CHAPTER xx

The Making of the Soviet Bomb and the Shaping of Cold War Science

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Preface: Oppenheimer and the History of the Soviet Bomb

Until relatively recently, it has seemed a rather thankless job to study the history of the Soviet atomic project. Some basic pieces of information were solid; most others relied on ambiguous sources such as censored official accounts and propaganda, conspiracy theories of espionage "experts," circumspect memoirs, banquet speeches, unverifiable rumors, or recollections and interviews recorded long after the fact. A few outside scholars, most notably David Holloway, were capable of navigating through this swamp, separating realistic from rhetorical and deceptive descriptions.[1] Yet from the professional historian's standpoint, the situation appeared frustrating—not because historians are unable to deal with a deficient source base, but because it was all too clear that incomparably richer collections of authentic primary documents existed somewhere very near, behind concrete walls, awaiting their time to become accessible. And it was hard to predict how long the wait might last.

Then things suddenly began to change—thanks in part to J. Robert Oppenheimer's ironic role in the infamous "Sudoplatov affair" of 1994. That affair has a history of its own, which in this context merits a brief excursion. The retired KGB lieutenant-general Pavel Sudoplatov had once supervised special operations, including the assassination of Leon Trotsky in 1940 and guerilla actions against the Nazi occupiers during the Second World War. After the arrest of his boss, Lavrenty Beria, a few months following Stalin's death in 1953, Sudoplatov was also arrested on accusations of mismanaging espionage networks. He spent fifteen years behind bars, and more than twenty years thereafter trying to rehabilitate himself in the eyes of the KGB and Soviet authorities. He finally

The following abbreviations are used: *Atomnyi*, *Atomnyi proekt SSSR*. 6 vols. (Moscow, 1998-2003); *VIET*, *Voprosy istorii estestvoznaniia i tekhniki* (*Russian journal for history of science and technology*).

1. David Holloway, *Stalin and the bomb: The Soviet Union and atomic energy, 1939-1956* (New Haven, CT, 1994). For reliable accounts by "insiders," see I.F. Zhezherun, *Stroitel'stvo i pusk pervogo v sovetskom soiuze atomnogo reaktora* (Moscow, 1978) and Arkady Kruglov, *Kak sozdavalas' atomnaia promyshlennost' v SSSR* (Moscow, 1994).

succeeded in getting cleared of those earlier charges only in 1992, when the Soviet Union was no more. In the new atmosphere of the criminal market, the collapse of old values, and the search for new kinds of profit, Sudoplatov's son, Anatoly, approached the American journalist Jerrold L. Schecter with a book proposal aimed at a Western publisher. And when Schecter and his wife, Leona, a literary agent, initially showed little enthusiasm—in their opinion, the proposal lacked in names familiar to Western readers—Anatoly responded with a document from his father that briefly mentioned Klaus Fuchs, Enrico Fermi, and Robert Oppenheimer as "sources" for the Soviet atomic project. These names, in particular Oppenheimer's, helped clinch the deal. Knowing what was required to make the memoir publishable, Anatoly questioned his father for additional details and, in collaboration with the Schecters, wrote the book.[2]

The historian Robert Conquest, who proclaimed the memoir in his introduction to be "perhaps the most important single contribution to our knowledge since Khrushchev's Secret Speech," called its chapter on nuclear espionage "the most striking and informative." In this chapter, a brief and unclear reference in the earlier document developed into full-blown charges of espionage against Oppenheimer, Fermi, Leo Szilard, and Niels Bohr, who reportedly "agreed to share information on nuclear weapons with Soviet scientists."[3] Just as the Schecters had predicted, the chapter became a media sensation, driving up sales—but it was also this very chapter that almost immediately proved unreliable.[4] The attention the book initially aroused in the American media quickly subsided; but, however short, it sufficed to produce an important effect in post-communist Russia. There, uncritical attitudes towards revelations contradicting official portrayals of the Soviet era also created a media hype around Sudoplatov's book, which quite unexpectedly produced a major crack in the concrete dams of official secrecy. A presidential decree of February 1995 ordered the Atomic Energy Ministry to launch a major declassification project and publish an official volume of authentic archival documents on the history of nuclear weapons.[5]

2. Pavel Sudoplatov and Anatoly Sudoplatov, with Jerrold L. Schecter and Leona P. Schecter, *Special tasks: The memoirs of an unwanted witness—a Soviet spymaster* (Boston, 1994), esp. xvii-xviii, 481.

3. Sudoplatov et al. (ref. 2), vii, ix, 172.

4. As a result, the entire book lost credibility, although most of its problems, it appears, are confined to the chapter on atomic spies, specifically designed to meet the wishes of literary agents. Professional historians quickly pointed out many details that were supposed to corroborate the main charge of espionage, but either contradicted well-established facts or included second-hand borrowings from published descriptions of events that happened elsewhere and involved different people. See Federation of American Scientists, *F.A.S. public interest report*, May/June 1994. One of Sudoplatov's stories—that Soviet intelligence sent a physicist to Copenhagen to interview Bohr about the uranium problem—found partial confirmation; but according to independent documents, the timing, goals, and results of the mission were very different. Bohr, in particular, had been careful to not provide any specifically classified information. A.V. Andreev and A.B. Kozhevnikov, "Kopengagenskaia operatsiia sovetskoi razvedki," *VIET*, 1994, no. 2, 18-21.

5. *Atomnyi proekt SSSR*, 6 vols. (Moscow, 1998-2003), esp. *I:1*, 3.

To be sure, historians who are not part of the official team are still deprived of direct access to primary documents on the Soviet atomic project. The work has proceeded along bureaucratic lines, with a ministerial commission reviewing existing collections, deciding what can be declassified, and preparing commented publications. The scale of the entire undertaking, however, has greatly exceeded initial expectations: as of the moment of this writing, volume I (documents prior to 1945) has appeared in two books; volume II (documents on the atomic bomb, 1945-1954) has come out in four books, altogether over 4300 printed pages. Volume III (the hydrogen bomb, 1945-1956) is still in preparation. Although some understandable restrictions apply, the project—along with an accompanying wave of publications by institutions and individuals of their own stories, documents, and recollections[6]—has reversed the situation: we, the historians on the outside, are no longer in a position to complain about the lack of sources, but find ourselves behind the curve of declassification, trying to catch up, digest, and comprehend the sheer quantity of newly available documents.

The following short essay cannot pretend to offer a new synthetic analysis, which will certainly require from historians much more time, space, and effort.[7] Elsewhere I have offered a brief narrative of the Soviet atomic bomb project that includes at least some of the new evidence,[8] while here I will concentrate on a few important interpretative points. The atomic spies issue would not qualify among them: it has been discussed far too often in the literature, especially that aimed at a general public, in comparison to its actual importance for the case. Other, historically more significant aspects of the story, on the other hand, have been largely ignored and need closer attention. Three are discussed below: first, the main difficulty that could have derailed the Soviet bomb; then the most important advantage that helped the project succeed, as well as its chief strategic dilemmas; and, finally, the contribution of nuclear weapons to postwar conservatism in science—on both sides of the Iron Curtain. Each aspect gives insight into the tasks of nuclear weapons construction and the nature of U.S.-Soviet competition, as they also came to shape Oppenheimer's era.

6. See, for example, *Sozdanie pervoi sovetskoi yadernoi bomby* (Moscow, 1995); *Sovetskii atomnyi proekt* (Arzamas-16, 1995); B.L. Vannikov, *Memuary, vospominaniia, stat'i* (Moscow, 1997); V.I. Shevchenko, *Pervyi reaktornyi zavod* (Ozersk, 1998); A. Emel'ianenkov, *Arkhipelag Sredmash* (Moscow, 2000); A.P. Zaveniagin, *Stranitsy zhizni* (Moscow, 2002).

7. For some of the recent studies contributing towards a new synthesis see: V.P. Vizgin, "Atomnyi proekt SSSR: Predvaritel'nye itogi izucheniia i novye materialy," VIET, 1996, no. 2, 86-93; *Science and society: History of the Soviet atomic project (1940s-1950s), Proceedings of the international symposium* (2 vols., Moscow, 1997-1999); Gennady Gorelik, *Andrei Sakharov: Nauka i svoboda* (Moscow, Izhevsk, 2000); Christoph Mick, *Forschen für Stalin: Deutsche Fachleute in der Sowjetischen Rüstungsindustrie, 1945-1958* (Munich, 2000); Vladislav Larin, *Kombinat "Maiak"—Problema na veka*, 2nd edn. (Moscow, 2001); V.P. Vizgin, ed., *Istoriia sovetskogo atomnogo proekta: Dokumenty, vospominaniia, issledovaniia*, Vol. 1 (Moscow, 1998), Vol. 2 (St. Petersburg, 2002), esp. G.A. Goncharov, "Termoiadernyi proekt SSSR: predystoriia i desiat' let puti k vodorodnoi bombe," *2*, 49-148.

8. Alexei Kojevnikov, *Stalin's great science: The times and adventures of Soviet physicists* (London, 2004), chapt. 6.

The Critical Shortage

With the exception of a few perceptive observers whose statements in this regard remained largely unnoticed in the public perception,[9] most commentators hardly mention the single most important obstacle that severely delayed the Soviet post-Hiroshima drive to acquire atomic weapons—indeed, could have undermined it entirely. The newly available documentary evidence makes this omission hard to sustain, and the obstacle itself difficult to overstate. The matter in question is the shortage of raw materials, especially uranium.

Unlike most journalists and politicians (and many later historians), General Leslie R. Groves evidently understood that control over fissionable materials was more important for maintaining an American nuclear monopoly than anything called "the atomic secret." This consideration, according to his biographer, the late Stanley Goldberg, formed the reasoning behind Groves's optimistic postwar estimate of the length of time the Soviet Union would need to produce the atomic bomb. Indeed, one of Groves's first decisions as head of the Manhattan Engineer District was to try to acquire all the uranium from the world's richest and highest-quality deposit in the Belgian Congo. He subsequently managed to secure American control or exclusive rights over most identified resources of uranium in the world. It remained unknown to him, however, how much uranium might exist and be mined across the vast territory of the Soviet Union; his estimates in this regard must have been very approximate.[10]

As of 1945, Soviet authorities and experts themselves did not know much about the availability of uranium either, and their existing stock was negligible to the point of hopelessness. Prior to the war, uranium as a chemical element had almost no industrial use, except as a minor addition in dyes and photographic processing. There was no particular need to search for it underground, either, and most of the explored deposits were known because of the demand for radium, an element then regarded as much more useful and valuable. The geochemist Vladimir Vernadsky had initiated in 1911 a modest exploration of Russia's territory in search of radioactive ores under the auspices of the Radium Commission at the St. Petersburg Imperial Academy of Sciences. The Commission found a minor deposit of radium (and uranium) in Central Asia, and in 1918, with a subsidy from the Bolshevik government, the chemist Vitaly Khlopin, Vernadsky's collaborator, established a small factory in the Ural Mountains that in 1921 would extract the first Soviet radium from uranium ores.[11]

Uranium itself was largely seen as a by-product or even waste product of the radium industry until the discovery of fission in Germany in late 1938. Soviet physicists in

9. Holloway (ref. 1), Kruglov (ref. 1).

10. Stanley Goldberg, presentation at the conference "Wissenschaft und Krieg," Greifswald, Germany, May 1995; Robert S. Norris, *Racing for the bomb: General Leslie R. Groves, the Manhattan Project's indispensable man* (South Royalton, VT, 2002), 178-179; Holloway (ref. 1), 174; *Atomnyi I:1*, 450-462; *II:2*, 313-316.

11. *Atomnyi I:2*, 450-462; *II:2*, 313-316; Holloway (ref. 1), 174; B.V. Komlev, G.S. Sinitsina, and M.P. Koval'skaia, "V. G. Khlopin i uranovaia problema," *VIET*, 1982, no. 1, 63-75.

Leningrad learned the news about fission in a matter of weeks, but Vernadsky at his Radium Institute was alerted more than a year later, in June 1940, by a serendipitous *New York Times* clipping mailed by his son, George Vernadsky, professor of Russian history at Yale. Vernadsky and his collaborators contacted the Soviet government with a memorandum about the possible technical application of uranium in a chain reaction with slow neutrons. They emphasized geological exploration above all else and proposed to establish a State Uranium Reserve. Upon their urging, the Academy of Sciences set up a special Uranium Commission under Khlopin to coordinate research at various institutes. Disciplinary rivalries undermined the Commission's efforts, however, with physicists prioritizing research on fission proper rather than the search for raw materials. The Commission set as its goal an increase in uranium extraction to ten tons annually, but less than one ton was actually mined in 1940.[12] The entire activity stopped in June 1941, when German armies invaded the Soviet Union.

When work resumed at the end of 1942, it was physicists rather than chemists who played leading roles. Igor Kurchatov, the director of the newly established Laboratory for research on the atomic bomb, must have regretted his pre-war disagreements with Khlopin in the Uranium Commission. In early 1943 Kurchatov had less than 100 kg of uranium salts, which was not sufficient even for laboratory measurements. Necessity being the mother of invention, the coefficients of neutron diffusion were measured in so-called exponential experiments, in which scarce uranium was stretched out thinly in one dimension and the results of scattering and absorption measurements recalculated for the case of three dimensions.[13]

The virtual absence of fissionable material set the wartime Soviet project apart not only from the Manhattan Project, but even from the much smaller project in Nazi Germany, which at least had enough uranium for building a working reactor (though it failed at that task). In the rest of the world, only a few deposits of uranium had been explored prior to the war, and even fewer mined. The oldest and best-developed mines in Czechoslovakia remained under German control for the duration of the war. Almost the entire accumulated stock from the Belgian Congo was appropriated by General Groves. The Soviet atomic bomb, in contrast, required not only researching and designing the bomb itself, but also the additional task—actually much larger and more expensive—of building from scratch an entire industry of mining (and enriching) uranium. The resumption of geological exploration was ordered in November 1942; by mid-1943 the production of uranium salts reached two hundred kilograms per month, with ten tons as the envisioned (optimistic) target estimate for the year of 1944. At such a pace—Kurchatov estimated—at least five to ten years would be necessary simply to accumulate material for the first working uranium-graphite reactor

12. Holloway (ref. 1), 59-60; *Atomnyi I:1*, 113-130, 200-202.

13. A.P. Aleksandrov, ed., *Vospominaniia ob Igore Vasil'evicheVasilieviche Kurchatove* (Moscow, 1988), 276-277; Zhezherun (ref. 1); *Igor Vasilievich Kurchatov v vospominaniiakh i dokumentakh* (Moscow, 2003), 548-549.

(or a pile, as it was then called).[14] Indeed, any possibility of building a reactor, to say nothing of the bomb, was completely ruled out for the duration of the war.

The fist sizable amount of uranium came from occupied Germany in 1945. After the end of fighting, Soviet ministries dispatched several groups of engineers and scientists in military uniforms to look for valuable industrial equipment and information. In the strategically important fields of atomic and missile technologies they did not find much: most of the hardware, documentation, and personnel had already been moved to the Western occupation zones and came under the control of analogous programs on the American and British sides. Some German experts, however, remained in the Soviet occupation zone, and several groups agreed to move to the U.S.S.R. to work on military programs.[15] The most important find for the Soviet atomic project was the remainder of the German stock of uranium oxide—about a hundred tons—serendipitously discovered at a factory near Berlin where it was disguised as an ordinary chemical.[16] After subsequent reduction and purification, this amount allowed the construction of an experimental nuclear pile capable of sustaining a chain reaction. The first Soviet "boiler" F-1 used almost 35 tons of pure metallic uranium, 13 tons of uranium oxide, and 420 tons of pure graphite. It went operational in Kurchatov's Moscow laboratory on December 25, 1946.[17]

The actual bomb project, including a larger industrial-scale reactor for producing plutonium, required much more. The lack of fissionable material would remain the main bottleneck in the entire Soviet drive for the atomic bomb until 1949. During the initial postwar years, most of the uranium was coming from Eastern Europe, from the already severely depleted mines in Czechoslovakia and some deposits in East Germany and Bulgaria. Altogether, they provided almost eighty percent of the entire stock of uranium acquired by the Soviet project through 1949, when the first bomb was tested.[18] Meanwhile, in 1946 a geological party led by Antonina Likhtar' and Lidia Ivanova discovered a new uranium deposit in Ukraine. Additional sources of uranium were also found in Central Asia, and the overall balance started shifting gradually from imports toward domestic production.[19] As it turned out, uranium was not all that

14. *Atomnyi I:1*, 352, 364-365; 409; Kruglov (ref. 1), chapt. 10.
15. Mick (ref. 7); *Atomnyi I:2*, 249-250; *II:2*, 60-61, 319-321. By the end of 1946, 257 German specialists worked in the Soviet atomic project (64 scientists, 48 engineers, and 145 technicians and qualified workers). 122 of them were hired from occupied Germany; the rest were recruited from among prisoners of war. *Atomnyi II:3*, 594. The group included several prominent physicists and chemists: Manfred von Ardenne, Gustav Hertz, Nikolaus Riehl, Max Steenbeck, Peter Adolf Thiessen, Max Volmer, and a prewar émigré from Germany, Fritz Lange.
16. I.S. Drovenikov and S.V. Romanov, "Trofeinyi uran, ili istoriia odnoi komandirovki," in Vizgin, *Istoriia* (ref. 7), *1*, 215-227. Other, higher estimates of the German bounty range up to 300 tons of uranium compounds, containing 150 to 200 tons of uranium; see Zaveniagin (ref. 6), 41-43; *Atomnyi, I:2*, 282-283, 287, 323-324, 423; *II:2*, 309-310.
17. Zhezherun (ref. 1); *Atomnyi II:1*, 631-632.
18. Kruglov (ref. 1), 263.
19. *Atomnyi II:3*, 264, 276-277, 523, 540-546, 686-688.

rare, and many more deposits would be eventually discovered. Soviet ores, however, were of a considerably poorer quality and required the invention of new methods of enrichment and extraction. Economically, developing the mining industry and the supply of uranium was the most challenging part of the entire Soviet atomic project, consuming the lion's share of total expenditures and manpower and determining the ultimate timetable for acquiring a bomb.

Most construction and mining work in the Soviet atomic industry until Stalin's death was done by convicts from labor camps, who worked in dismal conditions and suffered high mortality.[20] The atomic project was a terrible burden on the nation's economy, devastated as it was by four years of war, with half the country's cities lying in ruins and peasants starving in the villages, stripped once again of all their resources so the needs of speedy postwar industrial reconstruction could be met. The total human toll of producing the Soviet atomic bomb is hard to estimate, especially considering indirect casualties caused by the diversion of resources from human consumption into the defense projects of the escalating Cold War. Yet these sacrifices seemed justified to contemporaries, who had just barely survived the most destructive war in modern Russian history and did not need further proof of the consequences of a lack of military and technological preparedness in the face of a stronger adversary.

Socialist Big Science

Standard accounts of the Manhattan Project focus on elite nuclear physicists and their formulae. Thanks in large part to Thomas Hughes, a new view has started shifting the emphasis to the management of a gigantic industrial conglomeration with advanced research as its constitutive part.[21] A separate, long-existing historiographic tradition has described the Manhattan Project (sometimes in conjunction with other American undertakings during the war or slightly before) as initiating the transition to big science, a large-scale merger of advanced science, engineering, and the development of new, primarily military, technologies. A comparison with the Soviet experience can show the narrowness and short-sightedness of this traditional narrative as well. For a structurally very similar pattern of research and innovation had developed quite broadly in the Soviet Union beginning in the early 1920s. It was known there under a different name, the Soviet or socialist model of science—or perhaps not entirely different, as "socialist science" can also be translated into American political lingo as "big government science." This earlier Soviet history, unrecognized in the old historiography, made a difference for the atomic bomb. Prior experience with a similarly managed industrial-cum-R&D infrastructure made the task of imitating and replicating the Manhattan Project decisively easier for the Soviets.

20. Zh.A. Medvedev, "Atomnyi GULAG," *Voprosy istorii*, 2001, no. 1, 44-59.

21. Thomas P. Hughes, *American genesis: A century of invention and technological enthusiasm, 1870-1970* (New York, 1989), chapt. 8.

The idea of what later became known as the Soviet model of science goes back to the crisis of World War I, when Russian academics realized how isolated their research had been from the nation's economic and industrial needs. Abandoning the cult of pure science, they started looking for practical and military applications of their expertise. During the course of the war itself, relatively little could be accomplished to compensate for the previous almost total absence of links with, or often the very lack of, relevant industry. This inadequacy, exposed at a time of a major national crisis, stimulated plans and proposals by Russian academics for thoroughgoing changes in the goals and infrastructure of the country's scientific effort. Their drafts envisioned the recognition of science as a profession separate from teaching, with the creation of corresponding positions for researchers proper, the establishment of a network of research institutes for them, and an overall turn towards practical, applied investigations.[22]

In fact, these Russian proposals were not especially unique. Similar demands for "centrally planned and government-funded" science, public science policy, the opening of special research institutions, linking science to industrial and military needs, and an increased political role for scientists were also discussed during the war by academics in other belligerent nations in Europe and even in the United States.[23] Some of those initiatives failed, while others succeeded in part or temporarily, but most were abandoned after the war. In Russia, on the contrary, they were put into practice in a much more comprehensive and abrupt form because of the revolution and the ensuing Civil War of 1918-1920. Among a number of other modernist proposals for social change, the envisioned reform of science won support from the new Bolshevik regime, which helped give a material basis to the wartime plans, with some significant modifications, and assisted their further development during the subsequent period of peace.

The Bolsheviks were seeking cooperation with "bourgeois specialists"—their term for engineers, scientists, doctors, and other holders of special (including military) expertise—without whom, they understood, they were incapable of running the national economy. The resulting compromise between Bolshevik commissars and non-Communist experts ensured for scientists and engineers a historically unprecedented degree of access to state power, as the latter en masse took on responsible positions in government offices and played important, often decisive, roles in formulating and executing many state policies during the 1920s. "Specialists" also managed to secure

22. Alexei Kojevnikov, "The Great War, the Russian Civil War, and the invention of big science," *Science in context*, *15* (2002), 239-275.
23. Frank M. Turner, "Public science in Britain, 1880-1919," *Isis*, *71* (1980), 589-608; Andrew Hull, "War of words: The public science of the British scientific community and the origins of the Department of Scientific and Industrial Research, 1914-16," *British journal for the history of science*, *32* (1999), 461-481; Zuoyue Wang, "The First World War, academic science, and the 'two cultures': Educational reforms at the University of Cambridge," *Minerva*, *33* (1995-), 107-127; Soraya Boudia and Xavier Roqué, eds., *Science, medicine, and industry: The Curie and Joliot-Curie laboratories*, Special issue of *History and technology, 13* (1997), 241-343; Ronald C. Tobey, *The American ideology of national science, 1919-1930* (Pittsburgh, 1971).

a correspondingly unprecedented level of state support, material and ideological, for the development of science and technology.[24]

As part of their mutual pact, scientists and Soviet officials quickly agreed on an organizational form: the research institute was the best and the most progressive way of organizing science. To Nikolai Gorbunov—a chemical engineer by training and the most influential early patron of science in Bolshevik circles—the concept looked so genuinely novel and revolutionary that he managed to insert a phrase about linking research to industrial production and establishing the "entire network of new scientific applied institutes, laboratories, experimental stations, and testing facilities" into the new Communist Party Program adopted at the 1919 Party Congress.[25] Sergei Ol'denburg, the permanent secretary of the Russian Academy of Sciences, summarized the mutual consensus a few years later: "while the eighteenth century was, for science, the century of academies, the nineteenth century became the century of universities, and the twentieth century is starting to become the century of research institutes."[26]

Most of the newly established institutes grew out of World War I proposals and research initiatives modified by revolutionary visions. By various estimates, some forty to seventy research institutes were founded in the country by the end of the Civil War. Some remained affiliated with universities and colleges, but more and more were institutionally separated from higher education. The favored form was the state-sponsored research institution directed simultaneously towards advanced research and utilitarian service, and usually multidisciplinary in character. The dominant organizational principles emphasized centralism, planning, and collectivism. The magnificent practical goal, even if it was not always realistically achievable, reflected the typical revolutionary combination of utopianism and utilitarianism. Hope was usually founded upon a radically novel theory or technology with revolutionary symbolism, such as radio, aviation, automobile, genetics, X-rays, or radioactivity.

One early and in many ways prototypical institute, the State Optical Institute or GOI, was founded in 1918 by physicist Dmitry Rozhdestvensky, chemist Ilia Grebenshchikov, and engineer Nikolai Kachalov on the basis of war-time collaboration between Petrograd University and the Imperial Porcelain Works for the production of optical glass and military optics. In the 1920s, GOI led the creation of the country's optical industry as the Soviet Union developed into an independent producer and later exporter of optical technology. The work done at the institute ranged from Vladimir Fock's fundamental theories of atomic spectra (the Fock-Hartree method)

24. Kojevnikov (ref. 8), chapt. 11.
25. M.S. Bastrakova, K.V. Ostrovitianov, et al., eds. *Organizatsiia nauki v pervye gody sovetskoi vlasti (1917-1925): Sbornik dokumentov* (Leningrad, 1968), 91; N.P. Gorbunov, *Vospominaniia. Stat'i. Dokumenty* (Moscow,1986), 14-15. Gorbunov's influence depended not so much on his relatively low formal rank in the party hierarchy as on his post as the secretary of the Soviet government, which provided him direct access to all important decisionmakers.
26. S.F. Ol'denburg, "Vpechatleniia o nauchnoi zhizni v Germanii, Frantsii i Anglii," *Nauchnyi rabotnik* 1927, no. 2, 88-101, on 89.

and quantum electrodynamics to design of the entire spectrum of optical devices—lamps, cameras, microscopes, telescopes, sights, etc.—for both civilian and military use. The balance between different aspects of research—fundamental and applied, military and civilian, classified and open—changed with time and often created tensions, but the basic principle of combining science with technology, and physics with chemistry and engineering, remained valid for the entire Soviet period. GOI's staff grew in the process from about 30 in 1919 to 240 in 1931 and 600 in 1936, and during World War II—now under the scientific leadership of Sergei Vavilov, the state plenipotentiary for the optical industry—the institute was responsible for supplying the Red Army with optical devices and technology.[27]

The association of special research institutes with experimental factories or workshops established the general Soviet model for industrial modernization and development of new technology, which was driven primarily by science rather than by market mechanisms. As a rule, the new institutes' tasks included production—manufacturing X-ray tubes, making optical glass, designing aircraft, or improving the sorting of grain—and many had experimental factories or production units closely associated with or administratively subordinated to research, rather then reverse. The resulting Soviet system of research and development included most of the typical features traditionally associated with big science. Although not yet as gigantic as became common after the Second World War, it still constituted a quantum leap towards bigness in all quantitative measures—personnel, instruments, networks—and gave rise to a correspondingly more complex social structure and hierarchy. The Soviet R&D system essentially relied on and required increased governmental funding for science, which often came through military channels. It institutionally linked advanced research in fundamental science with production of new technology, rather than with teaching of undergraduate students, and established a new profession of "scientist-engineer."

In the U.S., the transition to the big-science "symbiosis [,]…a fusion of 'pure' science, technology, and engineering"[28] on the basis of state funding, came about mostly as a result of World War II. At first glance, the two developments, Soviet and American, appear independent, caused by similar challenges of war and military needs; yet a missing link between them may be found in the case of Great Britain. In the Europe of the 1930s, especially in France and Britain, influential leftist intellectuals saw certain advantages in the Soviet model of science, in particular a proportionally greater share of the state budget designated for science, the recognition of research

27. V.L. Chenakal, "Optika v dorevoliutsionnoi Rossii," *Trudy Instituta Istorii Estestvoznaniia i Tekhniki*, *1* (1947), 145-167; D.D. Gulo and A.N. Osinovsky, *Dmitry Sergeevich Rozhdestvensky* (Moscow, 1980); Yu. N. Gorokhovsky, ed., *50 let Gosudarstvennogo Opticheskogo Instituta im. S. I. Vavilova (1918-1968)* (Leningrad, 1968); S.E. Frish, *Skvoz' prizmu vremeni: Vospominaniia* (Moscow, 1992).
28. Dominique Pestre and John Krige, "Some thoughts on the early history of CERN," Peter Galison and Bruce Hevly, eds., *Big science: The growth of large-scale research* (Stanford, 1992), 78-99, on 93.

as a separate profession, and the attention to placing science in service of the needs of society. Their demands for reforms contributed in France to the establishment of CNRS and a ministerial position for science in the Popular Front government of 1936. In Britain, starting in 1932, J.D. Bernal and other pro-Communist scientists working through the Association of Scientific Workers popularized Marxist views among British academics and the general public and demanded changes in the social role and standing of science. In 1937, the British government still turned down Bernal's memorandum written on behalf of the Parliamentary Science Committee proposing reform in the funding of research. As the war drew closer, however, even the Royal Society and the liberal opponents of Marxism agreed with the demand for government coordination of science, while Bernal and his supporters dropped their previous opposition to military research.[29]

With the start of the war, the Communist Bernal entered government service and played a key role in numerous military planning and research committees, seeing in the war-time mobilization of science a realization of his Marxist proposals of the 1930s. When British scientists working on radar decided to meet regularly for informal discussions with the users of their devices in different branches of the military, they called their gathering the "Sunday Soviet."[30] In this light, the wartime collaboration between Oppenheimer, a (formerly) left-wing scientist, with Groves, a (normally) anti-Communist military officer, does not look like an anomaly at all. On the contrary, it looks fairly characteristic of the wartime antifascist alliance. We know that Oppenheimer was involved in scientific and academic union drives in Berkeley in the 1930s. What still needs to be studied is how *au courant* he was with Marxist proposals for scientific reform advanced by the British and the American Associations of Scientific Workers and other socialist scientists, and what of this left-wing baggage and views he brought into the organization of the Manhattan Project.

In view of the desperate military situation, the wartime mobilization of science in the Soviet Union diverted scientists from uranium research and other uncertain long-term projects into work deemed relevant for immediate survival. In summer 1941 Yakov Zeldovich and Yuli Khariton abandoned nuclear fission for research on conventional explosives—despite having just discovered one of the two realistic scenarios for building the atomic bomb: in collaboration with Isai Gurevich, they estimated that a critical mass of some ten kilos of pure uranium-235 would suffice to produce a nuclear explosion with fast neutrons.[31] Even when nuclear research resumed in early 1943, the project remained a pilot undertaking and for the duration of the war did not

29. William McGucken, *Scientists, society, and the state: The social relation of science movement in Great Britain, 1931-1947* (Columbus, OH, 1984); Spencer Weart, *Scientists in power* (Cambridge, 1979); Maurice Goldsmith, *Sage: A life of D. Bernal* (London, 1980).

30. Guy Hartcup, *The challenge of war: Britain's scientific and engineering contributions to World War II* (New York, 1970), 24-25.

31. *Atomnyi I:2*, 469-495; Ya.B. Zeldovich and Yu.B. Khariton, "The mechanism of nuclear fission. II" [1941], *Soviet physics uspekhi, 26* (1983), 279-290.

achieve the scale of big science even by relatively modest Soviet standards. Kurchatov's wartime laboratory counted approximately a hundred workers, about twenty-five of them scientists. Concentration of resources and manpower, and their prodigal use on a scale anywhere close to the hundred-thousand-strong Manhattan Project, were simply ruled out in war-devastated and bombed-out Europe. The Soviet uranium project remained considerably smaller than even those in Germany and Britain proper, which all differed from the Manhattan Project in their limited size, the mostly academic style of their management, and the absence of large-scale industrial development and of a military general at the top.

This all changed for the Soviet atomic project two weeks after Hiroshima. On August 20, 1945, the government created a Special Committee for all work related to nuclear energy, with Lavrenty Beria at its head. As a candidate member of the Communist Party Politburo, Beria participated in making the most important political decisions; as a member of the State Committee of Defense and subsequently first deputy prime minister, he commanded the necessary branches of industry; and as former chief of state security, he continued to coordinate intelligence efforts and could mobilize the forced labor of thousands of prisoners. The productive alignment of all these resources in a gigantic military-industrial project was crucial for its eventual success, and Marshal Beria would prove himself a ruthless, cynical, and very efficient administrator. His task was quite certainly made much easier by the tradition of big science undertakings, long a familiar and recognized feature of the Soviet scientific and industrial landscape.

While the dimensions of the enterprise had to be rescaled, the basic organization remained typically Soviet—and also perfectly suited for replicating the Manhattan Project. Both projects shared the basic organizational principles of military-style management, hierarchical order of command, centralization of resources, and involvement of top academic scientists in the process of industrial development. The example of the Manhattan Project determined most of strategic directions of work in the Soviet case, but it also created dilemmas. The physicist Piotr Kapitza, a member of the Special Committee, argued that instead of squandering limited resources and imitating the American model in all its major aspects (working along a number of parallel routes, including plutonium and uranium-235, reactors with graphite and with heavy water, a variety of methods of isotope separation, etc.), a more narrowly defined, cheaper, and possibly more original solution should be explored.[32] The first option was more secure, but guaranteed massive overspending, while the second promised to be more economical but entailed a larger risk of mistakes. For Stalin and Beria at that particular juncture, as for General Groves earlier, the chief priority must have been time and security, rather than saving resources or satisfying scientists' egos. They chose the first option, also represented by the physicist Kurchatov, against

32. J.W. Boag, P.E. Rubinin, and D. Shoenberg, eds., *Kapitza in Cambridge and Moscow: Life and letters of a Russian physicist* (Amsterdam, 1990); *Atomnyi II:1*, 613-623.

Kapitza's advice. In December 1945 Stalin met Kapitza's "request" and released him from membership in the Special Committee. Stalin received Kurchatov for the first time in February 1946 and urged him not to stint on resources, but to pursue the work on a "broad Russian scale." In a public speech a few weeks later, Stalin promised scientists that many new institutes would be constructed and offered them a slogan, "To catch up and to surpass!" The motto indirectly referred to the atomic bomb and reflected the same strategic choice of following the American path.[33]

Cold War Conservatism

Subsequent stages of work, in the Soviet Union as in the U.S., involved industrial development more than scientific research. Like General Groves before him, Marshal Beria ordered the work to be conducted in parallel, often even redundant fashion, and launched the construction of industrial facilities well before completion of the necessary research. The result, in both cases, was gross overcommitment of resources, but also an increased probability of overall success and some reduction in total time, which was the main priority. Beria distrusted Kurchatov and his team of scientists, but he also distrusted intelligence reports and documents smuggled from overseas, suspecting not merely mistakes, but deliberate disinformation. Typically, the security apparatus used espionage data to place alongside the Soviet scientists' research as a system of checks and counterchecks. As an additional precaution, many if not most concrete research and design tasks in the Soviet project were duplicated, with independent teams of scientists and engineers working in an indirect race. Often they became aware of each other's existence only when, towards the end of investigation, they had to meet face to face and argue whose product or solution was to be preferred and applied. Scientists in the Soviet atomic project learned the habits of working in remote secret locations, bound by the highest degree of compartmentalization and secrecy, living under surveillance and abiding military-style discipline. As a result of the atomic bomb, radar, missiles, and other "catch-up" military projects after the end of the war, big science in the U.S.S.R. became militarized to a much higher degree than it had been during the 1920 and 1930s, or even during the war itself.

In the U.S. and Great Britain, the transition to the Cold War destroyed the temporary alliance between socialists and liberals, and between left-wing scientists and the military.[34] Some of the consequences of their collaboration—those intended, such as the increased government support for science, and those unintended or expected to be temporary, such as its high militarization—became permanent fixtures in post-bomb science. On both sides of the Iron Curtain, militarization proceeded

33. *Atomnyi II:2*, 428-436; Stalin, "New five-year plan for Russia: Election address," *Vital speeches of the day*, *12:10* (1 Mar 1946), 300-304.

34. Jessica Wang, *American science in an age of anxiety: Scientists, anticommunism, and the Cold War* (Chapel Hill, NC, 1999).

along the two main paths: the movement of scientists into secret, military-oriented research centers, and the increased penetration of massive military funding and classified research into ostensibly civilian institutions. Probably a large majority of academic physicists in both the U.S.S.R. and the U.S. during the postwar decade did at least some military research. Many moved between classified and academic settings and ran parallel projects in both, often within the same laboratory buildings and with the same or similar set of instruments (purchased with military funds for the needs of the classified part of research).

Such a hybrid lifestyle brought changes in the predominant mentality of physicists and the types of projects they considered most worth pursuing even in their non-secret, academic research. Paul Forman has described one of these changes as "gadgeteering," or the tendency to define and value scientific projects in terms of the special gadgets they produce rather than knowledge per se.[35] Another, somewhat related, consequence was a generally more conservative intellectual atmosphere in science—conservative not in the sense of denying progress, but in defining it in terms of extensive development (the famous "endless frontier") while preserving the basic conceptual foundations of the existing knowledge. In post-bomb physics, in vogue were technical virtuosity and the prediction and calculation of complex effects—rather than radical conceptual revolutions, the subversion and overthrow of science's most basic laws, the activities valued most highly by physicists in the first half of the century.

One of those who felt and disapproved of the change in dominant mood was David Bohm, a former student of Oppenheimer who received his Ph.D. in Berkeley during the war and worked there on a project marginally related to the question of isotope separation. In 1947 Bohm moved to Princeton as an assistant professor, and like many American physicists returning to academic positions from wartime projects, he faced a decision on what topics to choose for further research. Oppenheimer, among others, advised him to work on renormalization and nuclear physics, then the hottest and most career-friendly trends, simultaneously fundamental and appreciated by military patrons. Bohm ignored the well-meaning advice of senior colleagues: he was already developing an aversion to nuclear physics as a fundamentally boring and intellectually uninspiring field.[36]

In Bohm's view, the postwar physics community was becoming too conformist, mindful of hierarchy but driven by mindless fashion. Putting aside their ability to think

35. Paul Forman, "Into quantum electronics: Maser as 'gadget' of Cold-War America," Paul Forman and J.M. Sanchez-Ron, eds., *National military establishments and the advancement of science and technology*, (Dordrecht, 1996), 261-326.

36. "Every time I hear the word 'nuclear physics,' it calls up to my mind an image of the most boring possible subject in the world. The surest way to discourage me from working in the quantum theory would be to continually remind me that it might be useful in nuclear physics." Bohm to Melba Phillips, late 1951 or early 1952, David Bohm Papers, Birkbeck College, London, C 46. See also Bohm, oral history conversations with Maurice Wilkins, Niels Bohr Library, American Institute of Physics, College Park, MD, 304-305, 320.

independently, physicists were behaving like sheep, jumping on the "bandwagon" of what was at the moment regarded as prestigious, and judging each other accordingly. Even Oppenheimer, the once revered teacher, has changed in that direction. Bohm commented: "I felt that was really very dull…I would have felt at the time…that if I had the qualities which enabled me, like Oppenheimer, [to] join the bandwagon and do what the majority were doing, then probably I would never have become a physicist. I would have become a furniture man. I would have become a businessman and perhaps one of the leading furniture dealers in Wilkes-Barre."[37]

Bohm preferred searching for unusual ideas, asking deep questions and thinking about foundations—a choice that a few years later led him to develop a causal interpretation of quantum mechanics. Bohm's theory explicitly contradicted the dominant Copenhagen interpretation, itself a revolutionary novelty a generation earlier, but a dogma during the early Cold War period. Running against the prevailing mood in the discipline cost Bohm dearly—his ideas were almost completely ignored for more than ten years—not so much because of the active opposition from the Copenhagen camp, but due to indifference on the part of his colleagues, who looked down upon such pursuits as unworthy of real professionals, preferring instead concrete results and calculations. Just as Bohm's Marxist beliefs and former Communist connections made him a political outcast in McCarthyite America, leading to the loss of his job and exile, his critical attitude towards the existing foundations of science made him marginal in the profession, his findings rejected by Cold War physics.[38]

As Bohm discovered with astonishment a few years later, a similar intellectual conservatism developed among the Soviet physics community, also in part because of the bomb. Initially, many Soviet physicists who went to work on the atomic project felt that they were sacrificing opportunities to accomplish more original research in fundamental science. Lev Landau was among those few who agreed to do the bomb work out of fear—in a precarious position after spending a year in prison during the Stalinist purges of the late 1930s, he felt that classified research provided additional protection. He still kept his involvement rather limited and withdrew at the first available opportunity after Stalin's death. Others, including Khariton, Kurchatov, Andrei Sakharov, Igor Tamm, and Zeldovich, participated out of a sense of moral and patriotic duty. Amounting to several years of complete engagement for some,

37. Bohm, oral history (ref. 36), 304-308.

38. On Bohm see David F. Peat, *Infinite potential: The life and times of David Bohm* (Reading, 1997); Russell Olwell, "Physical isolation and marginalization in physics: David Bohm's Cold War exile," *Isis*, *90* (1999), 738-756; Alexei Kojevnikov, "David Bohm and collective movement," *Historical studies in the physical and biological sciences*, *33:1* (2002), 161-192. On Bohm's interpretation of quantum mechanics, see Olival Freire Jr., "Science and exile: David Bohm, the hot times of Cold War, and his lasting struggle for a new interpretation of quantum mechanics," paper presented at the workshop on "Migrant scientists in the twentieth century," Milan, June 2003; Olival Freire Jr., "Quantum controversy and Marxism," *Historia scientiarum*, *7* (1997), 137-152.

for others becoming a lifelong commitment, no matter how strongly they felt about the necessity of the bomb work, they could not help regretting their diversion from fundamental physics. Not only did they view the atomic project as more technological than scientific, but also they found that the ultimate goal of the work consisted in large part of repeating and reproducing what had already been accomplished overseas.[39]

Kapitza's advice in 1945 to have it both ways—follow an original path and build the bomb—was rejected in favor of the strategy "to catch up and to surpass!" that minimized time and risks. Implementing this slogan in practice meant more often than not following the American lead, adopting many of the same strategic choices and goals, expending huge efforts and funds on catching up, usually trailing, while occasionally using chances to actually surpass, as happened with the hydrogen bomb of Sakharov's design. Some occasionally very heated discussions among Soviet physicists outside the atomic bomb project involved the same dilemma: whether to compete with American physics on its own terms or to seek entirely original directions in research. The latter choice entailed serious risks, which were particularly high in the Stalinist Soviet Union and were demonstrated there so disastrously by the 1948 Lysenko example in biology. Lysenko succeeded for a time being in persuading a large following and the political authorities that his theories were actually superior to foreign ones, but the majority of Soviet physicists saw him even during the period of his official dominance as a charlatan and imposter. For them then as for us now, Lysenko's rejection of international genetics meant great damage inflicted upon the whole of Soviet science.[40]

The combined positive example of the highly successful and appreciated atomic bomb project and the negative example of politically supported but ultimately disastrous Lysenkoist biology made Soviet scientists particularly wary of arguments in favor of seeking original socialist paths in science. Even after the completion of the main goals of the atomic project by mid-1950s, as military research was losing prestige and Soviet physicists were returning to civilian institutions and fundamental science, they brought back many of the new habits and attitudes acquired in the course of the bomb work.[41] Nuclear physicists became used to operating with industrial-scale resources and institutions and demanded similar level of support for their civilian projects. They also extended the same "catch up and surpass" strategy as the right way to compete in Cold War science in general. The ubiquitous slogan worked not only for physics, but also in other branches of postwar science, military and civilian alike. Interiorized and uncritically accepted by the wider academic community, it not only survived Stalin's death in 1953, but determined the mentality of Soviet science for decades thereafter.

39. See, for example, Andrei Sakharov, *Memoirs* (New York, 1990)
40. See the most recent account of the Lysenko affair and citations to the earlier literature in Nils Roll-Hansen, *The Lysenko effect: The politics of science* (Amherst, NY, 2004).
41. Konstanin Ivanov, "Science after Stalin: Forging a new image of Soviet science," *Science in context*, *15* (2002), 317-338.

In other European countries after the end of World War II, scientists faced the same dilemma as they contemplated strategies for coming to terms with the predominance of American science, methods, and money—and usually made the same choice of following overseas trends. The alternative—competing along different paths, as had usually been the case in scientific rivalries between leading European nations during the nineteenth and early twentieth centuries—was occasionally discussed, but more often than not deemed less promising of success or too risky.[42] For international science, the overall effects of the bomb and the Cold War resulted in a significant loss in diversity.

The bomb has long been seen as a milestone separating the two parts of the twentieth century with regard to governmental support for science, its militarization, and the overall dimensions of the scientific enterprise. It can also be seen as a milestone with regard to the trends discussed above: gadgeteering, homogeneity, and conservatism in attitudes towards the most basic conceptual foundations. These trends did not go unchallenged, in particular during the 1960s, but for the most part survived and continued to operate with fluctuating strength for the remainder of the century.

As does anyone who teaches the history of modern science, for my students I face the task of explaining why the first half of the twentieth century produced revolutions of basic scientific concepts, whereas the second, by comparison, was rich in devices, expenditures, and published papers. Helge Kragh, in his monumental history of twentieth-century physics, brings this curious phenomenon full circle.[43] His book opens with the often quoted view of the 1890s that the most basic laws of physics had already been established and were not expected to undergo major changes. Kragh's conclusion—five hundred pages, a great conceptual revolution, and over a hundred years later—evokes a similar feeling shared by the author and the majority of physicists at the end of the twentieth century. Can one not sense an irony here?

42. Pestre and Krige (ref. 28).

43. Helge Kragh, *Quantum generations: A history of physics in the twentieth century* (Princeton, 1999).