CENTRE DE RECHERCHE EN HISTOIRE DES SCIENCES ET DES TECHNIQUES
(Cité des Sciences et de l'Industrie de la Villette / CNRS)

ASSOCIATION DES AMIS DU PATRIMOINE POUDRIER ET PYROTECHNIQUE
(A3P)

TROISIEMES JOURNEES SCIENTIFIQUES

PAUL VIEILLE

Instrumentation, expérimentation et expertise des matériaux énergétiques (poudres, explosifs et pyrotechnie), du XVI^{e} siècle à nos jours

Cité des sciences et de l'industrie, PARIS - France

19 - 20 octobre 2000

No Smoking Gun : D. I. Mendeleev and Pyrocollodion Gunpowder*

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In 1890 the long sought-after search for personal stability of D. I. Mendeleev - the famous Russian chemist best known for his 1869 formulation of the periodic system of chemical elements - appeared to be at an end. He had resigned from St. Petersburg University on 19 March 1890, read his last academic lecture three days later, and though he temporarily still resided in a University-subsidized apartment, he was free of the one career that had sustained him both personally and financially for almost thirty years. Instead of lapsing into desperation, Mendeleev turned to the bosom of the Naval Ministry to begin six years of official involvement that would take him all over Europe and the elaborate contours of the Imperial Russian bureaucracy.

Mendeleev's involvement with the Navy began before the dust from his previous career had time to settle. That spring, after Mendeleev's last lecture, Mining Officer Ivan Mikhailovich Chel'tsov, a specialist in explosives, approached Mendeleev's former student V. E. Tishchenko and asked him if he knew of any chemist who would be able to spearhead the Navy's quest for a new form of smokeless gunpowder, a chemist who could both command authority among working assistants and maneuver through the Imperial bureaucracy. Tishchenko pointed him towards Mendeleev, who accepted almost instantly.[1] On 20 May, he had already contacted N. M. Chikhachev, the Naval Minister, and agreed to take the job with Chel'tsov and L. G. Fedotov (then head of a factory to produce a particular sort of smokeless gunpowder), and began preparation to head to Europe that June to begin their investigations.[2]

Mendeleev got on the boat to leave on 7 (19) June, arriving seven days later in London.[3] The trip was a resounding success. While in England he visited the Woolwich Arsenal with Chel'tsov on 4 July (N.S.), and went on a guided tour led by Frederick Abel, discoverer of cordite, the British version of smokeless gunpowder. Far from feeling restricted on their obviously military fact-finding mission, the Russians were given red-carpet treatment at sites generally considered restricted. On 27 June (9 July), Mendeleev wrote Chikhachev describing the tour, and explained that he had received a sample of the

British smokeless powder directly from the hands of its inventors at the Arsenal.[4] These blandishments were not distributed without a catch, however. V. I. Anderson, director general of the British ordnance factories and a native Russian speaker, told Mendeleev that the samples of British powder would only be released on the condition that the Russians send back all extant forms of Russian smokeless powder. Mendeleev encouraged Chikhachev to agree, and the eventual exchange led to an extreme relaxation of visitation restrictions for Russian officers at British ordnance sites.[5] Support was so unanimous that even the noted chemist and gunpowder expert James Dewar wrote Mendeleev on 17 July (N.S.) that he would "support any action you may take about powder in Russia."[6]

On 9 July (N.S.), Mendeleev and crew left London for Paris, the world center of smokeless gunpowder research and legendary for its secretiveness and resistance to distributing samples. First Berthellot, then Sarrau, directors of the Laboratoire central des poudres et salpêtres, pleaded secrecy to Mendeleev's requests for a sample, so Mendeleev went higher up the administrative food chain, and he was eventually given what the French called "a scientific sample for personal use" in the quantity of 2 grams. Mendeleev bragged in a letter: "It seems no one had yet been able to achieve this."[7] This sample, combined with the personal tours Mendeleev and Chelt'sov received from the French, convinced him that the still-classified production process of the French powder could at least be reverse-engineered to at least its original form.[8] Mendeleev left Paris on 15 (27) July for Petersburg with samples gained by the very attribute he had cultivated over his entire career: open scientific exchange between European peers, as long as that exchange worked to Russia's advantage.[9]

Thus began Mendeleev's involvement with the Naval Ministry's quest for smokeless gunpowder, an involvement that formed just one strand of what may be considered the great arms race of the second half of the nineteenth century. This paper traces the history of Mendeleev's search for smokeless gunpowder. A failure to treat Mendeleev's engagement with the military would be a grievous oversight for anyone wishing to understand the politics of science and technology in late Imperial Russia, a politics heavily centered on notions of "homogeneity" of all sorts. As we shall see, proposals to unify the Empire through the military, whether from Mendeleev or others, were highly charged attempts to formulate a new vision of a "modern Russia." One of the central issues explored here, and one often omitted in discussions of this period, is the remarkable variety of "modernizations" in Russia at this time. While one strand of modernization started Mendeleev on his search, another, fearful that he was going too far, blocked his path. The process of Mendeleev's development of his "pyrocollodion powder," and its eventual rejection by the Russian military, highlight not only aspects of Mendeleev as a skilled manipulator of both society and technology, but also provide an illuminating episode in the history of the category of technological determinism.[10]

MAKING SMOKING HISTORY: NITROCELLULOSE POWDERS

Scientists had been enrolled (and willingly so) in state-based gunpowder research for well over a century by the time Mendeleev became involved with the Russian Navy. Ever since the introduction of conventional gunpowder to the West in the fourteenth century, the simple mixture of saltpeter, sulfur, and charcoal dominated warfare until the end of the nineteenth century, when it was replaced almost universally with smokeless variants.[11] While the original gunpowder from the fourteenth century, suitably modified by generations of craft tinkering with its proportions, clearly possessed formidable advantages over bayonets and pikes on the battlefield, its shortcomings became more pronounced as the desire for rifled, breech-loading, rapid-repeating small arms emerged at mid-century. First of all, and most saliently, black powder left smoke, meaning that a proportion of the charge (up to 57%) used to propel the bullet had not fully burned, and thus there was substantial waste of fuel and a consequent reduction of muzzle velocity for a given weight of charge. A smokeless powder, which oxidized its fuel entirely, would thus fully convert its fuel to projectile power in the form of evolved gases, generating more bang for one's buck. Furthermore, black powder's smoke particles would line the gun barrel, which would diminish the accuracy-enhancement of rifling and occasionally ignite, causing "fouling," which destroyed a service weapon (and, often, the serviceman to boot).[12] Solving fouling also meant that the evolved gases could be used to automatically reset breech-loaders, a key innovation in machine-firearms technology.[13] Eliminating smoke solved a host of technical, strategic, and tactical problems at once.

Eliminating smoke was not easy. As it turned out, the quest for smokeless powder took the greater part of the nineteenth century, and even then the problem was only solved for a small, albeit important, class of calibers.[14] The first breakthrough in making a truly workable smokeless powder came in France in 1886, with the work of Paul Vieille, a researcher at the Laboratoire Central. He had managed to reduce nitrated gun-cotton to a relatively stable mixture of homogeneous and inhomogeneous pyroxylin, which could be converted into a gunpowder when dissolved in any of a variety of mixtures of ether and alcohol, all with different ballistic properties.[15] Shortly, two major competitors to the French pyroxylin powders emerged. The first was from England, Frederick Abel's cordite, derived from a chemically stable gun-cotton he had been developing from as far back as 1865. It became the principal English propellant and substantially transformed the British gunpowder-production industry. In 1887, Alfred Nobel patented ballistite, the first smokeless powder based entirely on nitroglycerin.[16] It was between these three gunpowders, or their derivatives, that military hierarchies in the rearmament race of the late nineteenth century had to decide.[17] Although the problems of higher calibers remained unsolved, by 1890 most European states had either rearmed their small caliber weapons with smokeless powder or were on their way to doing so.

By no means slowest in this endeavor was the Russian Army, located under the War Ministry. Experiments on smokeless powders began at the main Okhtenskii gunpowder factory in 1883, but after a rebuffed attempt in the mid-1880s to purchase French smokeless powder, Captain Z. V. Kalachev was put in charge by the Chief Artillery Board and Colonel A. V. Sukhinskii and told to speed the process up. First French engineers, including one Messan, were brought over to help direct the engineering process along the lines of French pyroxylin, but the venture went quite badly (including a few factory explosions), and the Army decided that Kalachev should undertake the effort by himself. In 1889, Tsar Alexander III ordered work on "rifles of reduced caliber and cartridges with smokeless powder." Lieutenant General N. I. Chagin headed the experimental effort to generate .30-caliber rifles to complement Kalachev's powder, which was essentially a copy of French pyroxylin.[18] Mendeleev both at the time and later was a substantial critic of French involvement in the development of the Army's powder. As he argued in an 1891 report to the Navy, Okhtenskii's strong French design influence meant that numerous flaws were built into the production process. In his private

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1890 laboratory notebook, Mendeleev wrote: "Everything is from the French, but stupidly done"; and "[The Army] believe the French at their word, but they can swindle."[19] The various disasters of Army involvement with the French were a large part of why the Navy wanted Russian scientists to engineer a gunpowder which met their specific needs.

Those needs were highly particular and could not be met by just copying a foreign smokeless gunpowder. In the cannons that formed almost the entire battery of Navy artillery, for example, one could not just heap in more pyroxylin to propel bigger shells, since such "scaling up" would also scale up burning temperatures and risk permanent damage to the gun, as well as increase the chances of spontaneous detonation. The crucial feature of smokeless powder for naval battles was increased muzzle velocity. Given that essentially all warbound navy vessels in Europe in the 1890s were ironclads, one needed substantial propellant force to penetrate their hulls. In addition, as a Naval Ministry report to the Naval Technical Committee put it on 28 May 1890: "In the Navy... smokeless gunpowder is absolutely necessary for rapid-fire shells, and thus the demands of the Navy cannot be satisfied by just the results of the trials carried out by the War Ministry."[20]

As a result, the Navy initiated its own smokeless-gunpowder research program largely independent of that administered by the Army at Okhtenskii Armory.[21] I. M. Chel'tsov, the officer who had approached Mendeleev, had in fact been hired to work on pyroxylin for the Navy as far back as 1878, although he had been unable to convert it into a workable naval gunpowder.[22] By the spring of 1890, Chel'tsov had worked out a plan to copy the French process of gunpowder production, and not the actual powder, as the Army had. He wanted to build a naval research laboratory into smokeless powders, and then, if possible to collaborate with the Army to work out a new Russian variant.[23] The problem with Chel'tsov's proposals was Chel'tsov himself: he lacked the necessary bureaucratic diplomatic skills to get his programs off the drawing board. This is why he received authorization to invite Mendeleev to join the Navy program.

Mendeleev had a long-standing interest in explosives, and it was more than financial necessity and a lack of professional alternatives that led him to accept Chel'tsov's proposal. In October 1857, Mendeleev started lecturing at the second cadet corps, where he met several Russian chemists involved in military affairs.[24] Mendeleev's first article on gunpowder topics appeared in that same year, a discussion of a form of pyroxylin created out of cotton paper, part of a series of popular-scientific pieces he abstracted from Western journals for the Journal of the Ministry of Popular Enlightenment. Although this article was ostensibly about a form of smokeless gunpowder, Mendeleev was much more interested in discussing how the radical NO4 worked in the various pyroxylins and how that related to assorted versions of organic type theory.[25] Explosiveness was beside the point, let alone smokiness.[26]

Later Mendeleev's interests in explosives intensified. On 10 January 1869, he responded to a request by the editors of the journal Activity for his opinions on an article about glycerin they were considering publishing. Mendeleev was savage in his attacks on the author's technical mistakes and for not addressing the native Russian literature on this topic: "It is hardly necessary for us to squander praises on nitroglycerin. Ten years ago we were already preparing it for exploding mines, its properties were studied by our chemists, and not any later than anywhere else. At the present time in Europe they

have already begun to see the disadvantages of nitroglycerin, which we have known about for a long time already." These disadvantages, Mendeleev claimed, ruled out for now "the possibility of a useful and safe general application of nitroglycerin."[27] And, after the Russo-Turkish War broke out, Mendeleev wrote the War Minister on 21 April 1877: "If for the needs of the war that has already begun my knowledge of various areas of the natural sciences with their applications to technology...do not refuse to demand them in practice." On 27 April General Lesovskii in fact asked Mendeleev what the effect of humidity would be on gunpowder on ships, and Mendeleev recommended sealing the casks with the adhesive gum. In June, the Navy actually built one ship in accordance with Mendeleev's suggestions.[28]

There were three main explanations for Mendeleev's interest: one scientific, one historical, and one political. For the scientific justification, Mendeleev pointed out in an appendix to an encyclopedia article on explosive substances in 1892 that most physics situations occur at low temperatures and pressures, and studying explosions gives one the opportunity to explore nature at the high extremes. One could also, he postulated, even use explosions in the air to precipitate rain during droughts.[29] The historical justification concerned Mendeleev's desire to continue the substantial tradition of gunpowder research by Russian chemists such as N. N. Zinin and V. F. Petrushevskii. Petrushevskii, for example, invented a magnesium-based dynamite (later dubbed "Russian dynamite") and also pioneered the research of nitroglycerin before Nobel. [30]

Mendeleev's political justification for gunpowder is perhaps the most interesting. In his encyclopedia supplement, Mendeleev noted that as gunpowder was introduced, warfare became more deadly and thus more and more people were required to wage war, while battles had become more dispersed as firing ranges increased. The net result of an even more powerful gunpowder would be to make warfare yet more deadly and thus deter war: "These observations lead only to the conclusion that the study of explosive substances and the perfection of the strength of firearms is one of the best and truest paths to the achievement of general peace."[31] Mendeleev was convinced that his work on gunpowder would have substantial real-world effects, and it was precisely his rhetoric propounding such claims that would lead to so much turbulence for his variant of smokeless powder. Given the appropriate set of circumstances, even flowery self-justifications can make or break a new technology. In the 1890s, the circumstances were just so.

SHOOTING DAGGERS: RUSSIAN REARMAMENT AFTER CRIMEA

When Mendeleev came upon the Russian military in 1890, he was dealing with a military entirely transformed, both technically and sociologically. It was also a military quite uncertain about whether technological modernization boded well or ill for the stability of Russian forces and, hence, of the Empire itself. Only when the traumas of military modernization are realized can the modern observer understand that Mendeleev was not just proposing a technological modernization: he was proposing modernization to an audience that was buffeted on the winds of change and was not at all sure whether they could trust yet another guru of progress. Mendeleev's failure to grasp this ideological shift would have serious consequences.

The Great Reforms of Alexander II, precipitated by the Russian rout in the Crimean War, left few traditional Imperial institutions untouched. While most historical attention has been trained on the most radical of the Reforms - the 1861 Emancipation of the serfs - the series of concomitant military reforms may have been even more far-reaching in their fundamental rethinking of how this pillar of autocracy was to function. The most salient of these reforms was the universal military draft in 1874, the last of the canonical Great Reforms. Military transformation had begun long before this, and it was almost immediately upon the end of the Crimean War in 1856 that Tsar Alexander II began to instruct his advisors to reform the military radically. Newly appointed War Minister Dmitrii Miliutin decentralized military administration on 6 August 1864 into a nationwide network of 15 military districts, which, when coupled with reforms of military education and industry, was designed to create a new generation of military bureaucrats who would be able to administer a modern fighting force efficiently.[32]

Although there was a series of other reforms as well, the most important for this paper was technical, and is often dubbed the Russian "firearms revolution." It was assumed by many veterans of the fighting in Crimea that the .70-caliber smooth-bore, muzzle-loading musket that had been the staple of Russian small arms since the early eighteenth century had to be replaced. In 1857 it was officially replaced by a .60-caliber rifled muzzle-loader made in Germany and Belgium, and 260,106 of these vintovki were issued by 1862. The 1866 Austro-Prussian war demonstrated to European observers that not only were rifled bores necessary to increase accuracy, but breech-loading substantially increased firing rates over muzzle-loaders. Russian officials now had to decide whether to acquire new weapons or modify the vintovki; they opted for both, with rather poor results.[33] The problems of Russian modernization in the 1870s were less due to military caution than to overt problems with standardization, training, finances and supply endemic to Russia's large army.[34] Nevertheless, when war broke out with Turkey in 1877, Russia's substantial military reforms were put to the test - and found wanting. Although Russia emerged victorious, losses were heavy, and victory more tenuous than it should have been against a second-rate power. The military reforms stayed in place, but the triumph in the war led many to construe them as failures.[35] For the Army, as for many strata of Russian society, the benefits of the Great Reforms were not uncontested.

The Navy was as much, if not more, transformed during the epoch of the Great Reforms. Grand Duke Konstantin Nikolaevich, Alexander II's brother, was appointed Minister of the Navy at the start of the Crimean War, and as the Navy began to crumble under English assaults, he and his advisors fashioned a reform program for their branch which in many ways exceeded the transformations in the Army, both in terms of social policy and technical modernization.[36] Just like the Army, however, the Navy had substantial difficulties rearming its heavy artillery, with perhaps the slowest performance of all the armed forces.[37] This was not unrelated to the lack of an appropriate smokeless gunpowder. Since one needed a clean-burning powder in order to sustain rapid-fire shelling without risk of fouling, the absence of large-caliber nitrocellulose powders was a limiting factor in the entire naval modernization program. Thus, when Mendeleev first set down in his laboratory - initially still the St. Petersburg University laboratory - to perform nitration experiments, many layers of competing interests in the Russian military were prepared to attribute decisive significance to whatever his results might be.

A ROOM OF ONE'S OWN : THE SCIENTIFIC-TECHNICAL LABORATORY

Characteristic of Mendeleev's imperial vision, he coupled the technical project of developing a workable naval smokeless powder with a reform project for generating unity within the Russian Empire. In order to trace Mendeleev's vision for restructuring the Empire through its military, we need to start where he did: in the laboratory. Mendeleev's countertop researches on new gunpowders were intimately connected with building in Russia a new way of conducting such research: the Scientific-Technical Laboratory.

The idea of a state-run laboratory for explosive substances was not new. Lavoisier had directed one in ancien régime France, and France and England had revealed to Mendeleev and Chel'tsov the benefits of active research of nitrocellulose substances. Mendeleev was convinced that smokeless gunpowder in itself demanded such research, and if Russia had survived before without a stable research environment for black powder, it could no longer do so. [38] Crucial was not just scientific research, but scientific research properly organized, as he wrote in his personal gunpowder notebooks in 1890 :

The currently established Chief Organizational and Executive committees, which are carrying out the entire rearmament matter, and consequently also the matter of gunpowder production, along with the inspector of gunpowder factories, have no possibility of entering in a detailed fashion to all of the conditions which can serve to lower the cost and improve the preservation of the qualities of a gunpowder so new in industrial terms as pyroxylin, because this gunpowder comprises a new product in chemical terms, demanding a most fundamental familiarity with chemical reactions and products, deeply differing from regular gunpowder.... In view of these considerations I consider the establishment of a new organ entirely unavoidable, an organ which is free of all traces of direct authority, and designated for the chemical-technical supervision of the production of smokeless gunpowder and for the recognition of competent judgments of the purely chemical-technical properties relating to the new [powder]...[39]

The standard argument to convince the military to reform was to point out that Western European powers were conducting such researches, and Mendeleev emphasized that almost all European states were gearing up for factory production of smokeless powders. In order to prepare for this, one needed to test various factory conditions in a laboratory[40] The subsidiary fail-safe argument, that laboratory research had been empirically proven to lower costs of production, was not far behind.[41] As he reported to the Army on 27 November 1890, staffing the military with the right chemical experts would solve many gunpowder problems :

I cannot do everything by myself and, I admit, I am afraid to be morally responsible in a matter of such great importance, although I am prepared to put the remaining of my powers into the matter of Russian military might, because I consider such a matter a satisfactory conclusion of a life dedicated to science. Thus, I considered it my duty to bring into the open: 1. The necessity of inviting to the matter of smokeless gunpowder several Russian scientists who can grasp the current tasks in their breadth. 2. The necessity to form from them a special committee on explosive substances. 3. The necessity to equip this committee not with exclusive power, but with trust to its knowledge and the right of scientific control in all issues which relate to smokeless gunpowder, and 4. The necessity to give to the committee all the means required for the new laboratory study of explosive substances and for the systematic scientific control of the study of questions related to this, in order to form the necessary kernel of autonomous experts of this branch of science....

Mendeleev then offered a list of people who could head the Laboratory, including Chel'tsov.[42]

Approval for the establishment of the Naval Scientific-Technical Laboratory was forthcoming, and Mendeleev - although officially only a consultant - immediately began to organize it and integrate it the military hierarchy.[43] Chel'tsov, the actual director of the imminent Naval laboratory, settled back and let his mentor do most of the thinking. An appropriate site was quickly found on the island of New Holland, located in the center of the Admiralty Canal in Petersburg.[44] (A Naval laboratory still stands on that island today.) It had already begun to be equipped through Chel'tsov's expenditures in France on manometers, thermometers, and other equipment for ballistic and chemical research. Mendeleev, on the other hand, was more concerned with issues of personnel. He started with defining the tasks of the laboratory director (Chel'tsov). The director was to be the nerve center of all operations, and needed to oversee all activity; he should be an academic professor of some kind, Mendeleev insisted, so he would know how to process scholarly information, and should possess "not only scientific training, but also a scientific name," so he could maintain contacts with Westerners.[45]

Mendeleev specifically envisioned a dialogue between the Navy and the Laboratory on the specifics of smokeless powder. It was one of the benefits of scientific investigation, Mendeleev argued, that it could respond to real-world problems and contribute to revisions in naval practice. He insisted that "a living connection must exist between naval practice and the laboratory of explosive substances."[46] Of course, understanding how sensitive military bureaucracies were to civilian meddling, he insisted that these establishments "are in essence scientific and collegial-advisory," and were meant to process information from the military, not to dictate tactics.[47]

So much for Mendeleev's laboratory in the abstract. The Scientific-Technical Laboratory was actually meant to conduct research to find the holy grail of a naval smokeless powder, and Mendeleev did indeed discover such a powder at St. Petersburg University's chemical labs while the New Holland site was under construction. The initial fruit of Mendeleev's trip abroad, the samples of French and English nitrocellulose powders, soon proved inadequate for the original project of reverse engineering these powders. All powders then on the market, it turned out, had severe flaws that made them unusable for naval artillery. Mendeleev now considered pyroxylin an inadequate starting point. First, pyroxylin was inhomogeneous in composition, which led to irregular burning and thus irregular pressures, which often damaged the interior of the gun. Vieille's pyroxylin was only good for temperatures of 50° to 110°C, but since naval guns frequently generated higher temperatures, this would lead to the disintegration of the gunpowder.[48] Furthermore, pyroxylin had the unfortunate property of spontaneously detonating in storage.[49] Abel's cordite and Nobel's ballistite, both having nitroglycerin components, tended to burn too hot, causing internal barrel damage.[50] Mendeleev would have to start from scratch.

Mendeleev's approach was one that had led to fruitful results over his entire career: he would abandon empirical reasoning and start with theory, deriving the best possible result, and then try to actualize that ideal formula.[51] Gunpowder was to be found in his tried-and-true fashion. The chemical properties that Mendeleev needed were those of a substance that was entirely soluble (so it could form a good powder) and that evolved the greatest possible volume of gases for a given weight. Physical properties like temperature invariance, stability over time, and smooth burning, he would worry about later. Since the substance would be a combination of hydrogen, oxygen, nitrogen, and carbon, Mendeleev deduced that the ideal formula should take the form of $C_nH_{2m}N_qO_{n+m}$. Upon total burning, this would evolve the maximum amount of gas for the least weight, and Mendeleev considered it the limiting case, the most perfect possible smokeless powder - $C_{30}H_{38}(NO_2)_{12}O_{25}$, dubbed "pyrocollodion." It would burn into $30CO + 19H_2O + 6N_2$, and could be easily formed by a simple polymerization of five molecules of cellulose ($C_6H_{10}O_5$) with nitric acid. After Mendeleev had deduced the theoretical structure of the compound, he then worked indefatigably from 9am to 6 or 7pm daily attempting to synthesize the substance.[52] When Mendeleev finally tried to dissolve it in a mixture of alcohol and ether, he exclaimed with glee to his assistant, S. P. Vukolov: "Look, look, it dissolves like sugar!"[53] When it turned out this substance did not detonate spontaneously, he had even more cause to celebrate.

Mendeleev's achievement in making pyrocollodion - so called because it had a colloid appearance like photographic gels and the explosive properties of pyroxylin - was only part of the picture. As one can see from following his seven laboratory notebooks on pyrocollodion, Mendeleev first consulted with a wide variety of experts in the field of gunpowder production, then performed a systematic variational analysis of each type in terms of acid concentration, soaking time, drying temperature, etc., until he came up with a list of definitive properties. In this fashion, Mendeleev clarified many theoretical problems that remained unresolved in the West until at least 1907.[54] Now that he had a gunpowder that was chemically homogeneous, Mendeleev was convinced that all the major technical hurdles had been surmounted. With a fixed nitrogen content, Mendeleev could directly claim greater homogeneity than any other smokeless powder. Making "homogeneity" a compelling selling point was another matter.

THE WELL-ORDERED CHEMICAL STATE: HOMOGENEITY

Post-Emancipation Russia was a state under transformation, a culture striving for unity. Yet unity, perhaps paradoxically, is a very diverse concept. Throughout Mendeleev's career, as he wove his way through the social tapestry of Petersburg, he experimented at defining modes of unity - through classification, expertise, economics, labor - and then attempted to sell these "unities" to the broader Russian audience. Smokeless gunpowder was no different. In this case, the brand of unity seized upon was "homogeneity" (odnorodnost' or odnoobrazie). Throughout this section, I will use the same categories as Mendeleev, who deployed the seemingly ill-fitting term "homogeneity" for a multitude of ends. Pyrocollodion for Mendeleev was a perfect weapon because it was homogeneous, and its homogeneity made it was able to serve as an exemplar, a stand-in, and a metaphor for how to reform and unify the Russian military. Once the military was transformed, Russian society would be stabilized, because the Army and Navy served as bulwarks for the autocratic state which was more and more apparently unraveling at the seams. In this section, I will trace the explicitly metaphorical rhetoric of homogeneity Mendeleev chose to sell pyrocollodion to the Navy and then to the armed forces generally. His efforts failed, the reason why being a question for the next section. For now, we will start with the internal composition of the gunpowder and move slowly outward, observing how broader and broader swaths of concepts become embedded in the cultural logic of homogeneity.

Pyrocollodion, unlike pyroxylin or cordite, was a chemical compound, not a mixture, and thus had the initial advantage of being chemically homogeneous. Mendeleev was most explicit on this elementary form of homogeneity; at this point, his claim was as far removed from metaphor as he ever became :

As to its chemical composition, pyrocollodion may be designated homogeneous, and herein consists one of its most important qualities. All previous and present forms of powder did not have and do not have this property to the degree here implied. From their very method of preparation, black and brown powders are coarse mechanical mixtures, for which any consideration of homogeneity is out of the question. The same is true for those smokeless powders containing ammonium nitrate, picrates, etc. Nitro-glycerin powders may be regarded as gelatinous solutions of nitro-cellulose in nitro-glycerin, which, from their composition, are, chemically, non-homogeneous; moreover, various solvents (alcohol, ether, acetone, etc.) dissolve certain constituents out of them, leaving others.[55]

Chemical homogeneity was occasionally cited by Mendeleev as important for practical reasons, for example that one could test the purity of a particular batch of pyrocollodion simply by measuring its weight and volume. Thus, the chemical homogeneity of pyrocollodion was so certain that it could be black-boxed and mere physical measuring processes could determine purity.[56] This trope of homogeneity was not drawn out of thin air. As Vice-Admiral Popov made clear in a letter to the administration of the Russian Society for the Production and Sale of Gunpowder on 29 January 1892, the issue of gunpowder's homogeneity (in terms of its stability) in storage was a dominant concern for the Navy.[57] Mendeleev picked up on a prevalent worry and ran with it.[58]

If it were just a case of chemical homogeneity, one could overlook the rhetorical function of Mendeleev's assertions and believe that he was merely describing a chemical property. Yet this language was extrapolated further and further from a strict chemical sense. The second type of homogeneity for Mendeleev's pyrocollodion was caliber homogeneity. Pyrocollodion burned uniformly, and not in fits and starts - a consequence of its chemical homogeneity. This meant that it could be used in any caliber weapon; burning in a laminar fashion, the thickness of a pyrocollodion charge was all that needed to be adjusted to move from pistols to naval howitzers :

The usual pyroxylin which serves for the preparation of smokeless powder and for mines is a miscellany of various types of nitrocellulose in various proportions. The homogeneity of composition of pyrocollodion gives warrant to the homogeneity of activity produced by the powder generated from pyrocollodion, which will be expressed in practice by the fact that the entire charge of powder can once and for all be established for the achievement of the desired pressures and speeds....[59]

Mendeleev thus felt he could also sell his pyrocollodion to the Army to replace their French-based pyroxylin, the political consequences of which will be explored below.

The third rhetorical sense was ballistic homogeneity. Mendeleev noted that when field tests of pyrocollodion were begun in April 1893, the muzzle velocities produced were almost entirely constant at 2500 ft/sec (pyroxylin tended to generate 2200 ft/sec). These results, he claimed, were predicted by laboratory tests, and provided "equality (homogeneity of results) of shooting with this gunpowder" in "the best form," with "peerless homogeneity."[60] It also lasted at high temperatures during 6-inch shell experiments for many hours, surpassing also Vieille's and Abel's rigorous gunpowder endurance tests even after years in storage.[61] In terms of performance under controlled laboratory conditions, it seemed to satisfy all the military's needs, and not just the Navy's.

Before continuing with Mendeleev's further expansions upon homogeneity, one should pause to note that it was by no means the case that all tests on pyrocollodion were positive, or that everyone was happy with it. The first problem was that while Mendeleev's gunpowder was easy to produce and incredibly homogeneous under laboratory conditions, when it was produced in trial samples outside of the laboratory, it tended to grow a mold that dissipated its ballistic advantages. The problem was impure water, but it was difficult to generate sufficient distilled water in Petersburg, and instead they had to compromise and take water from the middle of the Neva, a river hardly cleaner then than it is now.[62] Furthermore, the Army gunpowder engineers at Okhtenskii Armory were not at all pleased that Mendeleev was stealing their thunder. On 29 January 1894, the director of Okhtenskii released an internal report that objected to the Mendelevian claim that the means of production at Okhtenskii "do not present any guarantee of achieving a product homogeneous and constant in chemical composition, and thus all the heterogeneous types of pyroxylin prepared at the factory are nothing other than a mixture of nitrocelluloses at different stages of nitration." Instead, they argued, pyrocollodion was just a particular type of pyroxylin, and one that they had produced at the factory. The problem, and one that would beset Mendeleev as well, was that factory conditions were qualitatively different than laboratory conditions, and thus when pyrocollodion would be scaled up, it would prove to have just the same heterogeneity as pyroxylin. Vice-Admiral Pilkin of the Navy sent the report to Mendeleev on that same day and asked for Mendeleev's responses as soon as his health improved.[63] Mendeleev's responded that Okhtenskii had never produced a pyroxylin powder as homogeneous as pyrocollodion.[64] Despite Mendeleev's concern, these criticisms were very much in the background, and the vast majority of correspondence on pyrocollodion was effusively positive. The negative remarks and occasional mold seemed not to have tarnished pyrocollodion's stellar image. And meanwhile, Mendeleev continued to expound expansively on yet more benefits of his powder.

The next form of homogeneity was homogeneity of production, the weak spot that Okhtenskii armorers had attacked. Identical pyrocollodion, it turned out, could be made independently of the form of starch used to generate the cellulose, whether "cotton or flax or hemp."[65] Here Mendeleev had an argument for radically simplified production; it was virtually impossible to run out of raw materials for pyrocollodion, and, anyway, the process was not finicky, and could even be performed by unskilled workers. It was at this point that Mendeleev began to expand homogeneity outside of gunpowder directly, and to move to homogeneity of military procurement and production.

Smokeless gunpowder production in Russia had a short history by the time Mendeleev proposed pyrocollodion, but already it was one of incredible growth. Pyroxylin began to be produced in St. Petersburg in 1880, and the production values for the first seven years are striking, achieving almost eight-fold growth, capping at 884 pud annually.[66] By 1900, in reality, Russia had 1,324,079 pud, and in 1903, 1,350,000 pud, all of pyroxylin.[67] The traditional place where the Navy would have made Mendeleev's powder would have been Okhtenskii, and the Army at several points seemed more than ready to oblige, arguing they could make 15,000 pud a year without difficulty.[68] Mendeleev, however, disliked both the Army's production facilities and state-led production altogether. Instead, Mendeleev proposed decentralizing production to private factories - chemical plants that already produced sulfuric and nitric acids - and then giving them contracts for the various components of the gunpowder. The particular plant he had in mind was the factory of P. K. Ushkov in Elagub.[69] "[O]nly upon complete failure of this approach," Mendeleev argued, should the Navy "think of fulfilling the demand with state factories. In general it is desirable to have right away a combination of private and state factories."[70]

Mendeleev actually couched this move to privatize partially gunpowder production in a proposal to overhaul the basic structure of military procurement. Before pyrocollodion or pyroxylin, Russia's production of traditional black powder was purchased through the services of the Russian Society for the Production and Sale of Gunpowder, a guild-like organization which held a monopoly on military orders.[71] The technical sophistication of smokeless powder eliminated the Society from involvement in production, which meant that a new form of procurement had to be instituted as well. Instead of modeling this new system of production/procurement on other military technologies acquired by the Navy, however, Mendeleev suggested an entirely new mechanism, and then lobbied for the entire military structure to adapt to his model. Before the 1905 Revolution, the military rarely turned to private industry, and only new products like smokeless gunpowder or light artillery could generate enough of a push to allow for economic decentralization to parallel the military's administrative decentralization.[72] Inside each of the state and private factories, Mendeleev wanted to set up a small laboratory which could monitor the progress and quality of the product. These laboratories would all be coordinated from the central Naval Scientific-Technical Laboratory.[73]

Mendeleev now had to construct a state that was in line with his cultural logic of homogeneous unity. For a long period of time, the Russian Army - clearly the dominant force in a land power - clashed with the Navy, and there seemed to be no solution on the horizon. Mendeleev's plan for smoothing over difficulties centered, not surprisingly, on gunpowder. The first, and most generic form of homogeneity between the Army and Navy was to suggest that since pyrocollodion would work for all calibers of weapon, it should form the basis for rearmament of both branches of the armed forces. And in the process, since mutual problems would emerge, discussions between the two inevitably would promote unity.[74] Thus, the two armed forces would be forced by technology into dialogue, and this dialogue would in turn meld them, together with industry, into a powerful force to impose Russia's united will on the wider world, as Mendeleev wrote to the Naval Minister :

> *I am convinced that only by connecting Russian science with the development of national industry can one achieve the best and cheapest Russian smokeless powder...to the satisfaction of Russian demands and state power. To connect these yet more strongly than now, unifying science, the industry of the state, and its military is easy... with the help of smokeless powder. And this connection will frighten Russia's enemies....*[75]

Mendeleev even saw such a program of Imperial unity working in conjunction with the Ministry of Finance's plans for a united industry.[76] That unity, however, never came to pass, as Mendeleev's gunpowder was rejected by the armed forces. It is to this saga that we now turn.

REJECTION : THE POLITICS OF TECHNOLOGICAL DETERMINISM

In 1893, Mendeleev's attention increasingly began to shift to his work at the Chief Bureau of Weights and Measures, and he could devote less time to lobbying for his gunpowder. Mendeleev continued on as a consultant at the Navy until 1895, however, attempting to persuade all levels of the military hierarchy to replace pyroxylin with his new, "more perfect" form of nitrocellulose. On 26 October 1895, however, Mendeleev received a dismaying letter from new Naval Minister Pavel Tyrtov stating that, "not touching on the principal question of the superiority of either pyrocollodion or pyroxylin gunpowders until the end of their comparative testing, the Naval Ministry has rushed in the present year to the services of Okhtenskii gunpowder factory for the most speedy supply of ships that are heading abroad with smokeless pyroxylin gunpowder."[77] Shortly afterwards, Mendeleev retired, leaving Navy service for good on 4 December.[78] But Mendeleev continued to advise. On 5 December 1901, he received a letter from the Navy asking how he felt about the potential closing of the independent Navy smokeless powder factory. He responded on 8 December angrily:

> *This invention...is gradually proliferating...abroad...and the preservation of a small factory of the Navy for the preparation of an explosive substance is very useful for the defense of the state, and one could wish for the expansion of the activity of this factory... The expense demanded for the content of the small naval factory should be considered infinitesimal. And as this infinitesimal expense is connected with autonomous Russian progress in the matter of explosive substances, then I consider the closing of the Naval factory premature.*[79]

Although Mendeleev still lobbied for resumed comparative testing to War Minister M. I. Dragomirov, the Russo-Japanese War (1904-1905) forced all experimental quantities into battle and by 1909 the Navy's pyrocollodion factory was shut down "for lack of economy."[80]

What was the real reason why pyrocollodion was rejected by both branches of the military, even after such a hard sell by its inventor? One possibility, suggested by Mendeleev's former student and employee at the Scientific-Technical Laboratory, S. P. Vukolov, suggests concerns about Mendeleev's civilian status:

> *The explanation is extremely simple. In the eyes of those who then moved the gunpowder affairs of the army artillery, D. I. [Mendeleev] had one large disadvantage: he was a civilian man, not a military one, not having a degree from a high artillery school. They could not stomach it when this man, alien to their environment spoke with all the heat of his fervent nature about the burning of gunpowder in the barrel of a weapon, or the reasons for abnormal pressures upon firing, leading to the explosion of the firearm, when he spoke of the inadequacies of their gunpowder (the gunpowder of the French), pointing to the homogeneity, the limit of pyrocollodion powder.*[81]

What I would like to suggest in this conclusion is that there was in addition a cultural component of the story of Mendeleev's powder: Mendeleev deliberately targeted a particular faction within the military with his pronouncements - a faction of technological determinists whom Mendeleev perceived as rising in the military hierarchy - who were in fact losing power temporarily in the hiatus between Nicholas II's coronation (1894) and the onset of the Russo-Japanese War. Mendeleev's desire to hitch his wagon to their fortunes was part of the reason for his gunpowder's demise.

As Elting Morison has shown in his classic study of the prolonged delays in the adoption of continuous-aim firing by the U.S. Navy in exactly this period, militaries can be highly resistant to technological innovations that might alter their stable and highly structured social dynamics.[82] We have seen similar reluctance in the "firearms revolution" in Russia, where the modernization of weaponry only came after much resistance. This account stands in opposition to a popular philosophy of technology that has been labeled "technological determinism": the belief that technology develops autonomously from its environment and has a direct impact on that environment once it is created. Historians of technology have argued for some decades now, however, that it is rarely if ever inevitable that a technology introduces deep-seated changes into social structures all by itself. It takes work by people to convince the powers-that-be that such changes would follow in the wake of the technology. Although I as a historian have been arguing against any technological-determinist understanding of pyrocollodion, this rhetoric of technological determinism is often a very persuasive selling point, and Mendeleev frequently resorted to it when discussing the virtues of pyrocollodion.[83] And, in fact, military theorists at the time responded to the rhetoric of Mendeleev and others by engaging in widely ranging debates over the military implications of the introduction of smokeless powders.[84]

There was good reason for Mendeleev to expect that technological determinism was the right side to be on. In the 1880s and 1890s, a reformulation of military tactics and strategy in Russia had begun, largely evaluating the consequences of the reforms of the 1860s and 1870s. Military theorists split into two schools, the "academics," who adhered to the classic texts of military strategy like Clausewitz and Jomini, and the "Russian school," which turned to archives and applied new historical methodology.[85] One of the few theorists of this "Russian" camp actually to address the potential implications of smokeless powder was N. P. Mikhnevich, who trained his particular historical interpretative skills to issues of technical change in the military. Smokeless gunpowder, he was convinced, would on its own alter the structure of warfare: "The lessening of gunpowder smoke should influence the distribution and use of weapons in battle, and consequently the battle order and the battle itself, and consequently also the most important divisions of applied tactics."[86] Had those students trained under Mikhnevich's doctrines been making the decision over pyrocollodion in 1895 perhaps Mendeleev's gunpowder would have fared better.

As it turned out, the very concept that technology could or should have the determining role on the battlefield was precisely what was at issue in the Army and Navy hierarchies at this time. The first wave of modernization that had spurred smokeless gunpowder research had ended, and as the 1890s progressed different types of "modernizations" were under evaluation. M. I. Dragomirov had been elevated to the head of the War Ministry, and he was the leader of an alternative strategic faction which strongly emphasized bravery on the fields of battle over technological gadgetry. As Dragomirov perceived it, man was torn between two opposite impulses - self-preservation and self-sacrifice - correlated with intellect and will, respectively. The former went with firearms, the latter with bayonets. In any battle, while fire-power would set up the forces of attack and defense, in the end technology would stalemate, and a particular act of will broke that deadlock.[87] In other words, no war could be won without a bayonet charge, and placing one's reliance on technological improvements would lead nowhere, since technological arms races always ended in a tie. He was not opposed to all technology, but he did object to overconfidence in the ability of technology alone to resolve military conflicts. In late nineteenth-century Imperial Russia, Dragomirov's theoretical position carried a lot of intellectual weight beyond the

political resources he could muster behind it. Amid the anti-intellectual climate in military thought at the time, one could point to the way Russian soldiers held up bravely under severe firepower in the battles against Turkey in 1877-1878 to argue that Dragomirov was right: will did trump intellect in war.[88] While the military had a workable, if imperfect, smokeless gunpowder in pyroxylin, there seemed no need to spend more funds and institute more changes on the principle that technology must advance inexorably, when that was precisely what one was trying to control. The culture of the military at this time was uniquely inhospitable to Mendeleev's rhetoric of homogeneity.

Mendeleev left the Navy in a bit of a huff, and the Scientific-Technical Laboratory went on without him. It still tested various gunpowders that emerged, including an improved ballistite, but in general continued to lean toward the doomed pyrocollodion. Mendeleev stayed involved with the Navy, consulting on various questions, such as the combustion hazards of boat fuel, and in general keeping tabs on the progress of his creation: the Laboratory.[89] But the story of pyrocollodion powder does not end in total obscurity. As it turns out, in an ironic twist, by 1900 pyrocollodion was adopted as the naval smokeless powder of the U.S. Navy. Russia's naval agent in the United States, General Major D. F. Mertvyi, wrote to the General Naval Staff on 15 September 1899 that America seemed to have solved the problem of a naval powder:

The working out of the recipe of this gunpowder was carried out on the basis of the printed researches into the question by Professor Mendeleev. It turns out that there was in the American Navy a Lieutenant Bernadou who knows Russian and at the same time gave himself up to chemical researches. This dual quality of Bernadou...was used and the navy worked out for itself a satisfactory smokeless gunpowder.[90]

Mendeleev was aware of Bernadou's research, and did not discourage it; in fact, on 14 November 1900 the American consul in St. Petersburg, W. R. Holloway, told Mendeleev that S. L. Meyers from Chicago was interested in studying Russian smokeless powder and wanted samples sent to him. Mendeleev directed him to published articles.[91] Through publication, Mendeleev's gunpowder had finally trickled from East to West.

*** ABBREVIATIONS :**

ADIM	:	Arkhiv-Muzei D. I. Mendeleeva (D. I. Mendeleev Archive-Museum).
MS	:	D. I. Mendeleev, Sochineniia, 25 v. (Leningrad: Izd. AS SSSR, 1934-1954).
RGAVMF	:	Rossiiskii Gosudarstvennyi Arkhiv Voenno-Morskogo Flota (Russian State Archive of the Navy).
RGIA	:	Rossiiskii Gosudarstvennyi Istoricheskii Arkhiv (Russian State Historical Archive).
TIIEiT	:	Trudy Instituta Istorii Estestvoznaniia i Tekhniki.
VIET	:	Voprosy Istorii Estestvoznaniia i Tekhniki.

All dates are given in the old style Julian calendar, which lags 12 days behind the new-style Gregorian calendar in the nineteenth century, 13 days in the twentieth, unless otherwise indicated by (N.S.). Transliterations follow a modification of the standard Library of Congress format. All unattributed translations are mine.

REFERENCES

[1] V. E. Tishchenko and M. N. Mladentsev, *Dmitrii Ivanovich Mendeleev, ego zhizn' i deiatel'nost': Universitetskii period, 1861-1890 gg.* (Moscow: Nauka, 1993), 127. The official hire only went through on 3 September 1891, when he was brought on as Chel'tsov's consultant (RGAVMF, f. 410, op. 3, d. 268, l. 1).

[2] MS, XXV, 425.

[3] Mendeleev to Chikhachev, 20 May 1890, RGAVMF, f. 421, op. 2, d. 678, ll. 81-81ob. Mendeleev did try to secure Frederick Abel's presence at Woolwich despite the strained schedule. See the undated telegram in ADIM I-A-45-1-8.

[4] RGAVMF, f. 421, op. 2, d. 678, ll. 115-116. For a secondary description of Mendeleev's visit to England, see A. Ia. Averbukh, "D. I. Mendeleev i Nauchno-tekhnicheskaia laboratoriia Morskogo vedomstva," TIIEiT 39 (1962): 222-247, on 225-226.

[5] Mendeleev to Chikhachev, 19 July 1890, RGAVMF, f. 421, op. 2, d. 678, ll. 130-133; Mendeleev to Chikhachev, 12 November 1890, RGAVMF, f. 421, op. 2, d. 678, ll. 242, 244; and V. Anderson to Mendeleev, 19 November 1890 (N.S.), RGAVMF, f. 421, op. 2, d. 678, l. 243. On Russian access to factories, see the letter of the Russian Naval agent in London, Nikolai Zelenii, to N. I. Ivanov, 28 February (12 March) 1891, RGAVMF, f. 421, op. 2, d. 722, ll. 71, 73.

[6] Quoted in Mendeleev to Chikhachev, 19 July 1890, MS, IX, 12.

[7] Mendeleev in ADIM Album 2/505, quoted in Averbukh, "D. I. Mendeleev i Nauchno-tekhnicheskaia laboratoriia Morskogo vedomstva," 227.

[8] Mendeleev to Chikhachev, 19 July 1890, MS, IX, 11-12. As an indication of how serious the Russians were about reverse engineering, Chel'tsov was given *carte blanche* to spend 8,700 francs buying French gunpowder production equipment for the Naval laboratory. See his expense report, 23 October 1890, RGAVMF, f. 427, op. 2, d. 197, ll. 86-89.

[9] As is clear from these accounts, Mendeleev received his pyroxylin samples entirely openly, and without the least recourse to the espionage that romanticizing Soviet historiographers have occasionally attributed to him. This story sometimes takes the form of Mendeleev watching the trains arriving at the French gunpowder factory and calculating the composition of the powder from the sizes of their shipments.

[9] See E. M. Primakov, ed., *Ocherki istorii rossiiskoi vneshnei razvedki*, v. 1 (Moscow: Mezhdunarodnye otnosheniia, 1996), 163; and N. A. Shost'in, *D. I. Mendeleev i problemy izmereniia* (Moscow: Komitet po delam mer i izmeritel'nykh priborov pri Sovete ministrov Soiuza SSSR, 1947), 37, 133-134. That account is actually derived from a bedtime story Mendeleev told his youngest son Vanya and has no correlation to reality. For refutations of this account, see I. S. Dmitriev, "'Osobaia missiia' Mendeleeva: Fakty i argumenty," *VIET*, no. 3 (1996): 126-141; N. A. Figurovskii, *Dmitrii Ivanovich Mendeleev, 1834-1907* (Moscow: Izd. AN SSSR, 1961), 205; and Averbukh, "D. I. Mendeleev i Nauchno-tekhnicheskaia laboratoriia Morskogo vedomstva," 224. Russian chemists had spied in the past, however. In 1854-1856, during the Crimean War, chemist P. A. Il'enkov was sent to Westphalia to spy on gunpowder plants. See Dmitriev, "'Osobaia missiia' Mendeleeva," 135.

[10] An inspiring historicization of how technology came to be seen as a determining force divorced from politics in the context of armaments engineering in the French Revolution is provided by Ken Alder, *Engineering the Revolution: Arms and Enlightenment in France, 1763-1815* (Princeton : Princeton University Press, 1997). On "heterogeneous engineering" as a valuable category for studies of technology, see John Law, "Technology and Heterogeneous Engineering: The Case of Portuguese Expansion," in Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch, eds., *The Social Construction of Technological Systems : New Directions in the Sociology and History of Technology* (Cambridge, Massachusetts : MIT Press, 1987).

[11] See Seymour H. Mauskopf, "From Rumford to Rodman: The Scientific Study of the Physical Characteristics of Gunpowder in the First Part of the Nineteenth Century," in Brenda J. Buchanan, ed., *Gunpowder : The History of an International Technology* (Bath: Bath University Press, 1996): 277-293; and idem, "Chemistry and Cannon: J.-L. Proust and Gunpowder Analysis," *Technology and Culture* 31 (1990): 398-426, on 404. On Lavoisier, see idem, "Gunpowder and the Chemical Revolution," *Osiris* 4 (1988): 93-118; Jean-Pierre Poirier, *Lavoisier: Chemist, Biologist, and Economist*, tr. Rebecca Balinski (Philadelphia, University of Philadelphia Press, 1993), 89-94, 117-119; and Robert P. Multhauf, "The French Crash Program for Saltpeter Production, 1776-94," *Technology and Culture* 12 (1971): 163-181. Gay-Lussac, Mendeleev's precursor on gas research, was heavily involved on gunpowder research during the Restoration, publicly developing methods of gunpowder analysis and sharing them with foreign chemists, including Berzelius. Maurice Crosland, *Gay-Lussac : Scientist and Bourgeois* (Cambridge : Cambridge University Press, 1978), 181-183, 216-217.

[12] John B. Bernadou, *Smokeless Powder, Nitro-Cellulose, and Theory of the Cellulose Molecule* (New York: John Wiley & Sons, 1901), 164 ; Bruce W. Menning, *Bayonets before Bullets: The Imperial Russian Army, 1861-1914* (Bloomington: Indiana University Press, 1992), 104, Manuel Eissler, *A Handbook of Modern Explosives* (London: Crosby Lockwood and Son, 1897), 181; Charles E. Munroe, "On the Development of Smokeless Powder," *Journal of the American Chemical Society* 18 (1896): 819-846, on 824. On the importance of muzzle velocity for all aspects of weapons calibration, see Shelford Bidwell and Dominick Graham, *Fire-Power : British Army Weapons and Theories of War, 1904-1945* (London: George Allen & Unwin, 1982), 108.

[13] Menning, *Bayonets before Bullets*, 104-106; Munroe, "On the Development of Smokeless Powder," 838-839.

[14] On the early history of *smokeless-powder* development, see Bernadou, Smokeless Powder, 1-2; Dmitriev, "'Osobaia missiia' Mendeleeva," 133; Eissler, *A Handbook of Modern Explosives*, v-vi. For a general overview of this history, see John Bernadou, "The Development of Smokeless Powder," a lecture delivered at the U.S. Naval War College on 20 July 1897, in Bernadou, *Smokeless Powder*, Appendix 4. One of the main difficulties was the lack of a tractable theory of the cellulose molecule, which hindered prediction of the properties of various mutations of gun-cotton. See Bernadou, *Smokeless Powder*, Chapter 4.

[15] On these French powders, see M. Barral, "Etudes des Poudres de Chasse Françaises et Recherche d'une Nouvelle Poudre de Chasse sans Fumée," *Mémorial des Poudres et Salpêtres* 5 (1892): 189-225; P. M. E. Vieille, "Researches upon the Nitraction of Cotton," in Bernadou, *Smokeless Powder*, Appendix 1; M. Berthellot and P. M. E. Vieille, "Rapport sur l'Étude du Nitrate de Diazobenzol," *Mémorial des Poudres et Salpêtres* 1 (1882-1883): 99-108; P. M. E. Vieille, "Note sure l'Hydrocellulose et sur le Composé Nitré qui en Dérive," *Mémorial des Poudres et Salpêtres* 2 (1884-1889): 21-35; and idem, "Recherches sur la Nitrification du Coton," *Mémorial des Poudres et Salpêtres* 2 (1884-1889): 212-224.

[16] Paul Everson and Wayne Cocroft, "The Royal Gunpowder Factory at Waltham Abbey: The Field of Archaeology of Gunpowder Manufacture," in Buchanan, ed., *Gunpowder* (1996): 377-394, on 392; and Ivan Ivanovich Vernidub, "One Hundred Years of Russian Smokeless (Nitrocellulose) Powder Industry," in *ibid.*: 395-400, on 396.

[17] Attempts had been made to arm with smokeless powder even before these three types had emerged, although with dubious success. Leading the way was Austria-Hungary, which introduced gun-cotton in around 1874 and then speedily abandoned it. The form they

were using was a compactly wound thread for field guns, but it proved disastrous in the field and the Austrian factory in Hirtenburg blew up for undetermined reasons. Experiments had begun at Woolwich Arsenal in England even earlier (1867-1868) with compressed gun-cotton, but field usage led to so many problems that "much evidently remained to be accomplished before the requisite uniformity of action could have been secured." Eissler, *A Handbook of Modern Explosives*, 75. On Hirtenburg, see Munroe, "On the Development of Smokeless Powder," 827.

[18] Quotation from Menning, *Bayonets before Bullets*, 104. See also Vernidub, "One Hundred Years of Russian Smokeless (Nitrocellulose) Powder Industry," 397; Dmitriev, "'Osobaia missiia' Mendeleeva," 134; and Averbukh, "D. I. Mendeleev i Nauchno-tekhnicheskaia laboratoriia Morskogo vedomstva," 231.

[19] Quotations from t. 2, l. 17a and t. 4, l. 13a of Mendeleev's gunpowder notebooks, reproduced in A. Ia. Averbukh, "Issledovaniia D. I. Mendeleeva v oblasti nitratsii. Otkrytie pirokollodiia," *Trudy Leningradskogo Tekhnologicheskogo Instituta* 30 (1954): 69-95, on 80. For the 1891 report's condemnation of French involvement, see MS, IX, 48.

[20] RGAVMF, f. 421, op. 2, d. 678, l. 89. See also Vice-Admiral Pilkin and Manager Dmitriev to the General Administration of Shipbuilding and Equipment, 28 December 1890, RGAVMF, f. 421, op. 2, d. 722, ll. 8-18; and Chikhachev to War Minister P. S. Vannovskii, 19 February 1892, RGAVMF, f. 421, op. 2, d. 768, l. 29.

[21] Overtures were made to establish some sort of clearing-house for information between the two Ministries, but I could detect no traces of anything actually being instituted. For an example of such an effort to establish "a defined order in the exchange of information and the communality (obshchenie) of both departments in questions of trials of smokeless gunpowder," see the Report of the Technical Committee of the Artillery of the Naval Ministry to the Chief Artillery Administration, 18 January 1890, RGAVMF, f. 421, op. 2, d. 678, l. 20ob.

[22] P. M. Luk'ianov, *Istorii khimicheskikh promyslov i khimicheskoi promyshlennosti Rossii do kontsa XIX veka*, v. 5 (Moscow: Izd. AN SSSR, 1961), 354.

[23] I. Chel'tsov, "K izucheniiu bezdymnogo porokha," 24 April 1890, RGAVMF, f. 421, op. 2, d. 678, ll. 83-84. See also L. Fedotov, "Ob ustroistve laboratorii dlia ispytaniia bezdymnykh porokhov," 30 April 1890, RGAVMF, f. 421, op. 2, d. 678, ll. 85-87.

[24] T. S. Kudriavtseva, "Novye dannye ob issledovaniiakh D. I. Mendeleeva v oblasti porokhodeliia," in N. A. Figurovskii *et al.*, eds., *Materialy po istorii otechestvennoi khimii* (Moscow: Izd. AN SSSR, 1953): 234-241, on 234.

[25] D. Mendeleev, "Sostav khlopchato-bumazhnago porokha ili piroksilina," *Zhurnal Ministerstva Narodnogo Prosveshcheniia*, v. 93, otd. VII (1857): 18.

[26] Smoke interested Mendeleev from an industrial point of view. In 1859 Mendeleev wrote a survey article about the need to eliminate smoke from industrial combustion, basing his argument on the inefficiency of partial burning in heat generation. MS, XVII, 34-45. This interest in industrial smoke continued to the 1890s, when he wrote an encyclopedia article on "Factory smokestacks." MS, XVII, 473-481.

[27] ADIM II-A-13, quoted in A. Ia. Averbukh, "Vasilii Fomich Petrushevskii (Raboty v oblasti vzryvchatykh veshchestv)," *TIIEiT* 35 (1961): 167-184, on 180. See also Kudriavtseva, "Novye dannye ob issledovaniiakh D. I. Mendeleeva v oblasti porokhodeliia," 235.

[28] Quoted in Kudriavtseva, "Novye dannye ob issledovaniiakh D. I. Mendeleeva v oblasti porokhodeliia," 236.

[29] MS, XXV, 444 (extremes) and 446 (meteorology). The suggestion about cloud seeding by explosions is especially interesting since Mendeleev later explicitly rejected this proposal when consulted by the Ministry of Finance as to its feasibility. A man named A. A. Konstantinov had written to the Ministry proposing this option to deal with periodic crop droughts, and Mendeleev's usual scientific advice was sought. Citing Russia's continental climate and the lack of evidence that explosions can actually have this effect on even moisture-rich air, he in no uncertain terms vetoed the idea. Mendeleev to S. Iu. Witte, 18 March 1902, RGIA, f. 1233, op. 1, d. 35, ll. 157-158. Gunpowder had long been cited by scientists as a valuable way to study matter under extremes, as detailed in Mauskopf, "Gunpowder and the Chemical Revolution."

[30] On Petrushevskii and Zinin, see Averbukh, "Vasilii Fomich Petrushevskii"; on Fadeev, see Vernidub, "One Hundred Years of Russian Smokeless (Nitrocellulose) Powder Industry," 395. Other examples are Colonel N. P. Nechaev, whose 1892 work on explosives was in Mendeleev's personal library : N. P. Nechaev, *Klassifikatsiia vzryvchatykh veshchestv: Obzor inostrannykh bezdymnykh porokhov i dinamitov* (Moscow: A. A. Levenson, 1892), ADIM Bib. 331/5; and Mendeleev's student, S. P. Vukolov, who worked with Mendeleev on smokeless powder and later went on to a distinguished career in explosives chemistry that extended well into the Soviet period (L. Bagal, "Semen Petrovich Vukolov," *Zhurnal Prikladnoi Khimii* 14, no. 4-5 [1941]: 517-520).

[31] MS, XXV, 445. To readers weaned on debates over deterrence during the Cold War, the notion that scientific weapons preserve peace will appear familiar, but to most of Mendeleev's contemporaries, the long pedigree of such claims going back to the Renaissance was unknown and largely irrelevant. The Baconian triad of the printing press, the compass, and gunpowder were widely considered in early modern Europe to be almost constitutive of modernity and the general progress of civilizations. For the printing press and the compass, the myriad benefits of the technologies were easy to demonstrate; gunpowder proved substantially more difficult to justify. On rhetorical defenses of gunpowder in this period, which bear a substantial affinity to both Mendeleev's claims and those bandied about Cold War America, see Roy S. Wolper, "The Rhetoric of Gunpowder and the Idea of Progress," *Journal of the History of Ideas* 31 (1970): 589-598.

[32] On these reforms of the Army, see Peter von Wahlde, "Russian Military Reform: 1862-1874," *Military Review* 39 (1960): 60-69; Dietrich Beyrau, *Militär und Gesellschaft im vorrevolutionären Russland* (Köln: Böhlau Verlag, 1984); Forrestt A. Miller, *Dmitrii Miliutin and the Reform Era in Russia* (Charlotte, North Carolina: Vanderbilt University Press, 1968). Although Miliutin is often given the credit for the reforms of the military, one can see the genesis of many of the subsequent policies under Sukhozanet, his predecessor. See E. Willis Brooks, "Reform in the Russian Army, 1856-1861," *Slavic Review* 43 (1984): 63-82. For a criticism of the decentralization policies as a panacea, see John L. H. Keep, *Soldiers of the Tsar : Army and Society in Russia, 1462-1874* (Oxford: Clarendon, 1985), 355.

[33] Menning, *Bayonets before Bullets*, 30.

[34] Bradley, *Guns for the Tsar*, 177; P. A. Zaionchkovskii, *Samoderzhavie i russkaia armiia na rubezhe XIX-XX stoletii, 1881-1903* (Moscow: Mysl', 1973), 155, 162; L. G. Beskrovnyi, *Armiia i flot Rossii v nachale XX v.: Ocherki voenno-ekonomicheskogo potentsiala* (Moscow: Nauka, 1986), 112; Fedorov, *Russkaia armiia*, Chapter 6; and A. V. Fedorov, *Obshchestvenno-politicheskoe dvizhenie v russkoi armii*, 40-70 gg. XIX v. (Moscow: Voennoe izd. Min. Oborony SSSR, 1958), 168-187.

[35] John S. Bushnell, "Miliutin and the Balkan War: Military Reform vs. Military Performance," in Ben Eklof, John Bushnell, and Larissa Zakharova, eds., *Russia's Great Reforms, 1855-1881* (Bloomington: Indiana University Press, 1994): 139-158; Menning, *Bayonets before Bullets*, 85; and Van Dyke, *Russian Imperial Military Doctrine and Education*, 84.

[36] Given the fact that sailors were more often exposed to other systems of

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military justice than soldiers due to their traveling, a substantial reform of the judicial and administrative structure was undertaken, removing arbitrary sentencing (1867) and abolishing corporal punishment (1863), as well as substantially unifying naval administration. Aurele J. Violette, "The Grand Duke Konstantin Nikolayevich and the Reform of Naval Administration, 1855-1870," *Slavonic and East European Review* 52 (1974): 584-601; and *idem*, "Judicial Reforms in the Russian Navy during the 'Era of Great Reforms': The Reform Act of 1867 and the Abolition of Corporal Punishment," *Slavonic and East European Review* 56 (1978): 586-603. On technical modernization, see : Jacob W. Kipp, "Consequences of Defeat : Modernizing the Russian Navy, 1856-1863," Jahrbücher *für Geschichte Osteuropas* 20 (1972): 210-225; and David Woodward, *The Russians at Sea : A History of the Russian Navy* (New York : Frederick A. Praeger, 1965), 117.

[37] Menning, *Bayonets before Bullets*, 273. The Russian Navy was idiosyncratic in its preference for light artillery. Russians opted for 3-inch shells instead of the European standard of 4.7 inch, and 10-inch where other European powers used 12-inch. Jane, *The Imperial Russian Navy*, 154. Navy rearmament was occasionally buffeted by disaster. In 1894 the new warship *Sissoi Velikii* was sent to the Mediterranean, where during a training exercise its gun turret blew off. Apparently, the turret was armed with two different guns, and the experimental starboard one, whose breechpiece was unlocked, looked much like the standard port one when locked. The starboard one was fired by accident, the breechpiece blew off, and several sailors died. In general, however, naval Obukhov guns did not burst. Jane, *The Imperial Russian Navy*, 286, 520.

[38] See, for example, Mendeleev's statement: "Black smoky gunpowder was found by Chinese and monks almost accidentally, gropingly, by mechanical fiddling in scientific darkness. Smokeless gunpowder was discovered under the full light of contemporary chemical knowledge. It comprises a new epoch of military affairs not because it does not give off eye-obscuring smoke, but primarily because it provides the possibility, under less weight, to convey a bullet and any other projectile to a typical speed up to 600, 800, even 1000 m per second, and at the same time presents all the advances of further perfection - with the help of scientific research of the invisible phenomena completed under its combustion. Smokeless gunpowder comprises a new link between the power of nations and their scientific development." MS, IX, 48.

[39] Mendeleev's gunpowder notebooks, t.4, ll. 4-5, reproduced in Averbukh, "Issledovaniia D. I. Mendeleeva v oblasti nitratsii," 78.

[40] MS, IX, 24, 27, and 38.

[41] MS, IX, 54n. On inhomogeneity's link to laboratory research, see MS, IX, 48n.

[42] ADIM II-Zh-51-1-1, quoted in Averbukh, "D. I. Mendeleev i Nauchno-tekhnicheskaia laboratoriia Morskogo vedomstva," 231-232. The potential members of this committee Mendeleev listed as : Leon Nikolaevich Shishkov, former professor of the artillery academy; Aleksei Romanovich Shuliachenko, chemist at the engineering academy; Chel'tsov; Nikolai Nikolaevich Sokolov; and Grigorii Aleksandrovich Zabudskii.

[43] Mendeleev's first letter to Chikhachev on 2 May 1890 in fact mentions the need for a fully equipped laboratory (ADIM Album 2/474). The "consultant" position was meant for someone who was "especially well-known for his works in the field of the physico-chemical sciences," and was essentially a job tailor-made for Mendeleev after he had already been selected. RGAVMF, f. 421, op. 2, d. 722, ll. 8-18. As a consultant, Mendeleev was also freer to quit at will.

[44] Report of Chief Engineer-Builder of St. Petersburg Port, 12 June 1890, RGAVMF, f. 421, op. 2, d. 678, ll. 108-110. For the specifications of the laboratory, see Vice-Admiral Kaznakov, "Izmenennyi proekt polozheniia o laboratorii Morskogo Ministerstva dlia issledovaniia porokhov i vzryvchatykh veshchestv," [Fall 1890], RGAVMF, f. 421, op. 2, d. 678, ll. 179-182.

[45] Mendeleev, "Ob"iasnitel'naia zapiska k proektu shtata Laboratorii Morskogo Ministerstva," 27 September 1890, RGAVMF, f. 421, op. 2, d. 722, ll. 22-23, on 22ob. Quotation from MS, IX, 147. These scientific credentials turned out to be important. As Chel'tsov wrote to Mendeleev during a Summer 1893 visit to Paris: "I have now returned from Berthollet's, he was glad to see me, to know that our laboratory is found on an island, is wonderfully set up, that in 2 years we had great success, that you worked in it, etc.; in conclusion he proposed that his lab will always be at my service when I am in Paris." ADIM I-B-42-1-93, quoted in Averbukh, "D. I. Mendeleev i Nauchno-tekhnicheskaia laboratoriia Morskogo vedomstva," 244.

[46] MS, IX, 42.

[47] MS, IX, 9.

[48] MS, IX, 39 (on preference for pyroxylin) and 31 (on temperature-dependence).

[49] Vukolov, "D. I. Mendeleev i bezdymnyi porokh," 1536.

[50] MS, IX, 36. Ballistite did possess just the right amount of oxygen for total burning, however, which meant that it could burn independently of the specific external conditions (p. 34). Mendeleev would try to replicate this property.

[51] I do not mean to suggest that none of the other smokeless gunpowders was motivated by theoretical considerations. Often, however, much of this reasoning was along physical lines like analogies to an engine, as opposed to the chemical reasoning employed by Mendeleev. John Bernadou provides an example: "The gun may be regarded as a gas engine in which the walls of the chamber and bore form the cylinder, the projectile, the piston. The expanding powder-gases perform work by imparting velocity to the projectile, the inertia of which they overcome just as gas by its expansion in the cylinder overcomes the inertia of the piston and the parts linked thereto. In the engine the gas is admitted alternately, first at one end of the cylinder and then at the other; in the gun it is admitted at the rear of the projectile but once, so that the gun is an engine of a single stroke. In the engine the steam is admitted into the cylinder through a valve, and, after the lapse of a period of time less than that required for a full stroke, admission is cut off and work for the rest of the stroke is performed expansively; in the gun the charge of powder constitutes both the gas itself and the valve that admits the gas - for each grain of powder may be considered as a notch of opening of a valve; the more grains there are the greater the ignition surface, the greater the rate of emission of gas, or the greater the number of notches the valve is open." Bernadou, *Smokeless Powder*, 177. For a French example of gas theories used to model the evolution of explosion products, see M. Sarrau and P. M. E. Vieille, "Note Relative à l'Influence du Rapprochement Moléculaire sur l'Équilibre Chimique de Systèmes Gazeux Homogènes," *Mémorial des Poudres et Salpêtres* 2 (1884-1889) : 337-340.

[52] P. P. Rybtsov, "Ocherk deiatel'nosti Dm. Iv. Mendeleeva v oblasti izucheniia vzryvchatykh veshchestv," in V. E. Tishchenko, ed., *Trudy pervago mendeleevskogo s"ezda po obshchei i prikladnoi khimii, sostoiavshagosia v S.-Peterburge s 20-go po 30-go dekabria 1907 g.* (St. Petersburg: M. P. Frolova, 1909): 152-161, on 157.

[53] Quoted in Vukolov, "D. I. Mendeleev i bezdymnyi porokh," 1537. Mendeleev listed the production process of pyrocollodion from cellulose on the first page of his published Morskoi Sbornik article which articulated the process (the article itself includes the theoretical reasoning), as the formula was still secret. ADIM Bib. I-1032-12, l. 1, quoted in Averbukh, "D. I. Mendeleev i Nauchno-tekhniches-kaia laboratoriia Morskogo vedomstva," 236; MS, IX 257, 264.

[54] Averbukh, "Issledovaniia D. I. Mendeleeva v oblasti nitratsii," 87. This article also reproduces substantial portions of his personal

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notebooks. In Appendix 2 of Bernadou, *Smokeless Powder,* 123-125, Mendeleev extensively worked through the various theoretical considerations that would discriminate the various smokeless powders.

[55] Mendeleev, "Pyrocollodion Smokeless Powder," Appendix 2 in Bernadou, *Smokeless Powder,* 97-98.

[56] MS, IX, 185n3.

[57] RGAVMF, f. 427, op. 2, d. 305, l. 27.

[58 To be fair, he was aware that he could not claim absolute homogeneity for his powder, and in a lone footnote he hazarded a qualification: "About complete chemical homogeneity in the purely scientific sense one is not speaking here, and one should not be, as even in cellulose itself there is no certainty. One speaks of relative or technical homogeneity, compared with other types of smokeless (and, of course, smoky) gunpowder." MS, IX, 254n1.

[59] Mendeleev to Chikhachev, June 1895, MS, IX, 183. Emphasis in original. See also Mendeleev to Chikhachev, 5 May 1893, RGAVMF, f. 421, op. 2, d. 821, ll. 134-139.

[60] Mendeleev to Chikhachev, 5 May 1893, RGAVMF, f. 421, op. 2, d. 821, ll. 134ob.-135; Mendeleev to Chikhachev, 18 June 1892, RGAVMF, f. 421, op. 2, d. 768, l. 178. See also MS, IX, 171.

[61] RGAVMF, f. 421, op. 2, d. 1233, l. 51. See also the letter to the Chief Inspector of Naval Artillery, 8 May 1895, RGAVMF, f. 421, op. 31 (art. chast'), d. 41, 1895, l. 3, reproduced in Luk'ianov, "O neizvestnykh pis'makh D. I. Mendeleeva i arkhivnykh dokumentakh, kasaiushchikhsia ego rabot po pirokollodiinomu porokhu," 265.

[62] "Zhurnal morskago tekhnicheskago komiteta po artillerii," 21 June 1895, RGAVMF, f. 427, op. 2, d. 527, ll. 262-263.

[63] "Zhurnal komissii, obrazovannoi po prikazaniiu Nachal'nika Okhtenskikh porokhovykh zavodov, dlia razsmotreniia dokladnoi zapiski professora Mendeleeva, predstavlennoi Upravliaiushchemu Morskim ministerstvom," 29 Jan 1894, RGAVMF, f. 421, op. 2, d. 879, ll. 84-86; quotation and Pilkin's handwritten referral both on 84.

[64] Mendeleev to Chikhachev, 5 February 1894, RGAVMF, f. 421, op. 2, d. 879, ll. 101-113.

[65] Mendeleev to Chikhachev, 17 October 1892, RGAVMF, f. 421, op. 2, d. 931, l. 2ob.

[66] See data in Luk'ianov, "O neizvestnykh pis'makh D. I. Mendeleeva i arkhivnykh dokumentakh, kasaiushchikhsia ego rabot po pirokollodiinomu porokhu," 260. For more detailed breakdowns, see P. M. Luk'ianov, *Istoriia khimicheskikh promyslov i khimicheskoi promyshlennosti Rossii do kontsa XIX veka,* V, 324-355.

[67] Beskrovnyi, *Armiia i flot Rossii v nachale XX v.,* 105.

[68] War Minister P. Vannovskii to Chikhachev, 23 June 1893, RGAVMF, f. 421, op. 2, d. 821, ll. 288-289.

[69] Ushkov, a graduate of Kazan University, was clearly Mendeleev's favorite for taking on pyrocollodion production. Mendeleev made several trips to Elagub to negotiate a contract, and Ushkov delivered on early samples before the Navy canceled the orders. See RGAVMF, f. 421, op. 2, d. 821, l. 133; f. 421, op. 2, d. 821, ll. 336-337; and the actual contract, which names Mendeleev as the official negotiator and liaison, f. 421, op. 2, d. 821, l. 509. Mendeleev repeatedly cited Ushkov in his economic writings as a good example of a chemical entrepreneur for a new Russia, and even wrote an obituary of him. For just some of these endorsements, see MS, IX, 54n1, 77, 86; MS, XXI, 318; MS, XVIII, 243 and 296; his obituary of Ushkov of 26 January 1898 in MS, XV, 630; and Mendeleev's chapter on the chemical industry in Departament Torgovli i Manufaktur Ministerstva Finansov, *Fabrichno-zavodkaia promyshlennost' i torgovlia Rossii. Vsemirnaia kolumbova vystavka 1893 g. v Chikago* (St. Petersburg: Tip. V. S. Balasheva and V. F. Demakova, 1893), 279. For his biography, see G. S. Vozdvizhenskii, *Stranitsy iz istorii kazanskoi khimicheskoi shkoly* (Kazan: Kazanskii khimiko-tekhnologicheskii institute imeni S. M. Kirova, 1960), 21.

[70] Mendeleev to Chikhachev, 5 May 1893, RGAVMF, f. 421, op. 2, d. 821, ll. 134-139, on 137; MS, IX, 53.

[71] See RGAVMF, f. 427, op. 2, d. 288. This entire delo concerns gunpowder purchasing affairs in 1890-1891, before Mendeleev had set up his laboratory.

[72] Peter Gatrell, *Government, Industry, and Rearmament in Russia, 1900-1914 : The Last Argument of Tsarism* (Cambridge: Cambridge University Press, 1994), 63. See also his Chapter 6 : "The Economics and Politics of Defence Procurement," which mostly focuses on the post-1905 period.

[73] MS, IX, 147.

[74] Note by A. Brink on the margin of Chel'tsov's letter to the Chief Inspector of Naval Artillery, 5 April 1893, RGAVMF, f. 421, op. 2, d. 821, l. 52 : "These questions [of storage] are very important and I consider it helpful to discuss them together with the Army..." See also Mendeleev to Chikhachev, 5 May 1893, RGAVMF, f. 421, op. 2, d. 821, l. 135; and MS, IX, 159 on uniting both forces with a joint laboratory.

[75] MS, IX, 58.

[76] MS, IX, 81: "Such a plan of action [for gunpowder] will find itself in harmonious agreement with the views of the government on the vitalization of all types of national industry, which is expressed in the highest injunctions, relating both to the review of the customs tariff and, especially, to its temporary increase set up by decree on 16 August 1890."

[77] RGAVMF, f. 427, op. 2, d. 527, l. 409.

[78] According to Mendeleev's own account, he had always expected friction from military decision-makers, and thus constantly carried a copy of a resignation letter in his pocket to be produced in time of need. Vukolov, "D. I. Mendeleev i bezdymnyi porokh," 1537.

[79] Quoted in Kudriavtseva, "Novye dannye ob issledovaniiakh D. I. Mendeleeva v oblasti porokhodeliia," 241.

[80] Vukolov, "D. I. Mendeleev i bezdymnyi porokh," 1538; Averbukh, "D. I. Mendeleev i sozdanie bezdymnogo porokha," 54.

[81] Vukolov, "D. I. Mendeleev i bezdymnyi porokh," 1537. It is not exactly true that Mendeleev was totally foreign to the military establishment. Perhaps unbeknownst to Vukolov, Mendeleev had taught courses at the Nikolaevskii military academy and at the Cadet corpus. See L. G. Beskrovnyi, *Russkaia armiia i flot v XIX veke: Voenno-ekonomicheskii potentsial Rossii* (Moscow: Nauka, 1986), 192.

[82] Elting Morison, *Men, Machines, and Modern Times* (Cambridge, Massachusetts: MIT Press, 1966), Chapter 2.

[83] For an example, see MS, XXV, 444. Mendeleev's employee at the Laboratory, P. P. Rybtsov, also echoed a similar sentiment in 1907, showing the persistence of such rhetoric: Rybtsov, "Ocherk deiatel'nosti Dm. Iv. Mendeleeva v oblasti izucheniia vzryvchatykh veshchestv," 152.

[84] Meshcheriakov, *Russkaia voennaia mysl' v XIX v.,* 267.

[85] Meshcheriakov, *Russkaia voennaia mysl' v XIX v.,* 232-244; Menning, *Bayonets before Bullets,* 125; von Wahlde, "Russian Military Reform," 61-63; Beskrovnyi, *Russkoe voennoe iskusstvo XIX v., passim;* and V. D'iakov, "O razvitii russkoi voenno-istoricheskoi mysli v poslednei chetverti XIX veka," *Voenno-Istoricheskii Zhurnal* 5 (1959): 60-72.

[86] N. P. Mikhnevich, "Taktika i ee evoliutsiia v zavisimosti ot uslovii komplektovaniia voisk i tekhnicheskikh izobretenii dannoi epokhi," in L. G. Beskrovnyi, ed., *Russkaia voenno-teoreticheskaia mysl' XIX i nachala XX vekov* (Moscow: Voennoe izd. Min. Oborony SSSR, 1960): 441-451, on 444. See also the excerpt of Mikhnevich's most important discussion of gunpowder: "Vliianie noveishikh tekhnicheskikh iz obretenii na taktiku voisk," in *ibid.:* 415-440. A substantial portion of this document discusses the exact changes smokeless powder would bring about on the battlefield. By the end of the nineteenth century, the Nikolaevskii academy had switched to Mikhnevich's textbook on strategy: N. P. Mikhnevich, *Istoriia voennago iskusstva s drevneishikh vremen do nachala deviatnadtsatago*

stoletiia (St. Petersburg: P. O. Iablonskii, 1896). Soviet historians have tended to view Mikhnevich as a positivist, which is slightly inaccurate, but demanded by the historiographical restrictions imposed at the time. For one such interpretation, see A. Ageev, "Voenno-teoreticheskie vzgliady N. P. Mikhnevicha," *Voenno-Istoricheskii Zhurnal*, no. 1 (1975): 90-95. Summaries in English of Mikhnevich's thought can be found in Van Dyke, *Russian Imperial Military Doctrine and Education*, 117-118; and Menning, *Bayonets before Bullets*, 132.

[87] M. Dragomirov, "Uchebnik Taktiki," in Beskrovnyi, ed., *Russkaia voenno-teoreticheskaia mysl'* (1960) : 339-347; Menning, *Bayonets before Bullets*, 39.

[88] Menning, *Bayonets before Bullets*, 85; Bradley, *Guns for the Tsar*, 124; Kenez, "A Profile of the Prerevolutionary Officer Corps," 124.

[89] Mendeleev's recommendations on boat-fuel safety were transmitted by Vice Admiral Verkhovskii to Commander of Alexander III port on 27 Jan 1900, RGAVMF, f. 928, op. 1, d. 20, l. 37.

[90] RGAVMF, f. 417, op. 1, d. 1967, l. 160. Bernadou himself stressed how he had worked out his gunpowder independently from Mendeleev at the Naval Torpedo Station at Newport, Rhode Island in 1895-1896. Bernadou, *Smokeless Gunpowder*, 28, 174n.

[91] Dmitriev, "'Osobaia missiia' Mendeleeva," 139.