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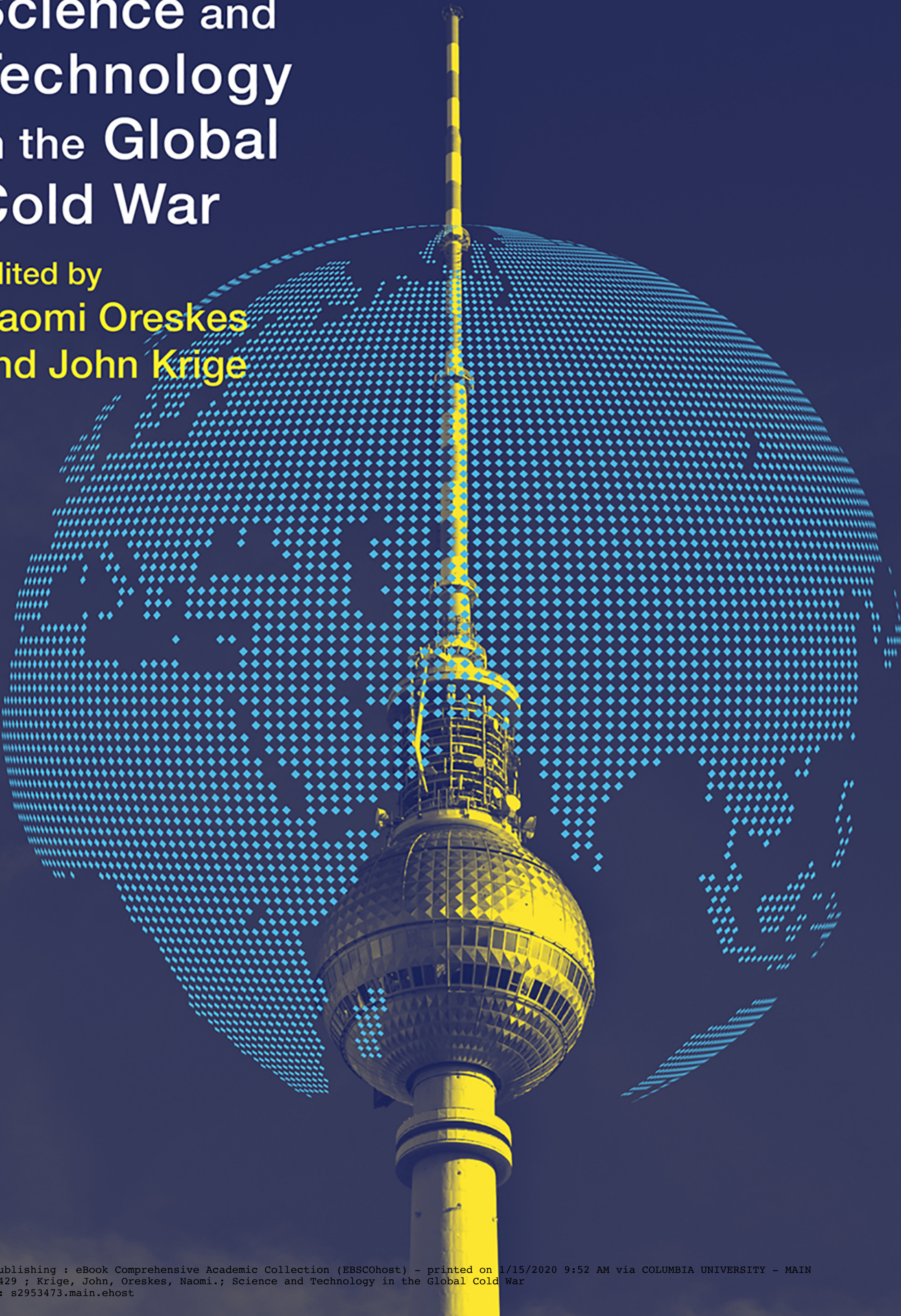

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6 Fighting Each Other: The N-1, Soviet Big Science, and the Cold War at Home

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In August of 1989, a few months before the fall of the Berlin Wall, the official newspaper of the Soviet government, *Izvestiia*, published a long essay by Sergei Leskov titled "How We Didn't We Land on the Moon."[1] Leskov, *Izvestiia*'s science journalist, had been trying to publish the piece for some time, but Glavlit, the Soviet Union's censorship agency, had repeatedly rejected his appeals. Later he recalled that "even in 1989, when there were no limits to *glasnost'*, it was such a great effort to publish the essay."[2] When it finally appeared in print, with the personal permission of a top-ranked minister, the essay caused a minor sensation. In the piece, Leskov mentioned a rocket that few Soviet citizens had ever heard of (the N-I) and a program that had never been officially acknowledged (a 4.5-billion-ruble project to land a Soviet cosmonaut on the moon in the 1960s).[3] For more than twenty years, the effort had been whitewashed out of history; save for the occasional rumor and the speculations of a few Western observers, there had been no indication that one of the Soviet Union's largest, complex, and most expensive engineering projects of the Cold War had collapsed in a series of rocket explosions in the late 1960s and the early 1970s. The Soviet project had been hidden so well that some saw Neil Armstrong's triumphant step on the moon in 1969 as a pyrrhic victory. For example, in 1974 the American newscaster Walter Cronkite commented "It turned out that the Russians were never in the race at all."[4]

After Leskov's piece appeared in *Izvestiia*, more and more articles added to this recovered history. People whose names had been classified granted interviews, and journalists, given free rein, were able to put flesh on a skeletal tale that seemed to symbolize the institutional dysfunction of late-period Soviet science.[5] Managerial gridlock, technological limitations, and economic shortages had plagued the N-I project from the very beginning. But as journalists, historians, and participants reflected on the reasons for the catastrophic failure of the project, they kept returning to a central episode in the narrative: a clash of personalities that all claimed doomed the project at its very inception. Sergei Korolev, the famous "chief designer" of the Soviet Union's spaceships and Valentin Glushko, the chief designer of its rocket engines, had almost come to blows over the selection of propellants for the N-I and eventually ceased communicating with each other. Korolev was left to guide the N-I project to success without Glushko. Despite the best efforts of thousands of engineers, and just as Glushko had warned, the N-I program—a quintessential yet largely unknown exemplar of Soviet big science and technology—eventually collapsed in a pile of rubble.

Big Science in the Soviet Context

Since the early 1990s, historians have devoted considerable attention to the fate of "big science" during the Cold War.[6] Having emerged out of interwar research and development into a full-blown phenomenon during World War II, such large-scale government-sponsored projects typically involved money, manpower, monumental machines, and often the military. In revisiting the Cold War, historians found that big science, and scientific practice in general, was hard to divorce from the forces, stresses, and demands of the national-security state. Scholars argued that scientific practice, at the institutional, cultural, and epistemological levels, thrived on instrumental, overlapping, and symbiotic relationships with high politics. Big science, because it was funded by the state, took on features that reflected the state's priorities. The possibility that Cold War imperatives altered the direction of particular disciplines was highlighted most famously in Paul Forman's meditation on how military patronage shifted scientific priorities in the United States from theoretical to applied physics.[7]

In the Soviet case, the notion of big science has meant different things to different people, but two central defining assumptions guided scholars working in the pre-archival period: the scale of the effort and the pervasive role of the state, or, as the historian Loren Graham has noted, "its bigness and high degree of government centralization."[8] In other words, the scale of Soviet science during the Cold War and its seemingly close and almost indistinguishable alignment with state sponsorship and priorities underscored the notion that big science and Soviet science were synonymous concepts. In defining what was meant by "big," Graham added that, "Soviet science was 'big' in several different ways: large in numbers of researchers, highly centralized in organization, and dominated by powerful leaders."[9]

Beyond scale and sponsorship, historians discerned other features of Soviet big science. Already by the early 1930s, the three major constituent elements of Soviet science were firmly set in place. These—the university system, the Soviet Academy of Sciences, and the industrial ministry system—represented three points of a pyramidal structure that employed hundreds of thousands of scientists, engineers, technicians, and workers at its peak in the 1970s. This tripartite system inherited traits from pre-Revolutionary Russian science. Alexei Kojevnikov identifies, in particular, the formation of research institutes separate from higher education and the emphasis on applied over basic research as embryonic and ultimately enduring features of the Soviet scientific system that first emerged during the 1910s.[10] These peculiarities became more evident after the Revolution when leading Bol'sheviks fully embraced a more utilitarian approach to science and technology. To the extent that applied science efforts translated to "technologies for the masses" (to use inspirational parlance from the 1930s), Soviet science became closely intertwined with what some have called "gigantomania"—a penchant for the monumental in many infrastructural and industrial projects.[11] According to this interpretation, Stalinist ideologues (and their successors) saw science and technology as most effective when a utilitarian ethos was combined with ostentatious and awesome exhibitions; in other words, science and technology had to both serve *and* represent the nation. This combination of size, science, and spectacle was most obviously embodied in such projects as the Moscow Metro, the Dneprostroi Dam (and hydroelectric station), the trans-Siberian railroad, and the Tu-144 supersonic transport.

In reflecting upon Forman's claim about the Cold War altering the balance between fundamental and applied science, in the Soviet context, the problem might be more accurately characterized as an appropriate distribution between theory and praxis. Marxists would have articulated this relationship as a demand that the production of scientific knowledge be closely connected to the economic, industrial, and *practical* needs of society. In Stalinist times, this requirement was frequently articulated and manifested in the priorities of the Soviet scientific establishment.[12] One of the fundamental campaigns of Stalinist science was to reinforce the link between scientific practice and the real needs of Soviet society, a quest made much more urgent during World War II. In one sense, the postwar development of the atomic bomb—perhaps the most expensive Soviet scientific project ever, facilitated as it was by a web of institutions spanning the Academy of Sciences system, the defense industrial ministries, and the security services—can be seen as emanating from this mapping of theory with praxis.[13]

The nuclear project also established a precedent for postwar Soviet big science in fortifying the deep connection between science and military requirements. The alignment between science and defense in the Soviet context was difficult to ignore; during the postwar era, the lion's share of state investment in science and engineering was devoted not to the Academy of Sciences or the universities but to the industrial ministry system dominated by the nine ministries that made up the core of the Soviet military-industrial complex.[14] By 1990, 87 percent of the Soviet R&D budget was allocated for the industrial network, most of it for military needs, leaving the remainder for the Academy of Sciences and the universities.[15] Through institutional connections or by research priorities, Soviet science during the Cold War era was deeply enmeshed with the military-industrial complex. Science and defense (with some exceptions) coexisted as one, as the "normative" state of Soviet science. Here, interrogating whether military imperatives altered the priorities (and nature) of Soviet science during the Cold War promises few insights—the answer would unequivocally be affirmative. But priorities don't tell the whole story; what other factors distinguished Soviet science during the Cold War from its predecessors? For example, did civilian imperatives, particularly the demand to *display* or "civilianize" certain science projects that were military in nature (and thus secret) reinforce certain ideological and functional characteristics of Soviet science during the Cold War?

These questions framed around the tension between the military and the civilian (and between secrecy and publicity) lead us to other seeming dichotomies relevant to the broader context of Soviet science in the post-Stalin era. The conflicting demands of theory and praxis, for example, were loosely manifested in a battle between two competing constituencies, the first comprising scientists invested in the basic sciences (particularly physics) who had accrued the perquisites of state patronage and desired a science that was "detached" from the practicalities of the day and the second comprising engineers (especially missile designers) who emerged in the late 1950s as a powerful bloc of specialists in what Russians understood as the "technical sciences" (*tekhnicheskie nauki*)—generally fields that Westerners would consider applied sciences or engineering.[16] Here we see the mutable boundaries between science and engineering, distinctions frequently lost to official Soviet spokespersons who advertised, for example, the successes of Sputnik and Gagarin as successes of "Soviet science" rather than "Soviet engineering" or "Soviet industry." In this context, it was not a little ironic that the principal body associated with Soviet science, the Academy of Sciences, was hardly involved in either Sputnik or the launch of the first human in space, Iurii Gagarin.[17] Yet the Soviet engineers who directed the space program not only embraced this conflation between science and engineering but actively encouraged it, even though they had largely been educated in entirely different institutions than pure scientists. In the early 1960s, the rocket engineers assumed for themselves the mantle of the public notion of "Soviet science," a role held for more than a decade by Soviet physicists.

The N-I rocket program, one of the largest science and technology projects implemented during the post-Stalin era, carried within it all these conflicting (and conflated) tensions: between fundamental and applied science, science and engineering, civilian and military imperatives, display value and maintaining secrecy. In each case, the program was never entirely one or the other, but usually a mix of both. Such ambiguities destabilize the conceptual framework of historians such as Loren Graham and Paul Josephson, who, in many ways, exchanged idealized features of the Soviet *state* with those of Soviet *science*. By focusing exclusively on those aspects identified with the centralized state, they missed important phenomena—among them the popular and populist campaigns for science and, in the case of big science, the messy complexities and ambivalences that subvert Western stereotypes of orthodoxy, centralization, and lack of innovation. In this chapter, I explore all these complexities and ambiguities through one critical episode in the early history of the N-I project: the selection of propellants and rocket engines for the rocket. In this debate, the two principal actors in the Soviet space program, members of a new and powerful constituency of missile engineers who had become influential stakeholders in the system of Soviet science, found themselves on opposing sides. The result was a project that perfectly embodied the contradictions and heterogeneity of Soviet science during the Cold War.

The Rise of the Space "Scientists"

By the mid 1950s, Soviet physicists—particularly, nuclear physicists—had acquired, in the words, of David Holloway, "unprecedented authority among the political leaders."[18] Soviet physicists' link to state power was underscored during Nikita Khrushchev's visit to Britain in 1956 when he introduced to Winston Churchill "Academician Kurchatov, who makes our hydrogen bomb."[19] The physicists also enjoyed a public role, fostering public interest in the possible uses of atomic energy for civilian purposes and reinforcing the notion that nuclear power was a panacea for a whole host of social ills.[20] Of course, the community of nuclear physicists did not act as one, nor did they share identical goals for the future of Soviet physics, but their influence was evidenced by the disproportionate power welded by the Division of Physico-Mathematical Sciences, the Academy section to which physicists belonged.

Both nuclear physicists and missile engineers took part in designing strategic weapons, but the missile engineers had little or no clout until the mid 1950s; their handiwork up until then—short-range missiles derived from the German V2—had been less than impressive. The first sign that rockets might have strategic uses appeared in 1953 when Sergei Korolev and his team in the northern Moscow suburb of Kaliningrad began test-firing a missile capable of flying 1,200 kilometers, just far enough to reach Great Britain. By early 1956, Korolev's engineers had modified this rocket, now known as the R-5M, and made it ready to carry a nuclear warhead. First launched on February 20, 1956, the missile flew 1,190 kilometers in a little over 10 minutes and deposited its 20-kiloton bomb over its target area in the Semipalatinsk range, where it exploded in a spellbinding inferno.[21] It was the first such missile test in the history of nuclear weapons. This naked display of power, spearheaded by Marshall Georgii Zhukov and leading nuclear physicists, was a watershed moment for the rocket designers, for it brought them, for the first time, squarely into the sights of top Party and government leaders. For nearly a decade, the missile engineers had been considered junior members in the pantheon of Soviet weapons makers. But by cooperating with famous nuclear project managers such as Igor' Kurchatov and Avramii Zaveniagin on this experiment, missile designers managed to equalize the power relationship with the nuclear empire.

Remembering the initial collaboration with the high-profile nuclear physicists, one of Korolev's senior test engineers noted:

At the start of this work Sergey Pavlovich [Korolev] gathered the project leaders to make a speech concerning the program. This was a meeting before the start of work with the atomic people. … The first thing he said was that we ought to be very careful in our activities … because they had been spoilt, first, due to publicity and second, because they considered themselves superior to everybody else … after developing the atomic bomb. … S. P. Korolev said that at least in the beginning we should pander to them. But pander very precisely and carefully such that in the end we would prove to them that we were in the driver's seat and they were merely passengers.[22]

The success of the R-5M test swiveled the center of gravity of influence away from the nuclear elite for the first time since they began their work in 1945. After 1956, missile designers, especially Sergei Korolev, began to have increased access to the top levels of the Kremlin. This was reflected both in symbolic and practical terms. A week after the nuclear test, Nikita Khrushchev, Nikolai Bulganin, Viacheslav Molotov, and several other Politburo members graced Korolev's design bureau with their presence, a rare honor accorded to few design organizations.[23] In his memoirs, Khrushchev conceded that the visitors were bewildered by the rocket, "walked around [it] like peasants at a bazaar ready to buy some calico, poking it and tugging to test its strength," but noted that "the leadership was soon filled with confidence in [Korolev]."[24] On April 20, the Supreme Soviet bestowed on three nuclear scientists, Andrei Sakharov, Iulii Khariton, and Iakov Zeldovich, the USSR's highest civilian honor, "Hero of Socialist Labor." For the first time missile designers were among the honored: they included the six main chief designers involved with the R-5M project, Sergei Korolev, Valentin Glushko, Nikolai Piliugin, Mikhail Riazanskii, Viktor Kuznetsov, and Vladimir Barmin, and Korolev's right-hand man, Vasilii Mishin. Many other junior designers in the missile industry were simultaneously given less prestigious but notable national awards. These events significantly elevated the authority of missile designers, especially Sergei Korolev, within the Soviet defense industry. "From then on," Nikita Khrushchev's son Sergei has written, "[Korolev] could phone Father directly, bypassing numerous bureaucratic obstacles."[25] This newfound authority, established on the basis of missile development, would prove critical in firmly integrating two different aspirations among the missile designers—the job of designing powerful missiles for the Soviet armed forces, and the dream of breaching the cosmos. To realize this connection, the line to the Kremlin was one of paramount importance.

Besides access to the top of the Party and government structure, the missile designers also began to make inroads into the apex of the Academy of Sciences. Traditionally, Academy members—particularly theoretical physicists—had been hostile to scholars from the technical fields, including electrical, mechanical, chemical, and aeronautical engineering.[26] Established academicians had a point: few of the leading "chief designers" from the defense industry had higher degrees, such as Candidate of (Technical) Sciences, and fewer had Doctorates of Sciences. Almost all had specialized degrees from technical schools such as the Bauman Moscow Higher Technical School. Additionally, most of the chief designers in charge of the key organizations involved in missile development had been born in the five-year period between 1907 and 1912, putting them in the demographic educated during and after the "Great Break" (roughly 1928–29), when educational reforms fundamentally transformed the curriculum to a more practical bent.[27] Many of the first generation of nuclear physicists, by contrast, were at least five or six years older and educated *before* the Bol'shevization of Soviet education, and thus more theoretically inclined than their junior colleagues.[28] Barring rare exceptions, the missile designers represented an entirely different academic sensibility and generation than the nuclear physicists, who were educated abroad or at Moscow's most elite universities.

The launch of the first ICBMs and Sputniks in 1957 provided a further boost to the fortunes of these missile designers in the Academy system. In October, despite the objection of a number of academicians, Korolev was awarded a "doctor of technical sciences" without having written a dissertation (or indeed published a single scientific paper). In December, two months after the first Sputnik, Nikita Khrushchev signed an order giving free dachas to the six members of the missile program's Council of Chief Designers.[29] The realignment culminated in 1958 with the unprecedented election of thirteen leading rocket designers into the Academy, either as full members or as (junior) corresponding members; all were voted into the now-growing Department of Technical Sciences.[30] Membership in the Academy had many material benefits but also represented public recognition from their peers in the world of basic sciences of the value of their intellectual and practical work. There were further additions through the 1960s as the Department of Technical Sciences surged with rocket designers and other professional designers from the defense industry, who were seen as interlopers by many specialists in the "pure" sciences.[31] In July of 1963, Korolev was elected to the Presidium of the Academy, the organization's highest deliberative body.[32]

No one person more expertly negotiated across the various divides of Soviet science—fundamental, applied, civilian, military—than Academy President Mstislav Keldysh, an applied mathematician by training.[33] Keldysh's stature steadily rose through the 1950s, largely because of his close working relationships with influential members of the scientific elite such as Kurchatov and Sakharov. With rising clout, Keldysh's portfolio diversified; by the mid 1950s, he was directly involved in thermonuclear weapons development, ICBM design, the intercontinental cruise missile project, and the development of supercomputers.[34] After becoming president of the Academy in 1961, Keldysh served as one of the most prominent public faces of Soviet science, even as a vast amount of his energy was, in fact, devoted to advising on the development of various Soviet armaments. By serving as the chairman of numerous "interdepartmental" review commissions tasked by Nikita Khrushchev or Leonid Brezhnev to evaluate important weapons systems, he influenced the outcome of many intractable conflicts between designers. Keldysh's personal opinion (or relationships) were thus important barometers of the direction of such massive Soviet scientific and technical projects as anti-ballistic missile systems, research on charged particle beams, high-speed computing, and, most important, the space program.

Scientific research constituted a very small portion of the early Soviet space program, especially in the 1960s. In fact, the effort was overwhelmingly dominated by military infrastructure, needs, and services. In the formative years, almost every single aspect of the program, from the smallest electronic component to the largest networked system, was produced *by* the Soviet defense industry. On the client side, the spacecraft and rockets were all produced *for* the Soviet military. And all of the infrastructure was operated by the armed forces. Dedicated scientific projects were extremely rare in the first decade of the Soviet space program, and even those had a strong military bent to them.[35]

The most prominent contracting organization in the Soviet space program—similar in many ways to a giant aerospace firm in the Western context—was the Experimental Design Bureau-1 (Opytno-konstruktorskoe biuro-1, abbreviated OKB-1), based in the northeastern Moscow suburb of Kaliningrad (or Podlipki) and headed by Sergei Korolev. In the late 1950s, OKB-1 had driven the agenda for the early Soviet space program benefiting from its leading role in developing Sputnik and the rocket that launched it. In subsequent years, OKB-1 created further Sputnik and Luna spacecraft, and by the early 1960s it enjoyed a dominant position within the emerging space program, thanks largely to Korolev's headstrong personality and unbridled ambitions. Although only OKB-1's space accomplishments were known to the outside world, the overwhelming bulk of its work was dedicated to developing military systems, particularly ballistic missiles and intelligence-gathering satellites. This preference for military systems, dictated largely by the military, clashed with Korolev's personal interest, which was increasingly drawn to the kind of space exploration that inspired science fiction buffs. Weaned on the ideas of the early-twentieth-century theoretician Konstantin Tsiolkovskii, Korolev's vision for the Soviet space program—much like Wernher von Braun's for the American program—saw it as expanding progressively from Earth orbit to the moon and eventually to the inner planets.[36]

Korolev's monopoly, both in developing missiles and exploring space, faced stiff competition in the early 1960s as other ambitious designers began to encroach on his domain. By the time of Gagarin's flight, in 1961, two other prominent designers, Vladimir Chelomei and Mikhail Iangel', challenged Korolev's monopoly and influence in the space arena.[37] For all three, work on civilian spacecraft was at best a luxury, allowed if their primary work on missiles was not impeded in any way. In this situation, the missile-designers-turned-spacecraft designers faced a conundrum. The most effective way for them to accrue publicity was to engage in space activities that resonated deeply with a newly proud and hopeful Soviet populace. Yet their bread and butter—their funding—came from the armed services, which resisted their penchant for wasting time on space-related activities.[38] This dilemma was central to the battle that tore the N-I program apart.

The Market for Innovation

The increased authority of missile designers in the wake of the space successes of the late 1950s gave them unprecedented influence on the direction of future space research, particularly because the upper management had less expertise in evaluating the technical efficacy of space-related proposals than in assessing missile-related ones. In the post-Sputnik era, the Communist Party and the government had overlapping structures to direct and manage the space program. The most important organ at the government level was the so-called Military-Industrial Commission (Voennaia-promyshlennaia komissiia, VPK), representing the various ministries and industrial branches responsible for building hardware. The commission, established in December 1957 in the wake of Sputnik, was tasked with "leadership and monitoring of work on the creation and quick introduction into production of rocket and reactive armaments and other forms of military technology, and also to coordinate this work between branches of industry independent of their branch affiliation."[39] The VPK was established to coordinate work on all Soviet military technology—not only rockets but also tanks, airplanes, guns, ships, and submarines—but its leaders were largely grizzled veterans from the missile industry who were on good terms with missile designers such as Korolev and Iangel' and more receptive to their proposals than, say, to a proposal from a submarine designer.[40] On the other hand, these industrial managers were more than a bit bewildered by all this talk of space exploration; they had only the barest level of expertise with which to compare a wildly ambitious Mars-exploration program using ion-engine-equipped winged spacecraft (as Chelomei proposed) or a modest and sober idea for a film-return reconnaissance satellite (as Korolev proposed). This combination of familiarity with missile designers and lack of knowledge about space systems produced a systemic problem: there was a welcoming environment for the missile designers to send up all sorts of outlandish ideas for approval, but a lack of expertise to evaluate their value.

Conventional wisdom has it that the Soviet defense industry operated in much the same way as the rest of the economy, i.e., that this was a centrally driven command economy with no market choices. Already during the Cold War, it was evident to some Western analysts that this was not so. "Competition," David Holloway noted in 1984, "has been a common, though by no means universal, practice in the development of new weapons, especially of aircraft and missiles. Two or more design bureaus might be given the same requirements and asked to produce designs: the Ministry of Defense then selects the best design for development. This gives the customer a degree of choice unusual in the Soviet economy."[41] Recent evidence confirms this view that a uniquely Soviet quasi-market competition existed at certain stages of weapons design as a result of practices that dated back to the 1930s.[42] Naturally, both the buyer and the sellers of weapons systems were owned by the state; yet, at key points in the research and development process, market behavior very similar to US weapons research and development was tolerated; this quasi-market emerged at the level where the clients (usually, a broad coalition of representatives from the military-industrial complex) had to arbitrate between multiple proposals for a new weapons system. In principle, this meant that the military would select a particular designer's idea from a pool of proposals sent up to the VPK, based on a fit with requirements for the weapon. In practice the process rarely operated as expected.[43] Instead, other more subjective factors intervened. Favoritism predicated on professional and personal networks was crucial in the process; Chief Designer Mikhail Iangel', for example, hailed from Dnepropetrovsk, the Ukrainian industrial city where Brezhnev had served as a regional Communist Party secretary. Designers, like American companies responding to a request for proposals, also wildly exaggerated the capabilities of their own systems and promised highly optimistic timetables. Most crucially, they would each invoke American superiority in a particular field and guarantee that they and they alone could counter the potential threat. To the designers, new projects guaranteed continuing funding, and if they expressed some outward camaraderie or publicly appealed to a common national purpose, at the design proposal level, they were deeply competitive and often hostile toward one other. Each major chief designer of a weapons system ruled over a fiefdom whose well-being (and often existence) depended on large and continuing contracts.

The result was a chaotic research and development process that belied the public image of a command economy pursuing a sustained and well-conceived path. In reality, the VPK was completely unprepared to handle the large influx of proposals about future plans and, often, based on lobbying from a particular designer, approved multiple proposals for the same requirement, fearful that they would be treading on the toes of powerful patrons in Party and/or government who supported these ambitious chief designers. This combination of increased authority due to the successes of the early space program, personal connections with senior VPK officials, the (mis)use of technical knowledge as leverage, and inefficient institutional mechanisms meant that bureaucratic chaos was the norm rather than the exception in implementing large-scale Soviet space projects. And as more and more ambitious chief designers entered the fray by the early 1960s, formulation of any long-range and sustained vision of the

Soviet space program became all but impossible as the process became mired in petty disagreements nearly impossible to arbitrate.

A Tale of Rocket Propellants

The idea for a “super rocket” for the Soviet space program emerged as a part of plans to augment the standard and moderately powerful R-7 that had lofted the early Sputniks into orbit. As early as 1956, Sergei Korolev had referred to an idea for a massive rocket with a launch mass of 1,100 tons.[44] Such preliminary studies culminated in an intense period of investigation in early 1960 to develop some requirements and basic design choices. At this point, neither Party nor military officials evinced much interest in this idea, the former seeing this as a potentially costly diversion from immediate needs and the latter believing that a heavy-lift rocket would not be militarily useful. A meeting between Khrushchev and the leading space designers in January of 1960 appears to have altered the landscape, with Khrushchev calling for more intense efforts to develop space projects to respond to what he saw as ambitious American plans.[45] At the same time, Soviet military planners found statements from important American officials such as Senator Lyndon B. Johnson, the Democratic Senate Majority Leader, and Herbert F. York, the director of defense research and engineering at the Department of Defense, as being belligerent and advocating increased militarization of space. As a result, in the first few months of 1960, Soviet space designers scrambled to come up with an appropriate response, a grand seven-year plan for space exploration that would emphasize military operations. The central point in this ambition would be the development of a super-rocket.

After an intense series of negotiations, the Party and the government approved a long-range program of research on space travel in June of 1960. The heart of this program was assigned to Korolev’s OKB-1, which was to create “a new powerful rocket system with a launch mass of 1,000–2,000 tons” capable of putting 60 to 80 tons into Earth orbit and sending 20 to 40 tons on translunar and interplanetary trajectories. The main goal of such rockets would be to launch a “heavy interplanetary ship.” According to the plan, by 1962 there would be a initial rocket known as the N-I, and by 1967, and a more powerful one, the N-II. In drafting the decree to ensure that it would be approved at the highest level, Korolev and his associates noted that such super-rockets could be used for launching “space battle stations” into orbit and used for all manner of military operations in space, including “monitoring space and destroying enemy … satellites” and reconnaissance missions and even for hitting ground targets from space.[46] Tellingly, none of these ideas for military applications came from the military; high officials in the Strategic Rocket Forces had no idea why they needed such a powerful rocket, and had, in fact, stayed out of the discussions on its specifications. As was not uncommon for weapons projects on both sides of the Cold War divide, this was a case where the contractor spent an inordinate amount of time trying to convince a client why they needed something that barely interested them.

As money for the new super-rocket project started to flow in, there were a number of decisions to be made about its design. The most contentious of these centered on the engines, whose designers drew on the science of chemical propellants, dating back to the early twentieth century. In 1903, when the Russian theorist Konstantin Tsiolkovskii first mathematically substantiated the possibility of space exploration in a published essay, he noted that the most energetic rocket propellants would be a combination of liquid hydrogen (fuel) and liquid oxygen (oxidizer).[47]

A rocket engine's measure of efficiency, which depends on the characteristics of the chemicals in question, is typically indicated by a number ("specific impulse") which measures the change in momentum per unit amount of propellant used; the higher the specific impulse, the more efficient a rocket engine. For rockets launching objects into space, engineers naturally gravitated to engines that promised higher specific impulse ratings since such engines would require less propellant to attain a given momentum. Theorists considered liquid oxygen the best oxidizer, one that when combined with kerosene (or especially, liquid hydrogen) could produce very high specific impulse values. That made liquid oxygen the first choice for space launch vehicles in the early years of the space age. But high-energy propellants brought their own challenges: oxygen, for example, takes on a liquid state only at very low temperatures, from –223°C to –183°C. Thus, in order to keep oxygen in its liquid form in the tanks of rockets, engineers needed to deal with many technical challenges, such as developing special systems to store super-cooled (or cryogenic) liquid oxygen both on the ground and in the rocket. By increasing tank pressure, it was possible to bring up the boiling temperature of liquid oxygen, but very high chamber pressures raised their own challenges. Rockets with cryogenic propellants were also notoriously difficult to ready for firing, especially in the early years of the space age: in the case of early versions of the R-7 ICBM, it took as much as 20 hours to prepare it for launch, which made it practically useless for a surprise attack.

Non-cryogenic propellant combinations had their own advantages and liabilities. For example, when nitrogen tetroxide was used as an oxidizer and standard kerosene as a fuel, the combination was storable, implying that a rocket fueled with such propellants could be kept at the ready for a long time. For a military rocket, this was a crucial asset. Unlike liquid oxygen, nitrogen tetroxide remained in a liquid state at close to room temperature (from –11°C to 21.5°C), which made it easier to handle. Such combinations, however, had low specific impulse values and thus were not quite as efficient as cryogenic engines. Many storable propellants were also highly toxic. In 1960, a new Soviet ICBM, the R-16, had exploded on its launch pad and killed nearly

90 people, many of them through exposure to the highly toxic propellants.[48] Yet the singular advantage of being able to get keep a missile ready for launch on command kept military commanders coming back to such storable propellants as the most ideal for use in the Soviet offensive strategic force.

When Korolev's engineers first proposed engines for the N-I, they gravitated to cryogenic combinations, especially liquid oxygen and kerosene, which they had successfully used in the R-7, recently put on service duty as the Soviet Union's first intercontinental ballistic missile.[49] For future upper stages, they assumed that other high-energy propellants, including the liquid oxygen–liquid hydrogen combination and perhaps even nuclear rocket engines, would be used. As before, the powerful first-stage engines for the rockets would be developed under the tutelage of Valentin Glushko, the Soviet Union's preeminent rocket designer, who headed a large organization, OKB-456, based in Khimki, a suburb northwest of Moscow.

Korolev and Glushko, the two giants of the Soviet space industry, already had a long and storied relationship, one that had been marred for many years by the debate over propellants. They had met as young men in the early 1930s and worked together at a government-sponsored organization for rocket research, the Reactive Scientific-Research Institute (RNII), in the interwar years. Debates over the appropriate choice of propellants almost tore the institute apart; Glushko had staked out a clear position in favor of storable propellants, particularly nitric acid, because they did not require complicated ignition systems, were cheap to produce, and were easy to obtain in Leningrad, where he had served his apprenticeship. Others favored liquid oxygen. Many engineers left the institute in disgust when their favored propellant was privileged over another. These battles added poison to the traumas at the height of the Great Terror in the late 1930s when Korolev and Glushko were forced to denounce each other on trumped-up charges of sabotaging equipment.[50] Both spent time in the depths of the Gulag and worked together in a prison camp for engineers, where Korolev was Glushko's deputy. After the war, they helped Soviet teams scour through the detritus of German industry and then assumed leadership of separate design organizations, with Korolev, more influential, designing missiles, and Glushko producing engines for them.[51]

Perhaps because of their shared traumas, the two men remained on friendly and respectful terms through the years. This connection began to fray by the mid 1950s as several progressively bigger technical disagreements pulled them apart. The disputes, initially technical, became increasingly personal. First, there was Glushko's refusal to design verniers (small steering engines) for the main engines of the R-7 in the mid 1950s. Then there was Glushko's failure to deliver on time a particularly crucial upper-stage engine for an advanced rocket—a delay that stretched into several years, until Korolev abandoned the contract.[52] These small fissures widened further with a major conflict over engines for Korolev's first post-R-7 missile, the R-9 ICBM.

By this time, Korolev and Glushko had staked out clear positions on the choice of propellants, the former now favoring cryogenic propellants (including high-energy fuels, such as liquid hydrogen) and the latter continuing to support storables.

Beginning in the early 1950s, the Soviet military had demanded that Korolev design newer missiles using storable propellants, a demand that he had resisted. Late in the decade, he proposed a new rocket, the R-9, that would use liquid oxygen, and under severe pressure from Korolev, a number of chief designers reluctantly came out in favor of it.[53] After almost a year of discussion, the military grudgingly supported the project, but only if Korolev could guarantee high-speed launch operations.[54] Glushko, the only major rocket engine designer in the Soviet Union who could be counted on to design such powerful engines (approximately 144 tons of thrust at sea level), was tasked to build engines for the R-9; he did this reluctantly, since he had begun to turn his entire organization away from the tried and tested liquid oxygen–kerosene combination that had powered the earlier R-7 ICBM. He had technical reasons for doing so; in the early 1950s, his last attempt to build a high-thrust single-chamber liquid oxygen engine had ended in disaster as model after model exploded in ground-test stands due to high frequency oscillations in the combustion chamber.[55]

Korolev himself had little confidence that Glushko could overcome these problems. Resentful that Glushko had a near monopoly on rocket engine design in the Soviet Union, Korolev invited a number of "outsiders" to submit proposals for the liquid oxygen engines for the R-9. One of these was an organization based in the large industrial city of Kuibyshev, nearly 1,000 kilometers southeast of Moscow, on the banks of the Volga river close to Kazakhstan. Known by its cryptic name, OKB-276, the design bureau was headed by Chief Designer Nikolai Kuznetsov, who had no experience designing rocket engines; for nearly a decade he had led the design of turboprop engines, including the NK-12 engines that powered the famous Tupolev Tu-95 ("Bear") strategic bomber.[56] Kuznetsov's attention was drawn to missiles in the late 1950s, when Khrushchev, mesmerized by the power of rockets, had begun to limit work for firms in the Soviet aviation industry. Numerous aviation firms struggled to make ends meet by diversifying into other fields, such as the rocket and space industry. The Soviet premier reportedly suggested to Korolev that he invite some of these design bureaus to be subcontractors for the space program. A growing number of these aviation firms, hungering for contracts, quickly turned their attention to Korolev and other missile designers and began to solicit contracts. Kuznetsov's design bureau was one of them.[57]

Kuznetsov's foray into missiles cracked open the rift between Korolev and Glushko.[58] The Soviet leadership had originally approved the development of the new R-9 ICBM in May of 1959. Contracts were handed out, and Glushko began to develop a new and powerful liquid oxygen–kerosene engine. Lacking confidence in Glushko's ability to develop such an engine, Korolev, somewhat abruptly, at the end of the year, wrote a letter to Leonid Brezhnev, the Party curator in charge of the missile and space program, to eject Glushko from the R-9 missile program in favor of newcomer Kuznetsov. Korolev argued that Kuznetsov, despite his lack of experience in designing rocket engines, could produce a much better and more efficient engine in a shorter time; it didn't help that Glushko had repeatedly failed to deliver major contracts on time.[59] It was unprecedented and rare for a designer to demand that a government decision be revised, but Korolev's relationship with Glushko had soured by then and he was keen to break his professional relationship with his former colleague. Glushko was livid when he found out; he fired off a letter to the Military-Industrial Commission rejecting Korolev's plea. In the end, Korolev lost his gamble, and the ministry in charge of the program reiterated that Glushko's engines would remain as part of the R-9 missile. Korolev was forbidden to test any other engine in support of the ICBM.[60] The R-9 flew, albeit much later than had been planned, and with Glushko's engines, as originally intended. Yet the battle over this military missile undoubtedly darkened the relationship between the two men.

Glushko's Refusal

The battle over the R-9 was only a prelude. From late 1960 to the summer of 1962, there was a protracted conflict between Korolev and Glushko over propellants that effectively split the entire program into two. Glushko recognized that Korolev's N-I and N-II rockets would constitute the future of the Soviet space program, and he wanted to have major contracts for these rockets. But there was a problem: his opinions about rocket engine design had dramatically shifted between 1958 and 1961, and his change of heart put him directly at odds with Korolev. In the 1930s, Glushko's favored propellants had been storables, in particular nitric acid (as oxidizer) and kerosene (as fuel). After the discovery of the German V2 ballistic missile at the end of World War II, Glushko had abandoned storables and reoriented his work to the use of liquid oxygen and alcohol for about five years. Building on this experience, his organization had produced engines using liquid oxygen and kerosene for the first R-7 ICBM. This combination made it difficult to prepare the missile for launch (which made the military unhappy), but it did add a modicum of extra lifting power to the rocket (which made the space enthusiasts happy). But between 1958 and 1961, Glushko's thinking slowly migrated back to his earlier position on the use of oxidizers and fuels; he now rejected both liquid oxygen and kerosene.

First, he found a new fuel to replace kerosene. In 1949, the Leningrad-based State Institute for Applied Chemistry developed a new toxic compound, a kind of hydrazine fuel known as unsymmetrical dimethyl hydrazine (UDHM). According to Glushko's calculations, when UDMH was paired with liquid oxygen instead of the usual kerosene, one could potentially increase specific impulse values by approximately 4 percent. By the late 1950s, when, on assignment from Glushko, this institute developed an industrial base to mass produce UDMH, Glushko immediately latched on to it, determined to stop using kerosene and replace it with UDMH. He began building a series of liquid oxygen–UDMH engines, and in January of 1958 proposed to Korolev that the next ICBM should use this propellant combination.[61] From then on, Glushko's organization developed almost no rocket engine without UDMH as the fuel.

Second, he began to go a step further and replace the oxidizer, liquid oxygen. This came as no surprise to anyone who knew Glushko's history; he had a long-standing animus toward liquid oxygen that he had suspended only because the Germans had been using the substance in their V2. Although Glushko was a diehard space enthusiast (and thus would be expected to prefer oxygen), he was also a realist. In the early 1930s, when he was searching for an ideal combination of propellants, he gravitated to materials that were available from industry. But one important criteria for him was the problem of keeping rockets at a ready state. In 1936, bearing in mind that military rockets had to be ready to be launched immediately on command, he had written that "in terms of battle applications liquid oxygen [has] acute operational shortcomings." He added that "careful consideration of the properties of these materials shows that [liquid] oxygen is not the best oxidant and [liquid] hydrogen is simply not suitable for practical use."[62]

In replacing liquid oxygen, Glushko proposed tried and tested oxidizers such as nitric acid. His engineers began development of a series of engines using the nitric acid–UDMH combination in 1958 for new missiles developed for Chief Designer Mikhail Iangel', Korolev's primary competitor at the time.[63] Eventually, he found the ideal oxidizer, nitrogen tetroxide, which promised even better specific impulse ratings when combined with UDMH. By the end of 1960, his position had solidified: the best combination of propellants for future rockets and launch vehicles would be nitrogen tetroxide (as oxidizer) and UDHM (as fuel). In a letter to ministry bureaucrats and military officials in December 1960, he noted that the availability of factories producing nitrogen tetroxide in the USSR created favorable conditions for its use in rockets and that his design bureau had completely turned its attention to creating engines using this oxidizer. He added—using a common strategy to strengthen an argument—that the Americans were increasingly turning to the use of nitrogen tetroxide in their missiles.[64]

The evolution in his thinking that led Glushko to abandon liquid oxygen angered one constituency (Korolev) but pleased another. At the very same time that Glushko embraced storable propellants, the Soviet Strategic Rocket Forces was gearing up for a massive expansion, soliciting contracts from many different organizations to build new generations of intercontinental ballistic missiles. Almost no one in the military wanted liquid oxygen missiles; it was clear to most that if the Soviet Union were to have an effective ICBM force, it would need to have missiles that could be launched at a moment's notice. In the early 1960s, when the military handed out several contracts, Glushko's organization snapped up all the major slots for designing powerful first-stage engines for these rockets. All of them used the nitrogen tetroxide–UDMH combination, highly toxic to handle but much easier for operational use. With some logic, Glushko believed that he would maximize his resources if he could produce "dual-use" engines that could be used for both the "civilian" N-I and another military rocket.

At the very beginning of the process, when Korolev's engineers were busy conceptualizing the giant N-I rocket, they entertained Glushko's insistence that they consider storable propellants as a possible option for it.[65] By March of 1961, Glushko clearly and without equivocation informed Korolev that his organization, having done some serious research into possible combinations for propellants, strongly preferred nitrogen tetroxide and UDMH for the new super-rocket.[66] He offered two engines, known as the RD-253 and RD-254, for the N-I; simultaneously he offered these engines for use on a new proposed military rocket proposed by a competitor to Korolev, Vladimir Chelomei.

In 1961, Korolev's engineers did some intensive analysis of possible configurations of the N-I. In considering propellants, engineers performed comparative analyses of several combinations, some cryogenic (i.e., using liquid oxygen) and some storable. Increasingly, they came to the decision that cryogenic combinations would be ideally suitable for this rocket. Korolev had already handed out competitive contracts to several organizations in March of 1961 to produce engines: some contracts went to Glushko to produce his favored engines, while a parallel assignment disbursed enough money for Nikolai Kuznetsov, the aircraft engine designer in Kuibyshev, to begin work on several liquid oxygen–kerosene rocket engines.[67] As the year ended, engineers on both sides of the debate fully understood that, if at one point, Kuznetsov's engines represented an insurance policy for Korolev, by the end of 1961, they were Korolev's primary choice. But Glushko refused to back down. In late 1961, he fired off several letters to Korolev, to Academy of Sciences President Mstislav Keldysh, and to high officials in the Communist Party, pressuring them to make a decision in his favor.[68]

The Keldysh Commission

The crisis culminated in July 1962 when an "extraordinary commission" tasked by Nikita Khrushchev convened to examine the course of work on the N-I rocket. Headed by Keldysh, the commission included dozens of academics, military officers, scientists, and engineers.[69] Its goal was to review, over a period of two weeks, the documentation on the rocket that had been prepared under Korolev's tutelage, and ensure that the government approved the most optimal and efficient path of development. It was unusual for a technological system to be subjected to such scrutiny at the highest level, but the N-I was no ordinary technology; it was to be the most expensive single project in the history of the Soviet space program. The obvious important issue at hand was the selection of propellants for the N-I, a battle between Glushko's storable propellants and Korolev's cryogenic ones.[70]

The arguments from each side advocating for their particular propellants were generally grouped under four criteria: efficiency, cost, safety, and engine design and operation. Glushko argued his case in a series of letters to Korolev and others in late 1961 and early 1962. Korolev presented his case during the actual meetings of the Keldysh Commission in July. The most important issue here was efficiency, i.e., the ability of a certain propellant combination to lift a larger payload into orbit. Here, Glushko's argument was weak. He noted somewhat vaguely that "the payload mass inserted into orbit, is evidently less" when using liquid oxygen–kerosene because of the need to reduce the evaporation of oxygen, which would require special insulation material for the rocket tanks, thus making it heavier and thus less effective.[71] Korolev's engineers had a very strong case against this argument, since all their calculations showed that liquid oxygen–kerosene was much more efficient than storable pairs, despite any additional weight on the rocket. Perhaps sensing that his position would not fly with the Keldysh Commission, Glushko made a last-ditch argument: if Korolev's engineers calculated that their liquid oxygen–kerosene pair was more efficient, i.e., could lift more into orbit, it was simply because of "the particular design of the N-I launch vehicle [and] thus we can assume that the design layout of the N-I is not optimal for a heavy-class launch vehicle."[72] In other words, he tried to deflect attention to the design of the rocket rather than the propellant combination.

The second important factor was cost. Each side did extensive calculations on the use of their respective propellants. They produced wildly different numbers, then interpreted them with their own biases. Glushko noted that in 1962–63 nitrogen tetroxide and UDHM cost 55 rubles and 1,800 rubles per ton respectively, whereas liquid oxygen and kerosene cost 41 rubles and 39 rubles per ton respectively. He conceded that the latter pair was "8 times cheaper" than the former, but only "if you don't consider the cost of super-cooled oxygen." This was because of the perceived extra cost of complicated systems and processes designed to ensure storage of liquid oxygen in liquid form (at very low temperatures), both on the ground and on the rocket.[73] "With such an objective assessment of the actual cost of tons of supercooled oxygen," he added, "it inevitably turns out to be several times more expensive. … "[74] For his cost estimates, Korolev added overhead costs for both liquid oxygen and nitrogen tetroxide but still had a stronger argument: nitrogen tetroxide (181.4 rubles/ton) and UDHM (2,142.6 rubles/ton) came out a poor second to liquid oxygen (110.2 rubles/ton) and kerosene (79.6 rubles/ton). Korolev noted that both liquid oxygen and kerosene had large production bases in Soviet industry (as did nitrogen tetroxide) and were used widely in the Soviet economy. But concerns about having to develop storage and cooling systems for liquid oxygen, which tended to evaporate easily, could be put to rest, since such systems had already been developed for a military missile—the R-9A ICBM. On the contrary, he argued, using nitrogen tetroxide would require special equipment for the rocket, since the substance retained its liquid form only between –11°C (12.2°F) and 21.5°C (70.7°F), a range that was far exceeded at the launch site in Kazakhstan; in winter, special heating equipment would be required, and in summer, the tank pressure would need to be increased to ensure a higher boiling point, requiring thicker and thus heavier propellant tanks. In a comparison of one-time capital investments in the development of the engines, liquid oxygen–kerosene would be less than half as expensive (8.1 million rubles vs. 18.9 million rubles). The costs for subsequent launches would also favor liquid oxygen–kerosene (0.25 million rubles vs. 2 million rubles).[75]

The third issue was safety. Korolev noted that both UDMH and nitrogen tetroxide were highly toxic compounds, thus requiring extra ground equipment to neutralize waste, ensure drainage, "de-gas" facilities, and sanitize tanks after prolonged exposure to propellants. Ground crews would also need special masks and suits for their own safety. The fact that these components ignite upon contact with each other (that is, are hypergolic) increased the demands on tightness of joints significantly. Liquid oxygen and kerosene, on the other hand, were both non-toxic.[76] Glushko conceded that his propellants were toxic but noted that there had been no cases of poisoning when launch-site rules of operation had been strictly followed. In fact, experience with different rocket engines on earlier missiles showed that there were no cases of leaks in storable-propellant engines as opposed to many cases of dangerous leaks of liquid oxygen. The latter were especially hazardous, Glushko argued, because even a single leak of liquid oxygen was very dangerous in view of its low boiling point and extreme volatility, whereas with storable propellants *both* components would have to leak to cause an explosion.

The fourth major issue under discussion was engine design and operation. Both sides had compelling arguments. Glushko noted that because nitrogen tetroxide and UDMH were self-igniting (hypergolic), engines using such propellants would not require special ignition devices to start up; all that was needed was to put the propellants in contact with each other. Such engines were by definition more reliable and relatively easier to control—especially when simultaneously firing 24 engines, as would be the case for the first stage of the N-I. Hypergolic propellants also fired with less delay time, igniting on command, a facility critical to the operation of upper stages. Finally, Glushko argued, it was well known that high-thrust liquid oxygen engines suffered from irregular combustion and were more subject to high-frequency oscillations. In liquid oxygen engines, there was also the need to protect combustion chambers and nozzle walls from overheating. Glushko's design bureau had already faced these problems in the early 1950s in the course of developing single-chamber cryogenic engines. None of these problems afflicted storable-propellant rocket engines.[77] Korolev's engineers had a convincing counterargument: yes, they conceded, "normal" liquid oxygen engines were susceptible to unstable combustion and sometimes even exploded into fragments because of the particular mix of liquid and gaseous compounds that formed at the entry point of the combustion chamber. But all of Glushko's arguments were invalidated because Korolev was advocating the use of a new type of cryogenic engine: what Soviet engineers called a "closed-circuit" engine, known in the West as a type of "staged-combustion" engine. Such engines maximized the use of propellants by minimizing gas losses that occurred when driving turbines. They were extremely efficient (with high specific impulse ratings), safe from the common destructive properties of high-thrust liquid oxygen engines, and highly innovative for the period. American engineers had avoided such designs, believing them to be beyond the reach of current technology. Korolev, having already developed small staged-combustion engines, believed that a bigger one might be possible; in 1959, his new comrade-in-arms, Kuznetsov, had begun development of several new staged-combustion liquid oxygen rocket engines.[78]

As was typical for the time, final arguments were couched in terms of what the United States was doing. Glushko noted that "the early versions of the Atlas and Titan intercontinental rockets developed by the US used [liquid] oxygen and kerosene as propellants," but that "now [they are] urgently moving to use [nitrogen tetroxide] with hydrazine." "In this case," he continued, [they] have in mind the possibility to ensure long-term (several years) service of a fueled rocket in a battle-ready state with [launch] preparation time down to 1 minute. For some years now, the second stages of all Thor and Atlas missiles have been using only nitric acid and nitrogen tetroxide as oxidizers with UDMH."[79] Korolev argued almost the opposite:

> There is evidence that 95% of the work on [rocket engines] in the US is focused on the use of [liquid oxygen]. In 1960–61, the Rocketdyne-North American firm finished development of the H-1 and H-2 oxygen-kerosene engines with thrusts of 85 tons and 112 tons. … The H-1 engine has fully passed ground testing … and is now part of stage I of the Saturn rocket, which has successfully passed its first flight test. … All together in the US there are 19 [rocket engines] (90%) with a thrust [range] of more than 7 tons that use [liquid] oxygen and only two engines (10%) that work on nitrogen tetroxide.[80]

The arguments went back and forth for days without much compromise, sometimes fracturing the modicum of unity among the other chief designers. The choice, as presented by the two leading parties, was between two engines, those of Glushko and Kuznetsov, with Korolev arguing for the latter. Commission members debated various technical, industrial, and organizational issues. Eventually, the Keldysh Commission voted unanimously to recommend, as Korolev had argued, that the N-I use Kuznetsov's liquid oxygen engines, adding in its official report that the N-I technical documentation fulfilled "high scientific technical standards" that had been originally demanded in the initial proposals."[81] The commission justified its decision in favor of liquid oxygen and kerosene on the bases of efficiency, cost, and safety. On all three points, they were convinced that, as Korolev had argued, Kuznetsov's engines would have better lifting characteristics, would be safer to use, could take advantage of existing systems, and be cheaper, having accepted Korolev's cost numbers over those of Glushko.[82]

Glushko was livid. Despite the commission's conclusion, he insisted on a total revision of the N-I design so it would use his storable-propellant engines, under development for at least a year by then. Several prominent designers and highly placed military officials tried in vain to convince him to participate, but he categorically refused to make liquid oxygen rocket engines for the project.[83] Eventually Nikita Khrushchev was drawn into the battle, but even he was unable to mediate. "Differences of opinion," he wrote in his memoirs,

> started to pull [Korolev and Glushko] apart and the two of them couldn't stand to work together. I even invited them to my dacha with their wives. I wanted them to make peace with each other, so that they could devote more of their knowledge to the good of the country, rather than dissipate their energy on fights over details. It seemed to me that they were both talented, each in his own field. But nothing came of our meeting. Later Korolev broke all ties with Glushko.[84]

As a result, the job of developing the N-I engines went to Nikolai Kuznetsov, a designer of jet engines for Soviet civil aviation. The largest and most ambitious rocket ever built in the Soviet Union would have engines designed by an organization that had never flown a single one.

After the Decision

After Glushko was officially divorced from the program, he made repeated attempts to undermine the N-I project—a tactic he had adopted even before the 1962 settlement. In 1960–61, for example, during the conception stage of the N-I, Glushko had tried several times to push through alternative ideas for a similar monster rocket, using as a justification the goal of "maintaining the priority of the Soviet Union in this area [of rocket design]."[85] Korolev, who sought to maintain a monopoly on the building of the next generation of Soviet launch vehicles, bluntly rejected all these interventions without seriously evaluating their value. Glushko was also sufficiently shrewd to have an insurance plan in case the N-I didn't work out: long before the final decision on the N-I propellants had been made, and unknown to Korolev, Glushko had approached Korolev's rival Mikhail Iangel' and proposed the use of the same engines he was planning to use on Korolev's rocket for a competing variant produced by Iangel'.[86] When that attempt failed, he tried again the following year with a new Iangel' rocket, the R-56, proposing it as a much better alternative to the N-I, one that would use his unused nitrogen tetroxide–UDMH engines from the N-I. He tried to appeal to higher goals, imploring that "further delay in the development of rockets with … lifting capacity greater than the [American] Saturn I … will exacerbate the lag of the Soviet Union in the development of rocket technology."[87] Glushko's stubbornness eventually brought him into conflict with Mstislav Keldysh. In late 1964, two years after the decision against Glushko, when he brought up the propellant issue once again at a meeting on the N-I, Keldysh replied sharply: "The question over propellant components must stop. … It's now necessary to firmly reject everything that interferes with [our work]. … The arguments over this issue are just a waste of time."[88]

Glushko didn't give up. In 1964–65, he insisted on a repeat study to evaluate the characteristics of an N-1 rocket with his engines replacing Kuznetsov's liquid oxygen ones. In early 1965, a review commission rejected Glushko's suggestion to rework the N-1—not surprising, since millions of rubles had already been spent on the design approved by the Soviet government.[89] A last-ditch effort to derail the N-I program coalesced in the mid 1960s when Glushko joined with another Korolev competitor, Vladimir Chelomei, and sent appeals to the Party and the government proposing a new rocket that, if given the appropriate funds, could beat the Americans to the moon. This new imagined super-rocket would use powerful storable-propellant rocket engines developed by Glushko.[90] Even as more than 500 organizations nationwide were fully engaged in producing the N-1 rocket, a government decree allocated funds to Chelomei and Glushko to move ahead with their proposal. Eventually, saner heads prevailed, and the idea was scuttled in 1968.[91] Through it all, Glushko sent off several missives to the Soviet government severely criticizing Kuznetsov's work on liquid oxygen engines for the N-I. After a ground test of Kuznetsov's NK-15 engine went awry, Glushko wrote: "You can see for yourselves that the engine is bad. It's not fit for work, and certainly not for installation on such a crucial piece of hardware like the N-I."[92]

How was Glushko able to refuse a state mandate to participate in the N-1 project? How was he able to decline Khrushchev's overtures at mediation? And later, how was he able to mount repeated challenges to Korolev's program when it had already acquired significant organizational inertia? Three factors loom large here, all rooted in the way in which Cold War pressures at the international level affected "local" decision making.

First, Glushko's hubris was undoubtedly reinforced by the elevated authority of space-program chief designers in the aftermath of the success of Sputnik. One way this individual agency was instrumentalized was cowing Party and government bureaucrats with explicit claims that Khrushchev or Brezhnev had personally sanctioned some or other project and therefore the ministry had to act on it. Glushko was not shy about using firm language; in one letter to Korolev insisting on the use of storable propellants for the N-I, he underscored that his organization had been given the obligation to develop powerful rocket engines by the "repeated, direct, and personal instruction of N. S. Khrushchev."[93] With such invocations, missile chief designers were able to push through many projects that duplicated the efforts of others. There are innumerable cases of competitive projects tailored for singular goals when, because the Party and the government structure were ineffective in curbing the power of chief designers, simultaneous and similar projects were adopted and funded. The most striking case of such redundancy and waste was the so-called little civil war of the late 1960s, when competing missile designers—Vladimir Chelomei and Mikhail Iangel'—waged a battle through their patrons in the power structure to gain contracts for the third generation of Soviet ICBMs. In the end, Brezhnev, unable to decide between different options, funded similar high-performance missiles from both parties, squandering billions of rubles.[94]

Second, the authority of chief designers was undoubtedly affected by the perception of work being done in the United States. In the post-Stalin era, when missile chief designers appealed for funding for their pet projects, they invariably cited superior or better-funded work ongoing in the West. For example, in the battle over propellants for the N-I rocket, both Korolev and Glushko repeatedly used information about American missiles. In January of 1961, at a meeting with representatives of the Ministry of Defense on the future of the N-1, Glushko noted that "on the basis of published information it's worth nothing that in the second variant of the Titan rocket, the Americans are using nitrogen tetroxide as oxidizer, and a mixture of 50% dimethyl hydrazine and 50% hydrazine as fuel"—that is, storable propellants.[95] Later, in July of 1962, during the Keldysh Commission's two-week-long deliberations on the design of the N-I, Korolev produced a series of lengthy technical considerations to substantiate his position on the appropriateness of cryogenic propellants, but then in his conclusions specifically invoked concurrent American work.[96] As in the case of the N-I, each side could always find relevant information about American work to support its case, a task made easier by the inability of high government officials to discern actual sanctioned work going on in the United States from the speculations of American journalists.

Finally, there was the role of the Soviet military. When chief designers proposed ostensibly civilian space projects, such as a moon landing, they often articulated their ideas so as to suggest that these projects had both civilian and military uses. Barring rare exceptions—principally lunar and deep space missions—all Soviet space projects of the 1960s were military in nature or derived from military projects. To attract the military's attention, Korolev desperately tried to justify the N-I on the grounds that the military might need it. But the rocket's initial lifting capacity of 75 tons and its use of cryogenic components ensured that the military would find little or no use for it. In a meeting held in September 1960 to discuss the N-1, Major General Aleksandr Mrykin, a senior official in charge of procurement for the Strategic Rocket Forces, came right to the point: "Permit me to raise the following questions: for what purpose [do we need] heavy spaceships [weighing 75 tons] and what military application are they for?"[97] Even though several government decrees instructed the military to prepare proposals for what they could do with the N-I, the appropriate department within the Strategic Rocket Forces never produced a requirement, leaving Korolev to make up wildly ambitious ideas that bordered on fantasy, such as an idea to deploy an "orbital belt" of hundreds of military satellites that could continuously monitor the enemy and defend any space-based or ground-based asset belonging to the Soviet Union.[98] Even Korolev himself was self-aware enough to see the absurdity of some of his ideas for military space activities. In early 1961, in a letter to a defense industrialist, he conceded that "some of the proposals, on first glance, may seem dubious or even somewhat fantastic. But … one should not draw any hasty conclusions."[99]

Chief designers such as Iangel' or Chelomei or Glushko who tailored their work to be more in tune with prevailing military imperatives than Korolev did, were more likely to benefit from generous funding from the military services. In this context, developing a rocket to land a cosmonaut on the moon was seen by many in the military as a worthless sideshow to the real goal of achieving strategic parity. This was strikingly underscored by two consecutive Soviet ministers of defense, Marshal Rodion Malinovskii and Marshal Andrei Grechko. "We cannot afford to and will not build super powerful space launch vehicles and make flights to the moon," Malinovskii told Air Force officials in January of 1965.[100] His successor, Grechko, was equally firm, responding to a request for help by telling an official "I won't give you personnel. I won't give you money. Do what you like but I won't raise this with the government. … And in general, I am against flights to the moon."[101]

Because the military were hostile toward the "civilian" space program, Glushko was able to fortify his position by noting correctly that any storable-propellant engines he built could be used (or at least the technology would be useful) for military programs, particularly ICBM programs. Since the military were the primary clients for all space projects, even ostensibly civilian ones, by catering to military needs Glushko could have the military ensure a steady stream of funding for his organization. This security added to Glushko's rising stature; by the late 1960s, he enjoyed enormous authority as the man who produced the heart of the Soviet strategic missile force: its rocket engines. This connection to Soviet military power gave him significant leeway to continuously try to intervene in the ongoing N-I project. Who would challenge him?

Conclusions

The July 1962 decision by the Keldysh Commission effectively fractured the space program into the Korolev and Glushko camps, destroying any semblance of unity that may have existed during the Sputnik days. Although the break between Korolev and Glushko was ostensibly over technical issues, the repercussions were far-reaching: the two giants of the Soviet space program would not live to cooperate on another project. Korolev turned his back on the most powerful and successful rocket engine designer in the country and went to work with an organization that had almost no experience in the field, the Kuznetsov design bureau. Glushko, meanwhile, lost his role in what was to be the most expansive and greatest project in the history of the Soviet space program. In the end, these decisions, in favor of Kuznetsov's innovative, efficient, and "civilian" engines instead of Glushko's conservative, relatively inefficient "military" engines, doomed the remainder of the N-I project.

Kuznetsov, an outsider in the Soviet space program, found it very difficult to gain access to facilities for ground testing of his rocket engines, essential to certify his engines as flight-worthy. The majority of facilities at the premier Soviet site for testing rocket engines was devoted to Glushko's storable-propellant engines (built for ICBMs), and the resources to build ground infrastructure for Kuznetsov's engines were meager and late. His engines, though highly efficient, took far too long to develop, and their development was marred by the decision not to construct a full-scale ground-test stand for the rocket's entire first stage.[102] When four consecutive launches of the N-I ended in explosions in the late 1960s and the early 1970s, few were surprised.[103] For the Soviet space program, the collapse of the N-I project signaled the end of the beginning of a dramatic road that began with Sputnik, and it was the most visible manifestation of the program's fall from grace.

In untangling the main characteristic threads of this exemplar of late-period Soviet big science, it is worth revisiting Loren Graham's characterizations: "The system emphasized quantity over quality, seniority over creativity, military security over domestic welfare, and orthodoxy over freedom."[104] In the case of the N-I project, these rationales (quantity, seniority, security, orthodoxy) can be found in places, but they are neither the most important nor the most definitive attributes. What we see, in fact, are features (risk-taking, competition, discord within the scientific community, variable expertise) that are direct outcomes of the ways in which national goals set in the context of the Cold War, trickled down, and seeded science and engineering with "local" rationales, choices, and contours. In the case of the N-I, the result was a program that embodied multiplicities instead of singularities. Contradiction, messiness, ambivalence, and ambiguity were the *normative* modes of work in the case of N-I, not anomalies. Such seemingly discrepant strains are clearly also evident in other contemporaneous examples of Soviet big science in the postwar era, such as the anti-ballistic-missile project, the development of particle beams, and the Mars-exploration efforts, in each of which there was intractable conflict among the major players.[105]

From a purely technical perspective, perhaps the most important conflict was the tension between a conservative choice and a risky one (one whose outcome Graham saw as always being "quantity over quality"). Glushko's engines were less efficient, technically conservative, and could draw on established military contracts; Kuznetsov's motors, on the other hand, were highly efficient, technically innovative, and lacked institutional backing. When Korolev insisted on the latter for his giant space rocket, he was in, essence, trying to force an innovative and "civilian" solution into a milieu where conservatism and "military" options were privileged. This is not to suggest that innovation was the more difficult choice and was doomed to failure because of bureaucratic resistance; on the contrary, as the evidence shows, the N-I project made a space for both innovation and conservatism to exist in a tenuous balance. In each of these projects, powerful actors within the scientific and engineering communities exerted authority in favor of conservative or innovative solutions, sometimes in conflict with each other—solutions whose measure of success often depended on the degree of their professional clout. In the case of the rocket and space program, Korolev belonged to a small but powerful group of missile designers who had acquired unprecedented power and influence by the early 1960s, benefiting from the Cold War-driven successes of Sputnik and the space program. Their authority, predicated on access to the top levers of the Party and the government, combined with the institutionally "normal" Soviet approach to competition in the defense industry and the uneven technical expertise of managers, created a climate for chaotic infighting that existing institutional mechanisms were unable to arbitrate.

The experience of the N-I project shows that in the Soviet Union, competition and competitive contracts were designed not to invigorate innovation but instead to minimize risk or the chance of failure. Here, at one level, the competition was between different technological options: storable versus cryogenic, gas generator versus staged combustion, nitrogen tetroxide versus liquid oxygen, and so on. But at a deeper level, this was a competition between rival organizations. To the extent that organizations in the Soviet defense industry were identified with their chief designers, this was also a competition between *individuals*. Each of the designers competing for a contract would emphasize how his project was guaranteed to succeed and others guaranteed to fail; we see this dynamic in Glushko's continuing attacks on Kuznetsov's engines, for example. The bogeyman of America played a not insignificant role. Designers such as Korolev and Glushko could repeatedly invoke threats of American superiority or the blessing of Party leaders to defend their positions, and bureaucrats were too afraid to refuse their demands for fear of increasing risk—or, worse, offending the patrons of powerful designers. It was precisely this tendency—the growing power of chief designers—that the Military-Industrial Commission tried to counter in 1966 by signing into law a decree stipulating that every new proposal on a weapons system should be preceded by a detailed technical substantiation of the idea in the form of an "advance plan" (*avant-proekt*) that would be circulated *before* any direct conversation with top leaders. An official history of the Soviet military-industrial complex dryly notes that this decision "played a large role … in eliminating excessive expenses in creating new long-term technologies."[106]

The other built-in tensions, those between civilian and military imperatives and between publicity and secrecy, were also in evidence at the beginning of the N-I program. For example, the seemingly arcane and technical debate over propellant selection for the N-I rocket was, at heart, an outcome of different demands: should Soviet rockets use propellants appropriate for "military" use, or propellants appropriate for "civilian" use? The former would be wrapped up in the secrecy of the Strategic Rocket Forces. The latter would be elevated to display as a triumph of Soviet socialism for all to see—the first landing of humans on the moon. As leading architects of Soviet big science at the height of the Cold War, Korolev and Glushko embodied these conflicting rationales, but in slightly different and ultimately crucial ways. Korolev had firmly embraced the imperative for an expansive Soviet space program but was also acutely aware that he needed to cater to the military to realize his cosmic aspirations. These opposing impulses were in conflict. One the one hand, he wrote to defense industrialists about the military operations (such as "super-reconnaissance") that would be possible with the N-1, and invited the military to stipulate technical specifications (particularly, the launch mass) so that Korolev's designers could begin work on the rocket.[107] Almost simultaneously, he instructed his own deputies to determine the launch mass of the N-I so that it could perform a number of "civilian" tasks, such as circling and landing on the moon.[108]

For Korolev, then, the goal was to create a rocket that could, first and foremost, perform civilian missions such as landing on the moon. He would draw from this technology to cater to military needs. For Glushko, the goal was to create engines for ICBMs. He would draw on this technology to create a civilian rocket, the N-I, that could perform space missions. The former sought, with his innovative use of liquid oxygen, to create a military big science out of a civilian one. The latter sought, with his conservative storable propellants, to create a civilian big science from a military one. Fundamentally, both were trying to eliminate the inherent ambiguities and contradictions of Soviet big science by creating what they thought were more efficient versions. Unsurprisingly both failed in this quest.

In recovering the early history of the N-I project, then, one sees Soviet big science largely operating in an environment driven by conflicts between state intervention and competition, between military requirements and civilian goals, and between secrecy and display value. This was not the big science that Capshew and Rader described as possessing a "high degree of organization and coordination," nor was it Graham's model of quantity, seniority, security, and orthodoxy.[109] And neither does it echo accounts of the atomic bomb project—with its almost limitless state resources, involvement of security services, lack of competition (at least until the late 1950s), and insulation of leading scientists from broader ideological pressures—which for many has served as a surrogate for reflexive generalizations about Soviet big science when in fact the nuclear project was the exception and not the rule. What we find in the case of the N-I is a big science that embodied a clash of forces, one determined by imperatives defined at the global level of the Cold War (such as military, secrecy, and publicity) and the other pushed by a host of contradictory forces defined by local processes (such as professional, technical, historical) within various communities. The clash of the global and local in all its myriad forms created the archetypical Soviet big science: big, yes, but very different from the nuclear project, and full of contradictions, ambiguities, and contingencies.

Epilogue

When the N-I program was suspended, in 1974, Glushko was appointed to head the organization that Korolev—now dead—had headed. In a move that shocked many, Glushko immediately proposed development of a series of huge "super rockets," all using liquid oxygen–kerosene engines, of the very same type he had so vehemently railed against a decade earlier. One of these rockets, the Energiia, was successfully launched twice in the late 1980s, but the program was eventually canceled for lack of money after the Soviet Union collapsed. In the 1990s, the engines that had powered Energiia were scaled down and sold to General Dynamics (later acquired by Lockheed Martin), which now uses them on the American Atlas III and Atlas V launch vehicles. Meanwhile, the storable-propellant engines that Glushko originally offered to the N-I are now regularly used on the Proton rocket operated by International Launch Services, a joint US-Russian company. Because the Proton and the Atlas V are competitors, Glushko's storable-propellant and liquid oxygen rocket engines continue to compete with each other in the global launch market.

Equally striking was the "second act" for the highly innovative liquid oxygen engines that Kuznetsov designed and built for the N-I. Kuznetsov's engineers persevered and eventually flight-certified the engine despite the cancellation of the N-I project. For nearly twenty years, managers preserved 150 of the engines in a storehouse, three dozen of which were bought by the American company Aerojet in the 1990s. In early 2013, the Orbital Sciences Corporation used two of those engines—brought out of storage after nearly 40 years—on its Antares rocket, which launched a number of satellites into Earth orbit. A year later, an Antares rocket delivered supplies to the International Space Station, where American and Russian astronauts are stationed on long tours. All these Russian engines, widely considered high-performance systems, represent the peculiar but continuing embodiment of the arguments that shaped the discussions in 1962 between Korolev and Glushko. In that sense, it may be still too early to say whose argument won out.

Notes

1. S. Leskov, "Kak my ne sletali na lunu," *Izvestiia*, August 19, 1989.

2. S. Leskov, *Kak my ne sletali na lunu* (Panorama, 1991), 4. Much later, Leskov claimed that he published the piece without the permission of the censors. See "Obozrevatel' 'Izvestii' Sergei Leskov nagrazhden 'Znakom Gagarina'," *Izvestiia*, February 22, 2006.

3. The rocket has been various called "N-1," "N1," and "N-I." For the purposes of this chapter, I use the latter which is the most common designation in government documents.

4. James E. Oberg, *Red Star in Orbit* (Random House, 1981), 113.

5. For early published accounts of the lunar program, see A. Tarasov, "Polety vo sne i nayiu," *Pravda*, October 20, 1989; M. Rebrov, "A delo bylo tak: trudnaia sud'ba proekta N-1," *Krasnaia zvezda*, January 13, 1990; V. P. Mishin, "Pochemu my ne sletali na lunu?," *Znanie: seriia kosmonavtika, astronomiia* no. 12 (1990): 3–43; I. B. Afanas'ev, "Neizvestnye korabli," *Znanie: seriia kosmonavtika, astronomiia* no. 12 (1991): 1–64; R. Dolgopiatov, B. Dorofeev, and S. Kriukov, "Proekt N-1," *Aviatsiia i kosmonavtika* no. 9 (1992): 34–37; I. Afanas'ev, "N-1: sovershenno sekretno," *Kryl'ia rodiny* no. 9 (1993): 13–16; no. 10 (1993): 1–4; no. 11 (1993): 4–5.

6. For useful literature, see John H. Capshew and Karen A. Rader, "Big Science: Price to the Present," in Arnold Thackray, ed., "Science After '40,' " *Osiris* 7 (1992): 3–25; Peter Galison and Bruce Hevly, eds., *Big Science: The Growth of Large Scale Research* (Stanford University Press, 1992); Gregory McLauchlan and Gregory Hooks, "Last of the Dinosaurs? Big Weapons, Big Science, and the American State from Hiroshima to the End of the Cold War," *Sociological Quarterly* 36, no. 4 (1995): 749–776; David Reynolds, "Science, Technology, and the Cold War," in *The Cambridge History of the Cold War*, volume 3: *Endings*, ed. Melvyn P. Leffler and Odd Arne Westad (Cambridge University Press, 2010).

7. Paul Forman, "Behind Quantum Electronics: National Security as Basis for Physical Research in the United States, 1940–1960," *Historical Studies in the Physical and Biological Sciences* 18 (1987): 149–229.

8. Loren R. Graham, "Big Science in the Last Years of the Big Soviet Union," in "Science after '40," *Osiris* 7 (1992): 49–71.

9. Graham, "Big Science in the Last Years of the Big Soviet Union."

10. Alexei Kojevnikov, "The Great War, the Russian Civil War, and the Invention of Big Science," *Science in Context* 15, no. 2 (2002): 239–275.

11. Paul R. Josephson, "'Projects of the Century' in Soviet History: Large-Scale Technologies from Lenin to Gorbachev," *Technology and Culture* 36, no. 3 (1995): 519–559.

12. Loren R. Graham, ed., *Science and the Soviet Social Order* (Harvard University Press, 1990); Graham, *Science in Russia and the Soviet Union: A Short History* (Cambridge University Press, 1993); Nikolai Krementsov, *Stalinist Science* (Princeton University Press, 1997).

13. David Holloway, *Stalin and the Bomb: The Soviet Union and Atomic Energy, 1939–1956* (Yale University Press, 1994).

14. For post-Cold War works on the Soviet military-industrial complex, see N. S. Simonov, *Voenno-promyshlennyi kompleks sssr v 1920–1950-e gody: tempy ekonomicheskogo rosta, struktura, organizatsiia proizvodstva i upravlenie* (ROSSPEN, 1996); I. V. Bystrova, *Voenno-promyshlennyi kompleks sssr v gody kholodnoi voiny (vtoraia polovina 40-kh—nachalo 60-kh godov)* (Institut rossiiskoi istorii RAN, 2000). For a participant account in English, see Sergei Khrushchev, "The Military-Industrial Complex, 1953–1964," in *Nikita Khrushchev*, ed. William Taubman, Sergei Khrushchev, and Abbott Gleason (Yale University Press, 2000).

15. Graham, "Big Science in the Last Years of the Big Soviet Union," 51.

16. The Russian word *nauka* has historically implied a meaning closer to that of the German word *Wissenschaft* (meaning "scholarship") than to that of the English word, "science," with which it is most literally associated. Thus, *nauka* was used in popular media rather generally (and often carelessly) to encompass practices that Westerners might often associate with engineering. One of the most popular science journals during the Soviet era, *Nauka i zhizn'* (*Science and Life*) featured many stories about technology and engineering.

17. Asif A. Siddiqi, *The Red Rockets' Glare: Spaceflight and the Soviet Imagination, 1857–1957* (Cambridge University Press, 2010).

18. Holloway, *Stalin and the Bomb*, 366.

19. Ibid., 360.

20. See Paul Josephson, "Rockets, Reactors and Soviet Culture," in *Science and the Soviet Social Order*, ed. Loren Graham (Harvard University Press, 1990).

21. Iu. P. Semenov, ed., *Raketno-kosmicheskaia korporatsiia "Energiia" imeni S. P. Koroleva* [RKK Energiia named after S. P. Korolev], 1996), 51–54.

22. Memoir of A. I. Ostashev in *Nachalo kosmicheskoi ery: vospominaniia veteranov raketno-kosmicheskoi tekhniki i kosmonavtiki: vyp. vtoroi*, ed. Iu. A. Mozzhorin (RNITsKD, 1994), 69.

23. Besides the above named, the entourage also included L. M. Kaganovich, N. K. Kirichenko, and M. G. Pervukhin. The visit took place on February 27, 1956. Sergei Khrushchev has a long description of this visit based on his personal recollections. See Sergey N. Khrushchev, *Nikita Khrushchev and the Creation of a Superpower* (Pennsylvania State University Press, 2000), 101–112.

24. N. S. Khrushchev, *Vospominaniia, Kn. chetvertaia: Vremia. Liudi. Vlast'* (Moskovskie novosti, 1999), 191.

25. Khrushchev, *Nikita Khrushchev and the Creation of a Superpower*, 106.

26. See the discussion in Konstantin Ivanov, "Science after Stalin: Forging a New Image of Soviet Science," *Science in Context* 15, no. 2 (2002): 317–338 (see especially pp. 330–331). See also Alexander Vucinich, *Empire of Knowledge: The Academy of Sciences of the USSR (1917–1970)* (University of California Press, 1984).

27. See Sheila Fitzpatrick, *Education and Social Mobility in the Soviet Union, 1921–1934* (Cambridge University Press, 1979); Michael David-Fox, *Revolution of the Higher Mind: Higher Learning Among the Bolsheviks* (Cornell University Press, 1997); Kendall E. Bailes, *Technology and Society Under Lenin and Stalin: The Origins of the Soviet Technical Intelligentsia, 1917–1941* (Princeton University Press, 1978). These designers included those born in 1907 (S. P. Korolev), 1908 (M. M. Bondariuk, V. P. Glushko, A. M. Isaev, A. M. Liul'ka, N. A. Piliugin, A. A. Raspletin, D. D. Sevruk), 1909 (S. M. Alekseev, V. P. Barmin, M. S. Riazanskii), 1911 (N. D. Kuznetsov, M. K. Iangel'), and 1912 (B. M. Konoplev, B. P. Zhukov).

28. For a useful analysis of some of the elite designers as a demographic within the Soviet military-industrial complex, see Julian Cooper, "The Elite of the Defence Industry Complex" in *Elites and Political Power in the USSR*, ed. David Lane (Elgar, 1988).

29. G. S. Vetrov, ed., *S. P. Korolev i ego delo: svet i teni v istorii kosmonavtiki* (Nauka, 1998), 668. The six were S. P. Korolev (overall missile), V. P. Glushko (rocket engines), N.A. Pilyugin (inertial guidance), M. S. Riazanskii (radio guidance), V. I. Kuznetsov (gyroscopes), and V. P. Barmin (launch complex).

30. They included active members (V. P. Glushko, S. P. Korolev, and G. I. Petrov) and corresponding members (V. P. Barmin, V. N. Chelomei, P. D. Grushin, G. V. Kisun'ko, V. I. Kuznetsov, S. A. Lavochkin, V. P. Mishin, N. A. Piliugin, A. A. Raspletin, and M. S. Riazanskii).

31. By 1970 there were at least fourteen new corresponding members (G. N. Babakin, A. F. Bogomolov, B. V. Bunkin, K. D. Bushuev, B. E. Chertok, O. G. Gazenko, D. E. Okhotsimskii, S. S. Lavrov, N. S. Lidorenko, V. P. Makeev, B. V. Raushenbakh, V. S. Semenikhin, V. S. Shpak, and B. P. Zhukov) and thirteen new academicians (V. P. Barmin, V. N. Chelomei, P. D. Grushin, M. K. Iangel', A. Iu. Ishlinskii, V. I. Kuznetsov, V. P. Mishin, V. V. Parin, B. N. Petrov, N. A. Piliugin, A. A. Raspletin, R. Z. Sagdeev, and S. N. Vernov) whose primary work was in the missile and space sector. In addition, there were at least eight aviation designers (N. D. Kuznetsov, G. P. Svishchev, S. V. Il'iushin, A. M. Liul'ka, A. A. Makarevskii, A. I. Mikoian, V. V. Struminskii, and S. K. Tumanskii) who were elected into the Academy who did contract work for the missile and space programs. Lists of new Academy members from 1958 to 1970 show that the missile and space designers dominated the new entrants of designers from the defense industry.

32. These advances into the Academy occurred at the very moment when the institution was seeking to divest itself of applied scientific work. With the support of Nikita Khrushchev, the Academy adopted an official policy in 1961 of retaining the focus of the Academy on "fundamental science" while ejecting more than fifty applied research institutions to industry. See Ivanov, "Science after Stalin"; Nicholas DeWitt, "Reorganization of Science and Research in the USSR," *Science* 133, no. 3469 (1961): 1981–1991; Alexander G. Korol, *Soviet Research and Development: Its Organization, Personnel, and Funds* (MIT Press, 1965).

33. For more on Keldysh, see A. V. Zabrodin, ed., *M. V. Keldysh: tvorcheskii portret po vospominaniiam sovremennikov* (Nauka, 2001).

34. For Keldysh's role in nuclear weapons and missile development in the 1950s, see Iu. A. Trutnev, "M. V. Keldysh i ego kollektiv v reshenii atomnoi problemy" and V. A. Avduevskii and T. M. Eneev, "O rabotakh M. V. Keldysha po raketostroeniiu i kosmonavtike," in *M. V. Keldysh*, 66–78.

35. Asif A. Siddiqi, "Soviet Space Power During the Cold War," in *Harnessing the Heavens: National Defense Through Space*, ed. Paul G. Gillespie and Grant T. Weller (US Air Force Academy, 2008).

36. For English-language biographies, see Michael J. Neufeld, *Von Braun: Dreamer of Space, Engineer of War* (Knopf, 2007); James Harford, *Korolev: How One Man Masterminded the Soviet Drive to Beat America to the Moon* (Wiley, 1997).

37. William P. Barry, The Missile Design Bureaux and Soviet Piloted Space Policy, 1953–1970, DPhil dissertation, Merton College, University of Oxford, 1995.

38. See Asif A. Siddiqi, *Challenge to Apollo: The Soviet Union and the Space Race, 1945–1974* (NASA, 2000).

39. Quoted from the draft decree on the creation of the Military-Industrial Commission (December 4, 1957), Russian State Archive of the Economy (RGAE), f. 4372, op. 76, d. 320, ll. 33–38 (see especially l. 36).

40. Among the veterans of the missile industry who ended up near the top of the VPK structure were D. F. Ustinov (VPK chairman from 1957 to 1963), L. V. Smirnov (chairman from 1963 to 1985), G. N. Pashkov, S. I. Vetoshkin, A. N. Shchukin, and A. A. Kosmodem'ianskii. For more on the Military-Industrial Commission, see I. V. Bystrova, "K 50-letiiu voenno-promyshlennoi komissii," *Voenno-promyshlennyi kur'er* no. 47 (December 5–11, 2007).

41. David Holloway, *The Soviet Union and the Arms Race*, second edition (Yale University Press, 1984), 142.

42. See, for example, Mark Harrison, "A Soviet Quasi-Market for Inventions: Jet Propulsion, 1932–1946," *Research in Economic History* 23 (2005): 1–59; Andrei Markevich and Mark Harrison, "Quality, Experience, and Monopoly: The Soviet Market for Weapons under Stalin," *Economic History Review* 59, no. 1 (2006): 113–142; Mark Harrison, ed., *Guns and Rubles: The Defense Industry in the Stalinist State* (Yale University Press, 2008), chapters 3, 6, and 8.

43. These proposals were usually in the form of an *avant proekt* (advance plan). For an older but still quite useful summary of the Soviet weapons R&D process, see Arthur J. Alexander, "Decision-Making in Soviet Weapons Procurement," Adelphi Papers 147–148 (1978–1979), 1–64. For a more recent one, see Barry, "The Missile Design Bureaux and Soviet Piloted Space Policy, 1953–1970," 66–80.

44. Vetrov, *S. P. Korolev i ego delo*, 664.

45. Boris Chertok, *Rockets and People*, volume II: *Creating a Rocket Industry*, ed., Asif A. Siddiqi (NASA, 2006), 545–554; Vetrov, *S. P. Korolev i ego delo*, 288–289.

46. The decree, issued on June 23, 1960, was titled "On the Creation of Powerful Carrier-Rockets, Satellites, Spaceships, and the Conquest of Space in 1960–67." It has been published as "O sozdanii moshchnykh raket-nositelei, sputnikov, kosmicheskikh korablei i osvoenii kosmicheskogo prostrantsva v 1960–1967 godakh" (June 23, 1960) in *Sovetskaia kosmicheskaia initsiativa v gosudarstvennykh dokumentakh, 1946–1964 gg.*, ed. Iu. M. Baturin (RTSoft, 2008), 96–100.

47. Other early pioneers, such as the American Robert Goddard, and the Romanian-German Hermann Oberth, also came to the same conclusions.

48. There are many accounts of the R-16 disaster in print. See Chertok, *Rockets and People*, volume II, 597–634; Asif A. Siddiqi, "Mourning Star: The Nedelin Disaster," *Quest* 3, no. 4 (1994): 38–47.

49. The R-7 ICBM was officially declared operational on January 20, 1960.

50. Asif A. Siddiqi, "The Rockets' Red Glare: Technology, Conflict, and Terror in the Soviet Union," *Technology and Culture* 44, no. 3 (2003): 470–501.

51. Siddiqi, *The Red Rockets' Glare*, chapters 5–7.

52. This was the RD-109 engine. See I. Afanas'ev, "Neizvestnyi dvigatel' zabytoi rakety," *Novosti kosmonavtiki* no. 1 (2006): 66–67.

53. In the spring of 1958, Korolev pressured five other chief designers (including Glushko) to sign off on a report in favor of liquid oxygen for his new R-9. See S. P. Korolev et al., "O perspektivakh razvitiia kislorodnykh raket" (April 18, 1958), in Vetrov, *S. P. Korolev i ego delo*, 249–252.

54. On March 2, 1959, Minister of Defense R. Ia. Malinovskii and his deputy M. I. Nedelin wrote a letter to Korolev and chairman of the Military-Industrial Commission D. F. Ustinov agreeing to support the R-9 project as articulated by Korolev. See Vetrov, *S. P. Korolev i ego delo*, 286, 672.

55. This was the RD-110 engine. I. Afanas'ev, "'Kopii' dvigatelei dlia 'semerki,'" *Novosti kosmonavtiki* no. 7 (2005): 67–69.

56. For more on Kuibyshev and Kuznetsov, see Robert MacGregor, "The Little Engine That Could," paper presented at History of Science Workshop, Princeton University, 2010.

57. Korolev also made contact with A. M. Liul'ka's OKB-165 and S. A. Kosberg's OKB-154 to produce rocket engines for his missiles and spacecraft. In 1959, the Soviet party and government issued a decree calling for aviation design bureaus to produce rocket engines. See "O privlecheniia aviatsionnykh motorostroitel'nykh OKB k razrabotke raketnykh dvigatelei" (June 16, 1959) in *Zadacha osoboi gosudarstvennoi vazhnosti: iz istorii sozdaniia raketno-iadernogo oruzhiia i Raketnykh voisk strategicheskogo naznacheniia (1945–1959 gg.): sbornik dokumentov*, ed. V. I. Ivkin and G. A. Sukhina (Rosspen, 2010).

58. The Soviet government approved development of Kuznetsov's first rocket engine, the NK-9 (35 tons thrust), on June 26, 1959. See S. N. Tresviatskii et al., "Kosmicheskie dvigateli SNTK imeni N. D. Kuznetsova," *Aerokosmicheskii obzor* no. 3 (2006): 108–109.

59. S. P. Korolev to L. I. Brezhnev, November 25, 1959, in Vetrov, *S. P. Korolev i ego delo*, 284–287. Korolev also wrote a letter to the Central Committee of the Communist Party on December 8, 1959. The R-9 variant with Kuznetsov's engines was known as the R-9M.

60. For Glushko's report on a comparison between his and Kuznetsov's engines, see V. P. Glushko, "Vyvody k dokladu na komissii 14.12.1959 g" (December 14, 1959), in *Izbrannye raboty akademika V. P. Glushko: chast' 1*, ed. V. S. Sudakov et al. (NPO Energomash, 2008). For Glushko's letter to the government and other designers rejecting Korolev's appeal, see V. P. Glushko to D. F. Ustinov et al., December 25, 1959, in *Izbrannye raboty akademika V. P. Glushko*, 143–150. On January 18, 1960, the "minister" in charge of the defense industry, K. N. Rudnev, informed Korolev that R-9 rocket project would proceed as originally conceived, with Glushko's engines. See Vetrov, *S. P. Korolev i ego delo*, 676.

61. V. P. Glushko to S. P. Korolev (January 3, 1958), in *Izbrannye raboty akademika V. P. Glushko*, 133–135. The first engine he produced using this combination (liquid oxygen–UDMH) was the RD-109 upper stage. Subsequently, he proposed using the RD-112 and the RD-113 in his R-20 "super rocket" in early 1960, and the RD-114 and the RD-115 in an early variant of the N-I rocket in late 1960.

62. These words are from a series of lectures Glushko gave at the N. E. Zhukovskii Air Force Academy in 1933 and 1934, which were later published in a monograph in 1936. See V. P. Glushko, "Zhidkoe toplivo dlia reaktivnykh dvigatelei" (1936) in V. P. Glushko, *Put' v raketnoi tekhnike: izbrannye trudy, 1924–1946* (Mashinostroenie, 1977), 231–330. Glushko had other technical reservations about the use of liquid oxygen, which included: the challenge of cooling as a result of the unusually high temperatures during combustion that threatened to melt the metal casing; and the challenge of creating stable combustion within the combustion chamber since liquid oxygen engines at high pressure are prone to extremely dangerous high-frequency oscillations that destroy engines. He had identified the cooling problem as a technical challenge already in 1932 when he was only 24 years old. See his "Otchet po opytam s reaktivnymi motorami, provedennymi po 1 sentiabria 1932 goda" (September 1, 1932) in Glushko, *Put' v raketnoi tekhnike*, 143–157.

63. These included engines for the following missiles: the R-14 (the RD-216 engine) and the R-16 (the RD-218 and RD-219 engines). For details, see Asif Siddiqi, "Rocket Engines from the Glushko Design Bureau: 1946–2000," *Journal of the British Interplanetary Society* 54 (2001): 311–334.

64. V. P. Glushko to N. P. Antonov, December 9, 1960, in *Izbrannye raboty akademika V. P. Glushko*, 185–189.

65. At first, at an important meeting in September of 1960, Glushko had insisted on the nitric acid–UDMH combination for the N-I. See "Vypiska iz protokola soveshchaniia glavnykh konstrukturov po nositeliiu N-I" (September 23, 1960), in Vetrov, *S. P. Korolev i ego delo*, 305–308. In 1960, Glushko began developing several engines with this combination, including the RD-224 engine (for the R-26 ICBM), and the RD-220, RD-221, RD-222, and RD-223 engines (for early

conceptions of the N-I). But later, at a meeting in January of 1961, he replaced nitric acid with nitrogen tetroxide, and insisted on the nitrogen tetroxide–UDMH combination for the N-I. See "Vypiska iz protokola rasshirennogo soveshchaniia glavnykh konstruktorov" (January 31, 1961) on pp. 319–323 in the same source. These new engines for the N-I were the RD-253 and RD-254.

66. V. P. Glushko to S. P. Korolev, March 18, 1961, in *Izbrannye raboty akademika V. P. Glushko*, 195–199.

67. For details on these contracts, see Siddiqi, *Challenge to Apollo*, 314–318.

68. V. P. Glushko to S. P. Korolev, November 10, 1961, in *Izbrannye raboty akademika V. P. Glushko*, 204–211. See also Glushko to D. F. Ustinov, November 14, 1961; Glushko to M. V. Keldysh, November 24, 1961, in the same volume (pp. 211–212).

69. Korolev notes that there were "seven Academicians, nine Corresponding Members [of the Academy of Sciences], representatives of the Ministry of Defense, many doctors and candidates of science, including the best specialists in engine design, propellants, combustion processes, etc." See S. P. Korolev, "Otsenka plana rabot OKB V. P. Glushko" (September 30, 1963) in Vetrov, *S. P. Korolev i ego delo*, 426–431 (see especially 429).

70. The commission examined four different pairs of propellants: liquid oxygen–kerosene, liquid oxygen–UDMH, nitrogen tetroxide–UDMH, and nitric acid–UDMH.

71. V. P. Glushko to S. P. Korolev, November 10, 1961, in *Izbrannye raboty akademika V. P. Glushko*, 204–211. Glushko sent similar letters to D. F. Ustinov (on November 14), M. V. Keldysh (on November 24), and I. D. Serbin (on November 29).

72. V. P. Glushko to B. A. Komissarov, February 19, 1962, in *Izbrannye raboty akademika V. P. Glushko*, 216–218.

73. These, according to Glushko, would include additional electrical power, the cost of refrigeration equipment, costs of their maintenance and depreciation, maintaining extra staff, storage tanks with special insulation at the launch site, etc.

74. Glushko to Korolev, November 10, 1961, 207. Later in the letter, he notes that "the cost of oxygen-kerosene propellants is not much less expensive than nitric tetroxide with [UDMH], considering the costs of manufacturing and operating storage tanks for super-cooled oxygen and units for super-cooling."

75. "Doklad o moshchnoi rakete-nositele N-I na zasedanii ekspertnoi komissii" (July 2–16, 1962) in Vetrov, *S. P. Korolev i ego delo*, 363–382.

76. "Doklad o moshchnoi … ," 363–382.

77. Glushko to Korolev, November 10, 1961, 207–208.

78. Korolev's OKB-1 produced the S1.5400 engine for an upper-stage application in 1958–61, while Kuznetsov's OKB-276 started work on the NK-9, originally meant for an abandoned version of the R-9 known as the R-9M, in 1958. Korolev's arguments on staged-combustion engines are from "Doklad o moshchnoi … ," 368–370; S. S. Kriukov, "N-1: Istoriia proektirovaniia, stroitel'stva, ispytanii," in *S. S. Kriukov: izbrannye raboty: iz lichnogo arkhiva*, ed. A. M. Pesliak

(Izd.-vo MGTU im. N. E. Baumana, 2010), 49–138 (see especially pp. 57–60). For more on Kuznetsov's NK-15 engine and staged combustion in general, see MacGregor, "The Little Engine That Could."

79. Glushko to Korolev, November 10, 1961, 209.

80. "Doklad o moshchnoi … ," 369–370.

81. Kriukov, "N-1," 79–80.

82. The actual text of the decision notes the following advantages of the liquid oxygen–kerosene combination over storable propellants: (1) higher specific impulse; (2) lighter rocket; (3) higher payload to orbit; (4) safer; and (5) cheaper. See the excerpt from the commission's final decision quoted in Korolev, "Otsenka plana rabot OKB V. P. Glushko," 428–429.

83. G. Vetrov, "Trudnaia sud'ba rakety N-1," *Nauka i zhizn'* no. 5 (1994): 20–27.

84. Nikita Khrushchev, *Khrushchev Remembers: The Glasnost Tapes* (Little, Brown, 1990), 186.

85. Glushko describes his various attempts to propose alternatives to the N-I in a report in early 1962. See V. P. Glushko to D. F. Ustinov and L. V. Smirnov, March 12, 1962, in *Izbrannye raboty akademika V. P. Glushko*, 221–229.

86. This was Iangel's R-46 "super-rocket," an early competitive project to Korolev's N-I, which was never formally approved by the Soviet party and government. See V. P. Glushko to M. K. Iangel' (April 3, 1961) in *Izbrannye raboty akademika V. P. Glushko*, 199–202.

87. Glushko to Ustinov and Smirnov, March 12, 1962, in *Izbrannye raboty akademika V. P. Glushko*, 229. For an excellent discussion of the R-56 rocket, see Bart Hendrickx, "Heavy Launch Vehicles of the Yangel Design Bureau," *Space Chronicle JBIS* 63, Suppl. 2 (2010): 50–62 and 64, Suppl. 1 (2011).

88. "Protokol'naia zapis' vystupleniia na soveshchanii glavnykh konstruktorov o khode rabot po tiazhelomu nositeliiu N-I" (June 23, 1964), in Vetrov, *S. P. Korolev i ego delo*, 459.

89. On July 18, 1965, the leading research institute of the missile and space sector, NII-88, issued a report rejecting the proposal to replace Kuznetsov's engines on the N-I with those of Glushko. See Vetrov, *S. P. Korolev i ego delo*, 696.

90. For the initial proposal for this rocket, known as the UR-700, see V. N. Chelomei, V. P. Glushko, V. P. Barmin, and V. I. Kuznetsov, "Predlozhenie po sozdaniiu raketno-kosmicheskoi sistemi UR-700" (October 16, 1965) in *Izbrannye raboty akademika V. P. Glushko*, 288–293. See also "O provedenii rabot po raketno-kosmicheskoi sisteme UR-700-LK-700" (June 30, 1967), Russian State Archive of the Economy (RGAE), f. 4372, op. 81, d. 2519, ll. 125–129.

91. Siddiqi, *Challenge to Apollo*, 480–481, 538–546.

92. I. Afanas'ev, "N-1: sovershenno sekretno" [Part 2], *Kryl'ia rodiny* no. 11 (1993): 4–5.

93. V. P. Glushko to S. P. Korolev, November 10, 1961, in *Izbrannye raboty akademika V. P. Glushko*, 211.

94. These were Chelomei's UR-100N and Iangel's MR UR-100 missiles. For discussions of the "little civil war," see Boris Chertok, *Rockets and People*, volume III: *Hot Days of the Cold War*, ed. Asif A. Siddiqi (NASA, 2009), 148–154; N. A. Anfimov, ed., *Tak eto bylo … : memuary Yu. A. Mozzhorin: Mozzhorin v vospominaniiakh sovremennikov* (ZAO Mezhdunarodnaia programma obrazovaniia, 2000), 144–188.

95. Vetrov, *S. P. Korolev i ego delo*, 321.

96. "Doklad o moshchnoi … ," 369–370.

97. Vetrov, *S. P. Korolev i ego delo*, 307.

98. S. P. Korolev, "Dokladnaia zapiska o razvitii upravliaemykh chelovekom korablei-sputnikov i podgotovke neobkhodimykh kadrov spetsialistov dlia kosmicheskikh poletov" (April 20, 1962) in Vetrov, *S. P. Korolev i ego delo*, 360–363.

99. S. P. Korolev to K. N. Rudnev (January 15, 1961) in Vetrov, *S. P. Korolev i ego delo*, 316–319.

100. Siddiqi, *Challenge to Apollo*, 481.

101. N. P. Kamanin, *Skrytyi kosmos: kniga tret'ia, 1967–1968gg.* (OOO IID Novosti kosmonavtiki, 1999), 35.

102. For details on the static testing of the individual engines, see A. A. Makarov, ed., *Nazemnye ispytaniia raketno-kosmicheskoi tekhniki: opyt otrabotki raketnoi i raketno-kosmicheskoi tekhnik, 1949–1999 gg.* (Roskosmos/FGUP NII Khimmash, 2001).

103. For details, see Siddiqi, *Challenge to Apollo*, 679–684, 688–693, 701, 729–730, 754–756, 780, 818–824.

104. Graham, "Big Science in the Last Years of the Big Soviet Union," 51.

105. For the anti-ballistic missile program, see Mikhail Pervov, *"Annushki"—chasovye Moskvy: istoricheskii ocherk* (Stolichnaia entsiklopediia, 2010). For the particle beams program, see Peter J. Westwick, "'Space-Strike Weapons' and the Soviet Response to SDI," *Diplomatic History* 32, no. 5 (2008): 955–979. On Mars, see V. G. Perminov, *The Difficult Road to Mars: A Brief History of Mars Exploration in the Soviet Union* (NASA, 1999).

106. N. S. Stroyev, "Voennaia aviatsiia," in *Sovetskaia voennaia moshch' ot Stalina do Gorbacheva*, ed., A. V. Minaev (Voennyi parad, 1999), 280. This move to limit the chaos in the defense industry may have been part of a larger process of bureaucratic and industrial rationalization in the post-Khrushchev era connected with A. N. Kosygin's failed reforms to introduce quasi-market features into the command economy.

107. See the letter from Korolev to Rudnev (January 15, 1961) in Vetrov, *S. P. Korolev i ego delo*, 316–319.

108. S. P. Korolev to S. S. Kryukov, February 5, 1962, in Vetrov, *S. P. Korolev i ego delo*, 355–357.

109. Capshew and Rader, "Big Science," 10.