

The Metamorphosis of Andrei Sakharov

*The inventor of the Soviet hydrogen bomb
became an advocate of peace and human rights.
What led him to his fateful decision?*

by Gennady Gorelik

The cloud turned gray, quickly separated from the ground and swirled upward, shimmering with gleams of orange.... The shock wave blasted my ears and struck a sharp blow to my entire body; then there was a prolonged, ominous rumble that slowly died away after thirty seconds or so The cloud, which now filled half the sky, turned a sinister blue-black color."

It was August 12, 1953, and Andrei Dmitrievich Sakharov had just become father of the Soviet hydrogen bomb. Along with a few officials, he donned a dustproof jumpsuit and drove into the blast range. The car stopped beside an eagle that was trying to get off the ground; its wings had been badly burned. "I have been told that thousands of birds are destroyed during every test," Sakharov was later to write in his memoirs. "They take wing at the flash, but then fall to earth, burned and blinded."

The innocent victims of nuclear testing were to become a deepening concern, and ultimately an obsession, for this extraordinary man. While he continued to design ever more efficient bombs, he also agonized over how many human lives the fallout from each blast would cost. Sakharov's many fruitless attempts to stop unnecessary tests at last led to his realizing how little control he had over the weapons he had created.

Numerous tales have been invented to account for Sakharov's transformation to an advocate for human rights. After his death in 1989, the Russian state archives released many secret documents relating to his life and work, which are now to be found in the Sakharov Archives in Moscow. These papers, as well as Sakharov's own writings, show that his metamorphosis derived directly from his involvement in the weapons project. For years, Sakharov genuinely believed that nuclear—and thermonuclear—weapons were vital to maintaining military parity with and preventing aggression by the U.S. His transformation came not from a newfound morality but from his rather old-fashioned one, coupled with his accumulating experience with weapons and in the politics of weaponry.

A Sugary Layered Roll

Sakharov was born in 1921 to a family of Moscow intelligentsia. His father was a teacher of physics and a writer of popular science books, as well as a humane and forthright man. After graduating from high school, Andrei enrolled in Moscow University in 1938. When war broke out with Germany, his weak heart prevented him from being drafted. Graduating with honors in 1942, he refused to go on to higher studies: he wanted to contribute to the war effort. Accordingly, he became an

engineer in a military ammunition plant in Ulyanovsk, where he invented a magnetic device to test the cores of the bullets that were being manufactured.

At the factory he met Klavdia Vikhireva, whom he married at the age of 22. In those years he also dreamed up and solved some small problems in physics, which found their way through his father to Igor Tamm, the leading theoretical physicist at the P. N. Lebedev Physical Institute in Moscow. In early 1945 Sakharov was officially invited to Moscow to conduct graduate studies under Tamm's supervision.

One morning in August he saw in a newspaper that an atomic bomb had exploded over Hiroshima. He realized that "my fate and the fate of many others, perhaps of the entire world, had changed overnight."

Sakharov was clearly very able as a scientist and soon came up with a theory of sound propagation in a bubbly liquid, of importance in detecting submarines with sonar. He also calculated how fusion, the merging of two nuclei into one, might be catalyzed by a light, electronlike particle known as a muon. (Atoms that contain muons in place of electrons are much smaller and therefore would require less compression to be fused.)

Exhilarated by pure physics, he twice declined invitations from senior officials to join the Soviet atomic

weapons project. An atomic bomb involves the fission of a heavy nucleus such as uranium 235 into two roughly equal parts, accompanied by the release of energy. But one day in 1948 Tamm announced that he and some selected associates, including Sakharov, had been assigned to investigate the possibility of a hydrogen bomb. This kind of bomb is based on the fusion of light nuclei, most commonly the two forms of hydrogen called deuterium and tritium, emitting greater amounts of energy than a fission bomb does.

Yakov Zel'dovich, a brilliant physicist who headed theoretical research for the nuclear weapons program, handed Tamm a tentative design for the hydrogen bomb. Fusion requires two positively charged nuclei to be brought close enough, despite their mutual repulsion, to touch; such conditions can arise only from the tremendous energy generated by a preceding fission reaction. The idea was to use fission to ignite fusion—otherwise known as a thermonuclear reaction—at one end of a tube of deuterium and somehow make the fusion propagate through the tube. This plan for a “superbomb,” devised by American scientists, was given to Soviet intelligence authorities, most likely by physicist and spy Klaus Fuchs in 1945.

Sakharov turned out to be exceedingly adept at the combination of theoretical physics and engineering that was required in making a hydrogen bomb. Despite his junior status, he soon proposed a radically different design, called the *sloika*, or “layered roll”: a spherical configuration with an atom bomb in the center, surrounded by shells of deuterium alternating with heavy elements such as natural uranium. The electrons released by the initial atomic explosion generated tremendous pressure within the uranium shell, forcing the fusion of deuterium. The Soviets called the process “sakharization”—literally, “sugaring” (the Russian *sakhar* translates to “sugar”). The fusion in turn released neutrons that enabled the fission of uranium.

The concept, enhanced by an idea from Vitaly Ginzburg—that lithium deuteride replace deuterium as a fuel—allowed the Soviet program to catch up with the American one. It was not until 1950 that American scientists realized that their superbomb design was a dud. But Stanislaw Ulam and Edward Teller of Los Alamos National Laboratory in

New Mexico soon invented another design, and the thermonuclear arms race had taken off.

Although Sakharov was fascinated with the physics of fusion, his zeal in pursuing the bomb derived also from patriotism. He believed in concepts such as “strategic parity” and “nuclear deterrence,” which suggested that nuclear war was impossible. His emotional investment in the project was immense: “The monstrous destructive force, the scale of our enterprise and the price paid for it by our poor, hungry, war-torn country ... all these things inflamed our sense of drama and inspired us to make a maximum effort so that the sacrifices—which we accepted as inevitable—would not be in vain. We were possessed by a true war psychology.”

Yet when Sakharov received an invitation to join the Communist Party, he refused because of its past crimes. He had no choice, however, when in March 1950 he and Tamm were assigned exclusively to bomb work at a secret city where weapons designers lived and worked. Sakharov learned that this military facility had been built by prison labor in the old monastery town of Sarov, situated about 500 kilometers from Moscow. The entire city was surrounded by rows of barbed wire and erased from all maps. It was known to insiders by various code names, at the time Arzamas-16.

In a Secret City

Zel'dovich was already at Arzamas-16. The physicists spent much of the day ironing out details of bomb design. Nevertheless, Sakharov found time to conceive an idea for confining a plasma, gas so hot that electrons have been stripped from the atoms, leaving bare nuclei. The plasma would destroy any material walls but could be confined and even induced to fuse by means of magnetic fields. This principle, the basis of the tokamak reactor, is still the most promising design for producing energy from sustained fusion. (“Tokamak” is derived from the Russian phrase for a doughnut-shaped chamber with a magnetic coil.)

In November 1952 the U.S. had detonated a thermonuclear device. And by August 1953 Soviet scientists were ready to test the *sloika*. At the last minute, however, Viktor Gavrilov, a physicist trained as a meteorologist,

pointed out that the radioactive fallout from the explosion would spread far beyond the test site and affect neighboring populations. Somehow no one had thought of this problem. Using an American manual on the effects of test explosions, the physicists quickly worked out the fallout pattern and realized that thousands of people would have to be moved. The recommendation was followed (although, as one official informed an anxious Sakharov, such maneuvers typically cause 20 or 30 deaths).

The *sloika* was successfully tested, yielding an energy about 20 times that of the Hiroshima bomb. In a few months Sakharov was elected a member of the Soviet Academy of Sciences—at 32 its youngest physicist ever. He also received the Stalin Prize and was decorated with the title Hero of Socialist Labor. The Soviet leadership had great hopes for Sakharov: not only was he brilliant, he was also non-Jewish (unlike Zel'dovich and Ginzburg) and politically clean (unlike Tamm).

The *sloika* was, however, limited in scope—its yield could not be increased indefinitely—and soon Sakharov and Zel'dovich came up with a new design. The idea was to use the radiation (photons) generated by an initial atomic explosion to compress a tube, thereby igniting fusion within it. The design, similar to the Ulam-Teller one, had potentially unlimited yield because the length of the tube could be increased as required.

Life at Arzamas-16 was unusual in more than one way. The researchers discussed politics quite freely. Moreover, they had access to Western journals, including the *Bulletin of the Atomic Scientists*, which concerned itself mainly with the social dimensions of nuclear energy and demonstrated how scientists on the other side of the Iron Curtain sought to influence public affairs. One inspiring figure was Leo Szilard, who had discovered the “chain reaction” that makes atomic bombs possible but who turned into a vocal critic of nuclear weapons. Sakharov was also aware of the political writings of Albert Einstein, Niels Bohr and Albert Schweitzer, who doubtless influenced him as well.

A memo written by the administrative director of Arzamas-16 in 1955 noted that although Sakharov was an able scientist, he had substantial defects in the realm of politics. He had, for in-

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stance, declined an offer to be elected to the Council of People's Deputies, a legislative body at Arzamas. The "defects" were to get worse.

In November 1955 the Soviets tested the unlimited hydrogen bomb. This time the shock wave from the blast collapsed a distant trench, killing a soldier, and crumbled a building, killing a toddler. These events weighed heavily on Sakharov. When asked to propose a toast at the celebratory banquet that night, he announced, "May all our devices explode as successfully as today's, but always over test sites and never over cities." Marshal Mitrofan Nedelin replied with an obscene joke, whose point was that scientists should just make the bombs and let military men decide where they should explode. It was designed to put Sakharov in his place.

As variations of the basic thermonuclear devices continued to be tested, Sakharov became increasingly concerned about the unidentifiable victims of each blast. He taught himself enough genetics to calculate how many persons worldwide would be affected by cancers and other mutations as a result of nuclear testing.

In 1957 the U.S. press reported the development of a "clean bomb," a fusion bomb that used almost no fissionable material and seemingly produced no radioactive fallout. Sakharov found, however, on the basis of available biological data that a one-megaton (equivalent to a million tons of TNT) clean bomb would result in 6,600 deaths worldwide over a period of 8,000 years because of the proliferation of radioactive carbon 14 (produced when neutrons from the explosion interacted with atmospheric nitrogen). He published his results in 1958 in the Soviet journal *Atomic Energy*, concluding that the atmospheric testing of any hydrogen bomb—"clean" or not—is harmful to humans.

The Chips Fly

Soviet premier Nikita S. Khrushchev himself endorsed the publication of this article. It suited his purposes: in March of 1958 he had suddenly announced a unilateral cessation of nuclear tests. Sakharov was not, however, playing political games. His figures revealed, as he saw it, that "to the suffering and death already existing in the world there would be added hundreds of thousands of additional victims, including people living in neutral countries as well as in future genera-

tions." He was also troubled that "this crime is committed with complete impunity, since it is impossible to prove that a particular death was caused by radiation."

In the same year Teller published a book, *Our Nuclear Future*, laying out the majority view of both American and Soviet hydrogen-bomb experts—who did not share Sakharov's concern. Teller estimated the radiation dose from testing as roughly 100th of that from other sources (such as cosmic rays and medical x-ray examinations). He also noted that radiation from testing reduced life expectancy by about two days, whereas a pack of cigarettes a day or a sedentary job reduced it by 1,000 times more. "It has been claimed," he concluded, "that it is wrong to endanger any human life. Is it not more realistic and in fact more in keeping with the ideals of humanitarianism to strive toward a better life for all mankind?" To Sakharov, that statement sounded a lot like the Soviet slogan "when you chop wood, chips fly." He felt personally responsible for any deaths from the fallout of testing.

Meanwhile the U.S. and Britain continued testing, and after six months, a furious Khrushchev ordered that testing be resumed. Deeply concerned—because of the deaths he was convinced would ensue—Sakharov persuaded Igor Kurchatov, the scientific head of the atomic project, to visit Khrushchev and explain how computers, limited experiments and other kinds of modeling could make testing unnecessary. Khrushchev did not agree, nor did he welcome the advice. Sakharov repeated his efforts in 1961, when after a de facto moratorium the premier again announced new tests. Khrushchev angrily told him to leave politics to those who understood it.

In 1962 Sakharov learned that tests of two very similar designs of hydrogen bombs were going to be carried out. He tried his best to stop the duplicate test. He pulled all the strings he could, pleaded with Khrushchev, enraged his colleagues and bosses—all to no avail. When the second bomb was exploded, he put his face down on his desk and wept.

To his surprise, however, he was soon able to solve the larger problem. In 1963 his suggestion of a ban on the most harmful—atmospheric—testing was well received by the authorities and resulted in the signing of the Limited Test Ban Treaty in Moscow that same year. Sakharov was justifiably proud of his contribution. After atmospheric testing was stopped, its harmful effects ceased to worry him.

His concerns, however, had induced him to take two major steps: from science to the sphere of morals and finally to politics. The bomb program did not really need him anymore, but Sakharov was starting to feel that his presence would be essential to his retaining influence over the politics of weapons.

In these years Sakharov also found time to return to his first love, pure science. A problem that continues to plague scientists is the excess of matter over antimatter in the universe [see "The Asymmetry between Matter and Antimatter," by Helen R. Quinn and Michael S. Witherell; *SCIENTIFIC AMERICAN*, October 1998]. He laid out the conditions that could allow such an imbalance to arise, his most important contribution in theoretical physics. Vladimir Kartsev, a young physicist who asked Sakharov to write a preface for his popular science book, recalls that he looked very happy, full of creative energy and ideas about physics.

In 1966 Sakharov signed a collective letter to Soviet leaders against an ominous tendency to rehabilitate Stalin. Most tellingly, in December of that year he accepted an anonymous invitation to participate in a silent demonstration in support of human rights. But when he wrote to the Soviet government in support of dissidents, his salary was slashed, and he lost one of his administrative positions. The events, however, put him in increasing and ultimately fateful contact with activists in Moscow.

Sakharov's worldview was becoming increasingly radical, and it demanded an outlet. In July 1967 he sent via secret mail a letter to the government. He argued that a moratorium proposed by the U.S. on antiballistic-missile systems was to the benefit of the Soviet Union, because an arms race in this new technology would make a nuclear war much more probable. This nine-page memo, with two technical appendices, is now to be found in the Sakharov Archives. Among other things, the letter sought permission for publishing an accompanying 10-page manuscript in a Soviet newspaper to help "American scientists to curb their hawks." The article's style shows that Sakharov still considered himself a technical expert devoted to the "essential interests of Soviet policy."

Nevertheless, permission was refused. The rejection was yet another confirmation to the physicist that those who mattered were oblivious to the danger to which they were subjecting the world.

Early in 1968 Sakharov started working on a massive essay, entitled "Reflections on Progress, Peaceful Coexistence and Intellectual Freedom." He made no effort to hide this

manuscript—the secretary at Arzamas-16 retyped it, automatically handing a copy to the KGB. (This carbon copy is now in the president's archives in Moscow.) The article described the grave danger of thermonuclear war and went on to discuss other issues, such as pollution of the environment, overpopulation and the cold war. It argued that intellectual freedom—and more generally, human rights—is the only true basis for international security and called for the convergence of socialism and capitalism toward a system that combined the best aspects of both.

The Die Is Cast

By the end of April Sakharov had released to the samizdat, or underground press, this radical essay. In June he sent it to Leonid I. Brezhnev (who had already seen it, courtesy of the KGB), and in July its contents were described by the British Broadcasting Corporation and published in the *New York Times*. Sakharov recalled listening to the BBC broadcast with profound satisfaction: "The die was cast."

Sakharov was ordered to stay in Moscow and restricted from visiting Arzamas-16. He had spent 18 years of his life in the secret city. He was not, however, fired from the bomb project until the next year: deciding the fate of a Hero of Socialist Labor three times over, who, moreover, knows the nation's most sensitive secrets, can be tricky. Shortly after, his wife died of cancer, leaving him with three children, the youngest aged only 11. Grief-stricken, Sakharov donated all his savings to a cancer hospital and the Soviet Red Cross.

For Sakharov, a lifetime had ended, and another was about to begin. He had 20 years of life left. He was to meet Elena Bonner, the friend and love of his life, to be awarded the Nobel Prize in Peace in 1975, to pass seven years in exile at Gorki and, unbelievably, to spend his last seven months as an elected member of the Soviet parliament.

Perhaps the best person to explain Sakharov is Sakharov. "If I feel myself free," he once mused, "it is specifically because I am guided to action by my concrete moral evaluation, and I don't think I am bound by anything else." He always did exactly what he believed in, led by a clear, unwavering inner morality. In the 1970s one of his colleagues, Vladimir Ritus, asked him why he had taken the steps he did, thereby putting himself in such grave danger. Sakharov's reply was, "If not me, who?" It was not that he considered himself chosen in any way. He simply knew that fate, and his work on the hydrogen bomb, had uniquely placed him to make choices. And he felt compelled to make them.

The Author

GENNADY GORELIK has just written a biography of Andrei Sakharov with the aid of grants from the Guggenheim foundation and the MacArthur foundation. It is to be published by W. H. Freeman and Company. He received his Ph.D. in 1979 from the Institute for the History of Science and Technology of the Russian Academy of Sciences. Currently he is a research fellow at the Center for Philosophy and History of Science at Boston University. He also wrote for *Scientific American* in August 1997, on an anti-Stalin manifesto co-authored by physicist Lev Landau.

Further Reading

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ANDREI SAKHAROV: SOVIET PHYSICS, NUCLEAR WEAPONS, AND HUMAN RIGHTS. On-line exhibit from the American Institute of Physics is available at www.aip.org/history/sakharov on the World Wide Web.