive following experiments on its properties by his Russian chemistry teacher Nikolai Zinin.[29] Nobel found in 1861 that a fulminate detonator could be used to explode nitroglycerin, and the following year he began manufacturing the latter at the Heleneborg works near Stockholm as an oily liquid for blasting in mines. Devastating accidents at the factory did not deter Nobel, who was convinced that nitroglycerin could serve as an extremely powerful explosive if it could be made safer to handle. It was six or seven times more powerful than black powder, and the main ingredient, glycerol, was a cheap byproduct of the soap-making industry. Spurred by legislation restricting the use of nitroglycerin, Nobel experimented to find a material with which to bind the explosive so that it would be less sensitive to vibrations. Eventually in 1866, at his Krümmel factory in Geesthacht near Hamburg, Germany, Nobel found that the packing material kieselguhr (diatomite), a porous infusorial earth that was cheap and readily available near to the factory, could absorb three times its own weight of nitroglycerin, rendering the explosive much safer to handle. Nobel named the solid paste thus formed ‘dynamite’, from the Greek *dynamis* for ‘power’. Packed into a tube and ignited with a fulminate detonator, dynamite offered the first practicable alternative explosive to black powder, and being in stick-form, it could be inserted inside rocks, making its blasting power much more effective.[30]

Mass manufacture of dynamite soon began in Krümmel, and to exploit international markets, Nobel founded further factories in Germany, Britain, and the United States, which he eventually conglomerated into a single company. Fifteen factories were in operation by 1873, spreading dynamite across the world and inadvertently into the hands of radicals like Kibalchich. Shortly after, Nobel moved to Paris, and in 1875 devised a new explosive, blasting gelatine (gelignite). Dynamite suffered from the problem that if it became wet, the water dissolved the nitroglycerin which "sweated" or leaked out. Nobel solved the problem with a solidified form of nitroglycerin, containing about seven or eight percent collodion cotton, a form of gun-cotton, dissolved into it. Since gun-cotton was itself explosive, blasting gelatine was some 25% more powerful than regular dynamite.[31]

Many new 'scientific' explosives, synthesized by chemistry, followed in the second half of the nineteenth century. In 1867 the Swedish chemists Johann Ohlsson and Johan Hendrick Norrbin patented "ammoniakkrut", a nitroglycerin explosive using ammonium nitrate mixed with charcoal or coal dust, which was cheaper than dynamite, though it was less explosive and suffered when exposed to water.[32] By this time, scientists recognized that mixtures of precise quantities of different oxidizing and combustible substances could yield very specific products and powerful explosions. In 1871 Hermann Sprengel, a

German chemist working in England, followed this approach to propose numerous different oxidizing agents and fuels that could be mixed together on the spot to generate an explosion. Safety was enhanced because the materials on their own would not explode. The oxidizers included nitric acid and chlorate of potash, and the fuels included nitro-benzene and petroleum. By the turn of the twentieth century, so-called "Sprengel explosives" were used quite extensively in China and Russia.[33] Ultimately ANFO (Ammonium Nitrate Fuel Oil) became the most widely used form of Sprengel explosive in addition to finding use among terrorists in the late twentieth century (e.g. urea nitrate and hydrogen gas were used for the first attack on the World Trade Center in 1993).[34] But already in the nineteenth century, Johann Most advocated the use of Sprengel explosives for revolutionary actions when dynamite was unavailable, reckoning them to be cheaper and easier to make than dynamite.[35]

Most's *Science of Revolutionary Warfare* of 1885 explained not only how to make explosives but also how to detonate them. Dynamite was typically detonated with a blasting cap, consisting of a hollow tube with fulminate of mercury and potash at one end, into which was inserted a fabric-covered fuse. The fulminate detonator, inserted into the end of a stick of dynamite, would then ignite it on being lit by the fuse. Different lengths of fuse provided different amounts of time between lighting and the final explosion, allowing the user to move away from any danger. While these techniques appear straightforward, they too were the products of a long period of experimentation and research beginning in the early nineteenth century. The earliest detonating processes in guns entailed applying a lighted match to raw gunpowder in the weapon. Rain and wind made this operation difficult, so a sparking flint in a flintlock mechanism found favour in the eighteenth century. An early attempt to improve on the basic flintlock was the detonator lock developed by the Scottish minister Rev. Alexander John Forsyth in 1805, which used a hammer striking a tiny amount of potassium chlorate, charcoal and sulphur to fire a gun.[36] The detonator lock was itself soon superceded by the fulminate cap. The highly explosive nature of fulminates of silver and gold was well known in the seventeenth century. Edward Howard first described fulminate of mercury to the Royal Society of London in 1800.[37] It was made by mixing mercury, nitric acid, and alcohol in a cooled vessel. The addition of potash served to make the fulminate less liable to explosion during storage.[38] By the mid-1820s, several firms of gun-makers in London and Paris had patented copper percussion caps filled with fulminate of mercury and within a decade, the cap had been made into part of a complete cartridge containing a shot, powder, and cap. It was then Nobel's innovation to apply fulminate caps to dynamite, using the controlled explosion of the fulminate to detonate the dynamite.

Nobel's cap was 'pyrotechnic', relying on a burning fuse to ignite, but it was also possible to detonate the fulminate of mercury with an electric current passing between two wires to heat the fulminate. Electricity was first used by Benjamin Franklin in the eighteenth century to explode gunpowder, and the technique was applied to ignite fulminate caps in the late 1860s. By the closing decade of the nineteenth century, a variety of frictional electrical machines and induction coils were in use to set off dynamite and blasting charges. Turning a handle or compressing a plunger on a 'blasting machine' generated an electric charge which passed down conducting wires to a detonating device.[39]

Fuses also underwent a transformation in the nineteenth century. In the previous century, miners blasting coal or rocks with gunpowder lay a trail of gunpowder to the charge, or used reeds and quills filled with powder. Pyrotechnists and artillerists ignited fireworks and ordnance with 'quick and slow matches', strings of cotton or hemp soaked in vinegar boiled with gunpowder, saltpetre, and other incendiary ingredients.[40] In the 1830s, the Cornish currier William Bickford devised a miner's safety fuse which had a core of powder enclosed in a fabric cable, made to burn with a determined rate. Varnishes enabled the Bickford fuse to be water-proofed, and it was soon widely adopted.[41] It was a version of the Bickford fuse that Nobel used for blasting dynamite, and which Johann Most described in his *Science of Revolutionary Warfare*.

Ingenious firing mechanisms were also the hallmark of 'infernal machines', a term dating back to the sixteenth century.[42] Assassins and revolutionaries in the nineteenth century improvised a variety of weapons and if these entailed some unusual or complex mechanism, they might be referred to as infernal machines. In 1800, plotters planned to assassinate Napoleon on the Rue Saint-Nicaise using the 'little corporal', "a kind of barrel, hooped with iron, furnished with nails, and loaded with gunpowder and case-shot, to which [was] affixed a firmly adapted and loaded battery [of guns]… calculated to be discharged at any given moment by the aid of a match held by an engineer."[43] In 1835, an attempt on the life of King Louis-Philippe of France was made by Giusseppe Marco

Fieschi using twenty-five gun barrels attached to an oak frame secured inside Fieschi's room, which overlooked the Boulevard du Temple. A trail of gunpowder along a bar connecting the touch-holes of the guns was supposed to ignite and fire the guns all at once, but in the event several guns misfired and the King, processing along the Boulevard, was saved.[44] In St. Petersburg in 1887, the student nihilists Andreevsky and Petrov were caught attempting to kill the Tsar with a machine disguised as a law book. Inside was dynamite and bullets filled with the poison strychnine, above which were compartments of mercury fulminate and a tube of sulphuric acid tied to a string. When the book was thrown the tube would break, releasing the acid into the fulminate and detonating it and the dynamite.[45]

2. The relationship between the state and revolutionaries in the development of new weapons.

Infernal machines highlight the ingenuity of bomb-makers, yet the common image of revolutionaries' relationship to science and technology is one of the terrorist as a consumer, or perhaps at best an adaptive user of existing technologies. Often, science was personified by the revolutionaries as the generous donor of a powerful new technology which would serve the interests of humanity. "Dynamite! Of all the good stuff, this is the stuff… In giving dynamite to the downtrodden millions of the globe, science has done its best work."[46] As noted earlier, Johann Most reckoned it was futile to try to manufacture volatile chemicals such as nitroglycerin and fulminate of mercury on a small scale in homes or makeshift laboratories, and instead suggested revolutionaries buy or steal their explosives ready-made. Undoubtedly, for the most part, this *was* how revolutionaries proceeded, obtaining dynamite (which was relatively easy to buy) and other materials to use in home-made bombs. However, at least one case demonstrates that the state might also have learned from the revolutionaries, though it was loathe to admit it.

Sir William Congreve was the son of the William Congreve who reformed gunpowder production in England in the eighteenth century. A journalist and inventor who became established at London's Royal Arsenal in Woolwich, Congreve played an important role in the creation of the gas-lighting industry in Britain, and developed the earliest techniques for studying and measuring gas explosions.[47] In 1805, Congreve proposed a design for an incendiary war rocket, to be used against Napoleon's fleet.[48] In fact, the rockets might never need to be used, claimed Congreve, because the mere possibility of their use would act as a deterrent, "were it known to [the enemy] that the British navy possessed the means of burning any of their marine towns... what town, let me ask, would on a threat of such destruction, refuse to surrender any vessel or vessels that might have taken shelter under its batteries." Congreve's proposal, reminiscent of much later arguments about nuclear deterrence, reminds us that fear and terror were considered fair weapons in the official arsenals of the nineteenth-century state – and not just in France. Terror also secured colonial authority. In the 1830s, the captain of Charles Darwin's former ship HMS Beagle fired a Congreve rocket at the Australian aborigines, "lest familiarity should breed contempt, to give them a hint of our superiority."[49]

It is normally supposed that Congreve learned of the war rocket from the Indian use of the weapon in the wars between the East India Company and Mysore in the closing years of the eighteenth century. The Indian war rocket consisted of a large iron tube filled with incendiary composition, bound to a sword blade or bamboo stick. Fired against an enemy in volleys, these Indian rockets caused havoc. In his numerous publications, Congreve was dismissive of Indian rockets as crude and primitive, but in India, Company officers widely assumed Congreve rockets were adaptations of the Indian weapons.[50] Nevertheless, there is some evidence that Congreve did not learn of war rockets from India, but from Ireland, where Irish nationalists and Republicans used their own version of the Indian war rocket to revolt against the British in 1803.

Robert Emmet was a student of Trinity College, Dublin, where he belonged to the secret United Irish Society determined to end British rule in Ireland and found an independent republic.[51] Expelled for sedition after taking part in the Society's uprising of 1798, Emmet fled to France, where he hoped to gain support for a revolution in Ireland. A long-time student of chemistry, Emmet befriended the American inventor Robert Fulton in France, and may have learned of Indian war rockets from him. Certainly by the Spring of 1803, Emmet had returned to Dublin, where he established secret weapons-making depots across the city to prepare for another uprising against the British. In one of these, in Patrick Street, William Johnstone, said to have been a former pyrotechnist in the East India Company, manufactured war rockets similar to the Indian design. The rocket tubes were twenty inches long and two and a half inches wide, cut from sheet iron, held together with clasps and pointed at one end; they were attached to an eight-foot long pole on one side. This closely resembled the war rockets promoted by Congreve from c. 1805. Johnstone, Emmet, and others tested the rockets in the countryside near Irishtown in July 1803, but soon after disaster struck when an explosion wrecked the Patrick Street depot. Johnstone was badly injured and Emmet, knowing the British would soon know of his plans, brought forward the date of his uprising. In the event, the rebellion failed, and Emmet was arrested, then executed in Dublin in September. But the rockets appear to have attracted the interest of the British crown, and one of Johnstone and Emmet's collaborators, a carpenter named Pat Finerty managed to avoid prosecution by agreeing to move to Woolwich Arsenal in London, where he worked for William Congreve, to whom he allegedly sold the secret of the war rocket.

It is possible that Congreve was already experimenting on rockets at the time of Emmet's uprising, but several authors have asserted Emmet's priority. Thomas Addis Emmet, Robert's elder brother and his first biographer, was "positively of the opinion that the English Government decided that under no circumstances should the name of Robert Emmet be associated with the rocket as the inventor. Congreve was taken in hand and kept employed nominally in manufacturing it, until his name became permanently associated with it."[52] A more recent biographer, Patrick Geoghegan, reaches the same conclusion.[53] Whatever the case, the story of the war rocket indicates that at the very least, revolutionaries and inventors working for the state were at an equal level in the development of new explosive technologies around 1800. Moreover, the rocket was used aggressively by Emmet before it was used by the state – and before Emmet the rocket was an eastern technology, that moved from the periphery of the British empire to cause terror at its centre. Revolutionaries and radicals, then, might act as innovators in the design and use of explosives, and see their innovations copied by the state.

3. Terror in the Context of the Popularization and Professionalization of Science

To conclude it is worth setting the bomb-making practice of radicals and revolutionaries in the context of the changing nature of science in the nineteenth century. This practice occurred in a context of increasing public enthusiasm for science and growing efforts to popularize and broaden the pursuit of science, together with professionalization of the sciences and an accompanying turn to specialization and dedicated scientific instrumentation and spaces.

In their enthusiasm for science and technology, and their belief in progress, terrorists followed widespread public opinion brought about by enduring efforts in the nineteenth century on the part of scientists to encourage the popularity of the sciences.[54] Throughout the century, venues and occasions for scientific publishing, public lectures, and museum displays expanded to take in an ever wider section of the community. Chemical and mechanical knowledge was not just available in textbooks accessible to terrorists, but constantly promoted in popular magazines such as *Scientific American* (founded 1845) and *Popular Science Monthly* (founded 1872), which advertised cheap and simplified apparatus and experiments suitable for the home. Critics identified the threat of such communications. “The dangerous classes have learned from the savants that nitric acid mixed in a certain proportion with any combustible, cotton, or glycerine, or the like, will make an explosive of great force."[55]

Popularization was increasingly represented by scientists as the activity of professionals and experts in communicating science to a non-professional audience.[56] In the eighteenth century, no profession of science existed and a wide variety of physicians, ministers, artisans, and scholars made contributions to natural philosophy. But in the nineteenth century, it increasingly became the case that the 'scientist' (a term coined in the 1830s) was someone who had been educated at a university in a specialized field of natural knowledge and worked in a paid research position, either in a university or in industry. In the course of the century, as more people entered these new scientific careers, they might begin to pass through a widening number of ranks in science from lowly technician to celebrated intellectual. In practice, as the example of the rocket above suggests, and as a number of historians have shown, the boundaries of professionalism were ill-defined, and many important scientists did not work in salaried positions (Charles Darwin, for example). Nevertheless a distinction grew in the nineteenth century between professionals, who occupied paid research positions, and everyone else, generating a growing body of scientific personnel of whom only a limited number might become fully-fledged professionals. Conmmentators on terrorism sometimes identified this community with terrorism. "[E]xperience shows that the most dangerous of all anarchists are the lower men of science and the workmen trained in laboratories, who feel with a half-lunatic bitterness the difference between their intellectual acquirements and their position."[57] In Joseph Conrad' novel *The Secret Agent* (1907), bombs were made for a group of anarchists by the 'professor' who was "once assistant demonstrator in chemistry at some technical institute" and a former technician in the laboratory of a dye manufacturer. Impatient with the world's inability to recognize his genius, the professor turned against society.[58]

Another new condition of professionalized science that shaped the image of terrorist science was its material culture. In the eighteenth century, much emphasis was placed on 'making do' in natural philosophy, on the use of household utensils and readily-available materials to construct scientific apparatus. Joseph Priestley, for example, insisted on using such materials in order to make experimental chemistry accessible to a broad audience of polite society.[59] In the nineteenth century this attitude began to change. In the 1830s, the English chemist Michael Faraday continued to promote the use of kitchenware and homely items for chemistry to students.[60] But by the second half of the century, new methods of constructive synthesis in chemistry and growing numbers of students interested in studying the subject prompted a turn to increasingly specialized spaces and expensive, dedicated instrumentation.[61] The non-professional scientist was thus identified in part by their lack of access to such specialized space and equipment. In the case of the terrorists, improvisation in the face of scarcity became necessary. Johann Most's book, for example, explained that the best form of bomb consisted of a hollow sphere filled with explosives. "Where can you obtain such hollow spheres? The best ones are made of iron, and you could have them cast at a factory. However… if the people at the factory are not loyal comrades there is the possibility of betrayal."[62] The terrorist must improvise, and the author explained how to adapt gas and water pipes into homemade hand grenades and how to make nitroglycerin in the bathroom washtub using coffee pots covered with old window panes. Fruit cans filled with benzene and gunpowder and cigarettes to light them also served the bomb-maker.[63]

The confluence of popularization, professionalization, and specialization created a paradox at the heart of terrorist science. On the one hand, terrorists followed the popular enthusiasm for the sciences and believed that science offered unprecedented technologies of destruction that might allow them to attain social progress. On the other hand, the means and skills needed to make and use these technologies were now becoming so specialized that it was hard to replicate scientific practices on a small scale or using only adapted apparatus. Hence Johann Most's conviction, discussed in the introduction, that the simplest way for revolutionary bomb-makers to proceed was not to make their explosives at home but to buy (or steal) them ready-made. Revolutionaries were not lacking in ingenuity, but in taking up the banner of modern science they did not have access to the means needed to produce the novel weapons they wished to use.

Conclusion

The nineteenth century witnessed a new intimacy between scientific research and the development of explosives for industry, the military, and the state. Mining, engineering and artillery all benefitted from new, more powerful explosives such as dynamite and gun-cotton. These new explosives became potent tools for the actions of groups of anarchists, revolutionaries, and radicals, particularly after the invention of dynamite by Nobel in the 1860s. Nevertheless, acts of terror employed simpler and older weapons throughout the nineteenth century, and often knives and guns proved easier to manage than newfangled explosives. Terrorists manufactured explosive weapons and infernal machines in clandestine workshops and laboratories, but they also relied on ready-made explosives because small-scale manufacture was not as simple as some revolutionary literature might make out. This paradox was representative of terrorists' relationship to the sciences. Terrorists, like the public at large in the late nineteenth century, embraced science as a progressive force, following enduring efforts by scientists to popularize their work and encourage participation in science. They also took for granted an emerging social order of professional science in this period, marked by, among other things, differences in the material culture used by each community. Terrorists may have been revolutionary in their attitude to politics, but conformed to the scientific culture of their time. Nevertheless, while terrorists acted and saw themselves as consumers of innovative science, they could also contribute to innovations. The line between the skills of improvising radicals and those of legitimate scientists and inventors was not always clearly drawn.

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[2] Most, *Science of Revolutionary Warfare*, 3.

[3] Most, *Science of Revolutionary Warfare*, 4.

[4] Herbert K. Tillema, "A Brief Theory of Terrorism and Technology," in *Science and Technology of Terrorism and Counterterrorism*, eds. Tushar K. Ghosh, Mark A. Prelas, Dabir S. Viswanath and Sudarshan K. Loyalka (Boca Raton, FL: CRC Press, 2010), 15-30, on 23.

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[17] See Wm. M. Phillips, *Nightmares of Anarchy: Language and Cultural Change, 1870-1914* (Bucknell University Press, 2003), 27.

[18] Most, *Science of Revolutionary Warfare*, 38-39.

[19] Louis Médard, "L'œuvre scientifique de Paul Vieille (1854-1934)," *Revue d'histoire des sciences* 47 (1994): 381–404; Marshall, *Explosives*, vol. 1, 294-8.

[20] On calorimetry of explosives, see Berthelot, *Explosives and their Power*, 145-159.

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[23] Michael J. Schaack, *Anarchy and Anarchists* (F. J. Schulte, 1889), 30.

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[26] Croft, *Nikolai Ivanovich Kibalchich*, 63-4.

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[32] Marshall, *Explosives*, vol. 1, 42-43.

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[44] A. Bouveiron, *An Historical and Biographical Sketch of Fieschi* (London, 1835), 15-20.

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[49] John Lort Stokes, *Discoveries in Australia, with an Account of the Coasts and Rivers Explored and Surveyed During the Voyage of H.M.S. Beagle, in the Years 1837-38-39-40-41-42-43*, 2 vols (London, 1846), vol. 1, 98.

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[58] Joseph Conrad, *The Secret Agent* (London: Penguin, 1990), 98.

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