BOOKS BY RICHARD RHODES

FICTION

Sons of Earth

The Last Safari

Holy Secrets

The Ungodly

VERITY

Visions of Technology

Deadly Feasts

How to Write

Nuclear Renewal

Making Love

A Hole in the World

Farm

The Making of the Atomic Bomb

Looking for America

The Inland Ground

Richard
Rhodes

DARK SUN

THE MAKING OF THE HYDROGEN BOMB

SIMON & SCHUSTER PAPERBACKS
New York London Toronto Sydney

SIMON & SCHUSTER PAPERBACKS
Rockefeller Center
1230 Avenue of the Americas
New York, NY 10020

First Simon & Schuster paperback edition 2005

Designed by Irving Perkins Associates, Inc.

Manufactured in the United States of America

17 19 20 18 16

The Library of Congress has cataloged the hardcover edition as follows:
Rhodes, Richard.
Dark sun : the making of the hydrogen bomb.
p. cm.
1. Hydrogen bomb—History. I. Title.
UG1282.A8R46 1995
623.4'5119—dc20 95-11070

ISBN-13: 978-0-684-80400-2
ISBN-10: 0-684-80400-X
ISBN-13: 978-0-684-82414-7 (Pbk)
ISBN-10: 0-684-82414-0 (Pbk)

The author is grateful for permission to reprint the following:

Arthur Lawrence Norberg interviews with Norris Bradbury, Darol Froman, John Manley, J. Carson Mark and Raemer Schreiber quoted by permission of The Bancroft Library.

Excerpts from *The Journals of David E. Lilienthal, Vol. 2: The Atomic Energy Years, 1945–1950* by David E. Lilienthal. Copyright © 1964 by David E. Lilienthal. Copyright renewed 1992. Reprinted by permission of HarperCollins Publishers, Inc.

Excerpts from *Mission with LeMay* by Curtis E. LeMay with MacKinlay Kantor. Copyright © 1965 by Curtis E. LeMay and MacKinlay Kantor. Used by permission of Doubleday, a division of Bantam Doubleday Dell Publishing Group, Inc.

Excerpts from Yuli Khariton and Yuri Smirnov, "The Khariton Version," *Bulletin of the Atomic Scientists,* v.93, reprinted by permission of Yuri Smirnov.

Excerpts from the unpublished papers of John Manley quoted by permission of Kathleen B. Manley; of Raemer Schreiber quoted by permission of Raemer Schreiber.

Excerpts from Ilya Ehrenburg and Konstantin Simonov, *In One Newspaper.* Trans. Anatol Kagan. Copyright © 1985 by Sphinx Press and reprinted by permission.

(continued at back of book)

For Arthur L. Singer, Jr.

The author acknowledges with gratitude the support of the John D. and Catherine T. MacArthur Foundation and the Alfred P. Sloan Foundation in the research and writing of this book.

THIS BOOK IS PUBLISHED AS PART OF AN
ALFRED P. SLOAN FOUNDATION PROGRAM

Contents

Preface to the Sloan Technology Series 13
Prologue: Deliveries 17

Part One
A Choice Between Worlds

1. 'A Smell of Nuclear Powder' 27
2. Diffusion 49
3. 'Material of Immense Value' 66
4. A Russian Connection 83
5. 'Super Lend-Lease' 94
6. Rendezvous 103
7. 'Mass Production' 121
8. Explosions 146
9. 'Provide the Bomb' 165
10. A Pretty Good Description 180

Part Two
New Weapons Added to the Arsenals

11. Transitions 201
12. Peculiar Sovereignties 224
13. Changing History 244
14. F-1 264
15. *Modus Vivendi* 285
16. Sailing Near the Wind 302

17. Getting Down to Business 324
18. 'This Buck Rogers Universe' 345
19. First Lightning 364
20. 'Gung-ho for the Super' 382

Part Three
Scorpions in a Bottle

21. Fresh Horrors 411
22. Lessons of Limited War 438
23. Hydrodynamic Lenses and Radiation Mirrors 455
24. Mike 482
25. Powers of Retaliation 513
26. In the Matter of J. Robert Oppenheimer 530
27. Scorpions in a Bottle 560

Epilogue: 'The Gradual Removal of Prejudices' 577

Acknowledgments 589
Notes 591
Glossary of Names 671
Bibliography 689
Index 705

Preface to the Sloan Technology Series

TECHNOLOGY IS THE APPLICATION of science, engineering and industrial organization to create a human-built world. It has led, in developed nations, to a standard of living inconceivable a hundred years ago. The process, however, is not free of stress; by its very nature, technology brings change in society and undermines convention. It affects virtually every aspect of human endeavor: private and public institutions, economic systems, communications networks, political structures, international affiliations, the organization of societies and the condition of human lives. The effects are not one-way; just as technology changes society, so too do societal structures, attitudes and mores affect technology. But perhaps because technology is so rapidly and completely assimilated, the profound interplay of technology and other social endeavors in modern history has not been sufficiently recognized.

The Sloan Foundation has had a long-standing interest in deepening public understanding about modern technology, its origins and its impact on our lives. The Sloan Technology Series, of which the present volume is a part, seeks to present to the general reader the stories of the development of critical twentieth-century technologies. The aim of the series is to convey both the technical and human dimensions of the subject: the invention and effort entailed in devising the technologies and the comforts and stresses they have introduced into contemporary life. As the century draws to an end, it is hoped that the Series will disclose a past that might provide perspective on the present and inform the future.

The Foundation has been guided in its development of the Sloan Technology Series by a distinguished advisory committee. We express deep gratitude to John Armstrong, S. Michael Bessie, Samuel Y. Gibbon, Thomas P. Hughes, Victor McElheny, Robert K. Merton, Elting E. Morison and Richard Rhodes. The Foundation has been represented on the committee by Ralph E. Gomory, Arthur L. Singer, Jr., Hirsh G. Cohen, Raphael G. Kasper and A. Frank Mayadas.

Alfred P. Sloan Foundation

Fundamentally, and in the long run, the problem which is posed by the release of atomic energy is a problem of the ability of the human race to govern itself without war.

A REPORT OF A PANEL OF CONSULTANTS ON DISARMAMENT OF THE SECRETARY OF STATE, JANUARY 1953

Much that follows is new, and some of it surprising. A discussion of sources appears ahead of the Notes beginning on page 591; the Notes are keyed to a Bibliography that begins on page 689.

Readers unfamiliar with Russian names may take comfort in knowing that they are transliterated phonetically from their original Cyrillic, an alphabet borrowed from Greek and Hebrew. Sounding them out aloud two or three times usually fixes them in memory. A Glossary of Names, with approximate pronunciations, begins on page 671.

Prologue: Deliveries

THE WAR WAS OVER. The troops were coming home. Sick of mud and olive drab, of saltwater showers and sweltering holds, twelve million American soldiers and sailors counted their service points to see how soon they could ship out for Brooklyn and Ukiah and St. Joe. Tens of thousands of warplanes, ships, tanks, artillery pieces sat abandoned, the full industrial output of a prosperous nation, the work the women and the older men had done, soon to be junked. The Second World War had been the most destructive war in history, obliterating fifty-five million human lives. The German invasion of the Soviet Union and the obdurate Soviet response had accounted for more than half those deaths; with them, in Germany and the Soviet Union both, had followed general ruination. In the end, out in the Pacific, two planes carrying two bombs had compelled the war's termination. The two atomic bombs, ferocious as minor suns, had given an emperor descended from a god reason to surrender. The war was over. It was hard to imagine that there might ever be another.

Luis Alvarez, an American experimental physicist, a tall, ruddy Californian with ice-blond hair, had understood the message of the bomb on his way back from Hiroshima. Alvarez collected adventures. He liked to be on hand when history was made. After he invented ground-controlled approach radar he had flown a prototype unit to wartime England and personally tested it talking down British bombers returning through fog. At the secret laboratory at Los Alamos in New Mexico where the atomic bombs were designed and built by hand, he had arranged to observe intensely radioactive test explosions up close in a lead-lined tank. He had invented a new electric detonation system for the Fat Man plutonium implosion bomb that fired its multiple detonators with microsecond simultaneity. As the time to deploy the revolutionary new weapons approached, Alvarez had found a way to justify flying the historic first mission.

The Hiroshima bomb, Little Boy, was a uranium gun. It used sixty-four kilograms of rare uranium 235, all of that dense, purple-black metal the United States had been able to accumulate up to the end of July 1945. The uranium gun was an extremely conservative design. "We were confident it would work," Alvarez writes, but it had not been tested. To determine its efficiency, Los Alamos had needed to know its explosive yield. So Alvarez had invented a device for measuring that yield, a set of parachute-deployable pressure gauges to be dropped ahead of the bomb that would radio their readings to a backup plane. Riding in that backup plane, a B-29 named the *Great Artiste,* Alvarez had seen the bright flash of the Hiroshima explosion, had watched its pressure pulses register on the oscilloscopes mounted in the rear compartment he occupied, had felt the two sharp slaps of direct and ground-reflected shock waves slamming the plane like flak explosions, had moved to the window then and searched below while the plane circled the rising mushroom cloud. "I looked in vain for the city that had been our target. The cloud seemed to be rising out of a wooded area devoid of population." On the intercom the pilot confirmed that the aiming had been excellent; Alvarez could not see the city because the city had been destroyed.

On the way back to Tinian, the island in the Marianas from which the atomic bombing had been staged, Alvarez had passed the time writing a letter to keep for his son Walter, then four years old. "This is the first grown-up letter I have ever written to you," the physicist began. He reminded his son that they had inspected a B-29 together in Albuquerque—"probably you will remember climbing thru the tunnel over the bomb bay," he teased him, "as that really impressed you at the time." Then Alvarez described "what has happened to aerial warfare" as a result of the *Enola Gay*'s mission that morning:

> Last week the 20th Air Force . . . put over the biggest bombing raid in history, with 6,000 tons of bombs (about 3,000 tons of high explosives). Today, the lead plane in our formation dropped a single bomb which probably exploded with the force of 15,000 tons of high explosive. That means that the days of large bombing raids, with several hundred planes, are finished. A single plane disguised as a friendly transport can now wipe out a city. . . .
>
> What regrets I have about being a party to killing and maiming thousands of Japanese civilians this morning are tempered with the hope that this terrible weapon we have created may bring the countries of the world together and prevent further wars. Alfred Nobel thought that his invention of high explosives would have that effect, by making wars too terrible, but unfortunately it had just the opposite reaction. Our new destructive force is so many thousands of times worse that it may realize Nobel's dreams.

A second atomic bomb exploded three days later over Nagasaki reinforced the point and on August 14, 1945, the Japanese had surrendered. After the surrender, Robert Serber, the theoretical physicist who had directed the design of the Little Boy bomb, a lean, gentle Philadelphian with a steel-trap mind, had walked the streets of the city his bomb had destroyed. With other scientists and physicians, Serber had been assigned to visit the two atomic-bombed cities to study the damage; from Tokyo his group had caught a ride down Honshu in the personal plane of Admiral Richard E. Byrd, the Antarctic explorer, who wanted to see the destruction at first hand. In Nagasaki and then Hiroshima, Serber and British hydrodynamicist William Penney had collected dented gas cans, concrete rubble, a charred crate, a beaverboard panel burned with the shadow of a window frame. They had talked to returning Australian and Dutch prisoners of war temporarily housed in Nagasaki, living skeletons whom the Japanese had brutally abused and starved. They had visited a Japanese civilian hospital and seen women and children ill with flash burns and radiation sickness, an experience Serber still characterized almost fifty years later as "really harrowing." It had been easy to leave the United States during wartime. Returning now that the war was over was more complicated. "We had a little trouble in San Francisco," Serber remembers. "Peacetime practices were now in effect. We had to go through Customs (squashed gas cans, hunks of concrete, charred crate) and Immigration and it turned out that Bill didn't have a passport. However, our other identifications so impressed the immigration official that he decided he could call Bill a British RAF [Royal Air Force] officer and let him in." To a nation weary of war, the scientists who built the atomic bombs were heroes.

Major General Curtis LeMay riddled a different oracle from the ashes of Hiroshima and Nagasaki. A swarthy, burly, taciturn thirty-eight-year-old Ohio-born engineer, LeMay commanded the B-29s that had firebombed Japan to destruction, lifting from the vast coral runways of Guam, Saipan and Tinian like the thousand silver throwing-stars of a warrior god. LeMay still remembered vividly—would remember all his life—how unprepared the United States had been at the beginning of the war. "We came into the war with practically nothing," he told an interviewer in 1943. To an audience of fellow Ohio State alumni later in 1945 he would insist starkly:

> We tottered on the brink of defeat for two years before we could strike back. I know the feeling of our men [besieged] on Bataan and Corregidor because I commanded a bomb group in England in the early days of the war where we found the same situation—50 bombers against the entire German air forces. There came a time when we could see that at the existing loss rate with no reinforcements the last B-17 would take off to bomb Germany within 30 days. Fortunately, that unhappy day never arrived because the first trickle of help came just in time. It is quite an experience to see the reaction on people who have reconciled themselves to dying, [who] suddenly finish their combat tour and look forward to living again. I hope no American ever has to go through that experience in the future.

In England, LeMay had led his bombardment group's first combat mission. He had invented defensive formations that saved crew lives and bombing techniques that put twice and three times as many bombs on target as less imaginative commanding officers arranged. His byword was preparation. "Hit it right the first time," he taught his men, "and we won't have to go back." They called him Iron Ass because he trained them relentlessly, but they also called him "absolutely the best CO in the Army." From England in 1944 he had moved to India to attempt the thankless task of bombing the Japanese from bases in China supplied by air from India over the Himalayas, the infamous Hump. The B-29, the first intercontinental bomber, was just then coming into production and the leaders of the Air Forces, still a branch of the Army,* needed to prove the value of the investment. LeMay's B-29s had to haul their own gasoline over the Hump; it took a half-dozen Hump flights with bomb bays tanked with fuel to support one combat mission over Japan. Japan's weather moved in through north China, which Mao Zedong's army controlled. LeMay traded the Communist guerrilla leader medical supplies for crew rescues and weather reports.

The four-engine B-29, half the size of a football field, with electric control systems and two capacious bomb bays, was supposed to be a high-altitude precision bombing machine, aiming bombs down chimneys with the famous Norden bombsight from thirty thousand feet. But the force assembling in the Marianas while LeMay's crews labored from China had the bad luck to discover the jet stream. From one mission to the next it blew the planes off their targets. The Norden bombsight had not been designed to compensate for such furious drift. Once, when the B-29s were supposed to be bombing an aircraft factory ten miles north of Tokyo, they discovered their bombs had exploded in Tokyo Bay; the Japanese joked that the Americans were trying to drown them. LeMay was called in to fix the problem early in 1945. While he worked on improving precision, he and his staff studied strike photos and flak reports. They realized the Japanese had no night fighters and noticed that Japanese anti-aircraft fire clustered high. "We couldn't find any low-altitude defense," LeMay concludes.

Daylight precision bombing from low altitude would put LeMay's crews at risk. Advanced radar bombsights were not yet available for precision bombing at night. The USAAF wanted to end the war with air power before an Army and Navy invasion of Japan. LeMay worked out a radical change in strategy, ordered his B-29s stripped of armament to increase their carrying capacity, had 325 planes loaded with ten thousand pounds each of jellied-

* The US military air arm was called the Army Air Corps until June 1941, when its name was changed to the Army Air Forces (USAAF). In July 1947 the air arm separated from the Army; as an independent service it was and is designated the United States Air Force (USAF).

gasoline firebomb clusters and sent them over Tokyo on the night of March 10, 1945, staggered at from five to nine thousand feet, with pathfinder B-29s going ahead of them to mark out huge Xs in flame at their designated aiming points. LeMay's subsequent mission report emphasized that the object of the attack "was *not* to bomb indiscriminately civilian populations. The object *was* to destroy the *industrial and strategic targets* concentrated" in the Tokyo urban area. The firebombing successfully destroyed or damaged "twenty-two industrial target[s] . . . and many other unidentified industries." But the destruction that first windy night was in fact indiscriminate to the point of atrocity, as LeMay himself understood: 16.7 square miles of the Japanese capital burned to the ground, 100,000 people killed and hundreds of thousands injured in one night. "The physical destruction and loss of life at Tokyo," LeMay quotes from the official Air Force history of the Second World War, "exceeded that at Rome . . . or that of any of the great conflagrations of the western world—London, 1666 . . . Moscow, 1812 . . . Chicago, 1871 . . . San Francisco, 1906. . . . Only Japan itself, with the earthquake and fire of 1923 at Tokyo and Yokohama, had suffered so terrible a disaster. No other air attack of the war, either in Japan or Europe, was so destructive of life and property." With such compelling evidence that the new bombing strategy worked, LeMay laid on firebombings night after night against city after Japanese city until his supply depots ran out of bombs; resupplied, he pursued the firebombing campaign relentlessly through the spring and summer of 1945 until the end of the war, by which time sixty-three Japanese cities had been totally or partially burned out and hundreds of thousands of Japanese civilians killed, at a total cost to the Air Forces, as LeMay would lecture later, of "485 B-29s" and "approximately 3,000 combat crew personnel." Hiroshima and Nagasaki survived to be atomic-bombed only because Washington had removed them from Curtis LeMay's target list.

Long after the war, a dauntless cadet asked LeMay "how much moral considerations affected his decisions regarding the bombing of Japan." LeMay, as hard a man as Ulysses S. Grant, answered with his usual bluntness:

> Killing Japanese didn't bother me very much at that time. It was getting the war over that bothered me. So I wasn't worried particularly about how many people we killed in getting the job done. I suppose if I had lost the war, I would have been tried as a war criminal. Fortunately, we were on the winning side. Incidentally, everybody bemoans the fact that we dropped the atomic bomb and killed a lot of people at Hiroshima and Nagasaki. That I guess is immoral; but nobody says anything about the incendiary attacks on every industrial city in Japan, and the first attack on Tokyo killed more people than the atomic bomb did. Apparently, that was all right. . . .
>
> I guess the direct answer to your question is, yes, every soldier thinks

> something of the moral aspects of what he is doing. But all war is immoral, and if you let that bother you, you're not a good soldier.

At the Japanese surrender ceremonies on the battleship *Missouri* in Tokyo Bay on September 2, LeMay's B-29s, nearly five hundred of them, had roared overhead in salute while LeMay stood on the deck watching Douglas MacArthur stern at the table where the Japanese foreign minister grimly signed the surrender. LeMay was thinking of the boys who had died to get them there, he wrote later, thinking "that if I had done a better job we might have saved a few more crews." That was the overriding message Curtis Emerson LeMay took with him from the long, bloody war: preparation. "I think the main experience that I wouldn't want to repeat is the war experience that I had," he told the same cadets who heard his opinion of killing Japanese. "There is nothing worse that I've found in life than going into battle ill-prepared or not prepared at all." To the lesson of that elemental experience he would attribute the massive work he would accomplish postwar of building up a strategic air force.

"Like many other folks" at the end of the war, he writes, he was "pretty tired." He took time to fly up and down the Japanese coast to view the results of his firebombing, then returned to his headquarters on Guam. His aide-de-camp notes on September 3 that "General LeMay spent the night at General Spaatz's house—a last stand all night poker game. The game broke up at 0600 hours the morning of the fourth." Spaatz was LeMay's boss, Carl "Tooey" Spaatz, commanding general of the Strategic Air Force in the Pacific; who won the poker game, the aide doesn't record.

At the end of August, LeMay had heard through Spaatz that Washington had asked General James Doolittle, the air pioneer and Eighth Air Force commander, to lead a flight of three B-29s nonstop from Tokyo to Washington, and that Doolittle had recommended including LeMay. "Offhand," says LeMay, "I would guess that this flight was dreamed up to demonstrate and dramatize . . . the long-range capability of the [B-]29 to the American people and to the world at large." To make the long flight—nearly seven thousand miles—the bomb bays of the aircraft would need to be fitted with extra fuel tanks. Doolittle on Okinawa had studied the matter and concluded that six tanks would give the B-29s a gross takeoff weight of 142,800 pounds. "The trip can be made," Doolittle had messaged Spaatz by courier, provided they could find an airfield in Japan long enough and with enough bearing capacity to handle the load.

Spaatz replied on September 5 that "there are no fields in Japan suitable for take off at gross weight necessary. . . . Flight is not feasible." Never one to take no for an answer, Doolittle flew to Guam three days later to confer with LeMay. "We got together," writes LeMay, "and talked the thing over; we examined photographs and charts. The only field which might accommodate the B-29's was Mizutani, up on the northern Japanese island of Hokkaido. . . . Trouble was, we didn't have any troops in there as yet. . . . There was nobody of whom we could make inquiry concerning the runways." LeMay sent one of his commanders to scout Hokkaido in a B-17. The Japanese naval officers at Mizutani had heard their emperor's surrender broadcast and didn't shoot him. The runways, the man reported, would do.

LeMay ordered three B-29s stripped of spare equipment and outfitted with bomb-bay tanks. In the meantime, Doolittle was called ahead to Washington. Lieutenant General Barney Giles, commander of the Central Pacific Air Forces, took over Doolittle's place in the lead plane; LeMay and Brigadier General Emmett "Rosie" O'Donnell, Jr., would fly the other two. The three B-29s left Guam on Sunday, September 16, fueled at Iwo Jima and flew to Hokkaido, where they topped off their tanks with drum gasoline flown in on C-54s. "That night we slept in a barracks with three thousand polite Japanese sailors surrounding us," LeMay recalls. "No sweat." The trio of generals with their eleven-man crews took off for North America at 0600 hours on Wednesday, September 19, flew a Great Circle route northeast, crossed the International Date Line into the Western Hemisphere's Wednesday, made radio contact with Nome, reached their halfway point over Whitehorse in the Yukon at nine A.M. Eastern War Time and approached the northern Middle West late that afternoon. They had bucked headwinds most of the way that slowed their average speed to less than 250 knots and ate up their fuel. LeMay wanted to take a chance on making it to Washington, where the weather was reported marginal, but Giles and O'Donnell opted to refuel in Chicago. "I went on awhile," writes LeMay nonchalantly, "then received another Washington report. This time the weather was *really* marginal, and that didn't seem to make very good sense, with the small reserve of gas I'd have. I turned around and went back." From Chicago they flew on to Washington the same night and landed at National Airport just before nine to the clangor of a brass band the Air Forces had deployed for the occasion. Curtis LeMay, too, had come home.

The *Chicago Tribune* thought "the only significance" of the intercontinental nonstop flight of three US heavy bombers was "that it is going to be possible very soon to fly from here to Tokyo in 24 hours by commercial airliner." The Army Air Forces saw further significance in intercontinental flight. A document titled *A Strategic Chart of Certain Russian and Manchurian Urban Areas* had gone to Brigadier General Leslie R. Groves, the head of the atomic-bomb project, already on August 30, 1945; the document identified the important cities of the Soviet Union and Manchuria and charted their area, population, industrial capacities and target priority. Thus Moscow was estimated to have a population of four million, an area of 110 square miles, priorities of 1 for industry and 3 for oil and was estimated to supply 13 percent of Soviet plane output, 43 percent of truck output, 2 percent of steel and 15 percent of copper, machine-building, oil refinery and ballbearing output. Baku produced 61 percent of the Soviet Union's oil, Gorki 45 percent of its guns, Chelyabinsk 44 percent of its zinc. The list descended to cities of only 26,000 population, but was then refined to selections of "15 key Soviet cities"—Moscow, Baku, Novosibirsk, Gorki, Sverdlovsk, Chelyabinsk, Omsk, Kuibyshev, Kazan, Saratov, Molotov, Magnitogorsk, Grozny, Stalinsk, Mishni Tagil—and "25 leading Soviet cities." An appendix estimated how many atomic bombs would be needed to destroy each city—six each for Moscow and Leningrad. A map centered on the North Pole accompanied the chart; around the world from bases in Nome; Adak, in the Aleutians; Stavanger, Norway; Bremen, Germany; Foggia, Italy; Crete; Lahore, India; and Okinawa, B-29 flight paths had been overlaid darkly like segments of radar sweeps to cover the USSR.

The plan was something of a wish list. LeMay, Giles and O'Donnell had flown one way intercontinentally and then only by loading their bomb bays with fuel tanks. The realistic range of a B-29 with a bomb load was three thousand miles. Nor were all those convenient bases available. Before the US would have a force capable realistically of striking the Soviet Union, it would need forward bases, aerial refueling or a longer-range bomber. In the autumn of 1945 none of those capabilities yet existed.

If the Soviet Union had been the United States's Second World War ally, it was also the only possible enemy to survive the general destruction with sufficient military power to challenge American hegemony. Its army occupied the eastern half of Europe. The United States believed it had a trump card in the atomic bomb, but even that advantage was a wasting asset. On September 19, while Curtis LeMay and his colleagues were en route from Hokkaido to Washington proving that atomic bombs could be delivered great distances by plane, physicist Klaus Fuchs, a member of the British Mission at Los Alamos, was finishing up delivering information about the atomic bomb by hand to Harry Gold, an American industrial chemist who was a courier for Soviet intelligence. Fuchs had been passing information on the atomic-bomb project to Soviet agents since 1941. In June he had delivered to Gold a complete description of the Fat Man plutonium implosion bomb, including detailed cross-sectional drawings, which had been sent along immediately to Moscow. Now, driving Gold up into the Santa Fe hills overlooking the New Mexican capital in the early evening, Fuchs reported on the rate of US production of U235 and plutonium and on advanced concepts for improved bomb designs. In October 1945, with Fuchs's information and information from other US and British spies, the head of Soviet foreign intelligence in Moscow was able to send to the commissar for state security newly appointed to direct the Soviet atomic-bomb program, Lavrenti Beria, a detailed plan of the plutonium implosion bomb for Soviet scientists to duplicate. The war was over. The atomic arms race had begun.

PART ONE

A Choice Between Worlds

His decision to become a Communist seems to the man who makes it as a choice between a world that is dying and a world that is coming to birth.

WHITTAKER CHAMBERS

1

'A Smell of Nuclear Powder'

EARLY IN JANUARY 1939, nine months before the outbreak of the Second World War, a letter from Paris alerted physicists in the Soviet Union to the startling news that German radiochemists had discovered a fundamental new nuclear reaction. Bombarding uranium with neutrons, French physicist Frédéric Joliot-Curie wrote his Leningrad colleague Abram Fedorovich Ioffe, caused that heaviest of natural elements to disintegrate into two or more fragments that repelled each other with prodigious energy. It was fitting that the first report of a discovery that would challenge the dominant political system of the world should reach the Soviet Union from France, a nation to which Czarist Russia had looked for culture and technology. Joliot-Curie's letter to the grand old man of Russian physics "got a frenzied going-over" in a seminar at Ioffe's institute in Leningrad, a protégé of one of the participants reports. "The first communications about the discovery of fission... astounded us," Soviet physicist Georgi Flerov remembered in old age. "... There was a smell of nuclear powder in the air."

Reports in the British scientific journal *Nature* soon confirmed the German discovery and research on nuclear fission started up everywhere. The news fell on fertile ground in the Soviet Union. Russian interest in radioactivity extended back to the time of its discovery at the turn of the century. Vladimir I. Vernadski, a Russian mineralogist, told the Russian Academy of Sciences in 1910 that radioactivity opened up "new sources of atomic energy ... exceeding by millions of times all the sources of energy that the human imagination has envisaged." Academy geologists located a rich vein of uranium ore in the Fergana Valley in Uzbekistan in 1910; a private company mined pitchblende there at Tiuia-Muiun ("Camel's Neck") until 1914. After the First World War, the Red Army seized the residues of the company's extraction of uranium and vanadium. The residues contained valuable radium, which transmutes naturally from uranium by radioactive decay. The

Soviet radiochemist Vitali Grigorievich Khlopin extracted several grams of radium for medical use in 1921.

There were only about a thousand physicists in the world in 1895. Work in the new scientific discipline was centered in Western Europe in the early years of the twentieth century. A number of Russian scientists studied there. Abram Ioffe's career preparation included research in Germany with Nobel laureate Wilhelm Roentgen, the discoverer of X rays; Vernadski worked at the Curie Institute in Paris. The outstanding Viennese theoretical physicist Paul Ehrenfest taught in St. Petersburg for five years before the First World War. In 1918, in the midst of the Russian Revolution, Ioffe founded a new Institute of Physics and Technology in Petrograd.* Despite difficult conditions—the chemist N. N. Semenov describes "hunger and ruin everywhere, no instruments or equipment" as late as 1921—"Fiztekh" quickly became a national center for physics research. "The Institute was the most attractive place of employment for all the young scientists looking to contribute to the new physics," Soviet physicist Sergei E. Frish recalls. "... Ioffe was known for his up-to-date ideas and tolerant views. He willingly took on, as staff members, beginning physicists whom he judged talented.... Dedication to science was all that mattered to him." The crew Ioffe assembled was so young and eager that older hands nicknamed Fiztekh "the kindergarten."

During its first decade, Fiztekh specialized in the study of high-voltage electrical effects, practical research to support the new Communist state's drive for national electrification—the success of socialism, Lenin had proclaimed more than once, would come through electrical power. After 1928, having ousted his rivals and consolidated his rule, Josef Stalin promulgated the first of a brutal series of Five-Year Plans that set ragged peasants on short rations building monumental hydroelectric dams to harness Russia's wild rivers. "Stalin's realism was harsh and unillusioned," comments C. P. Snow. "He said, after the first two years of industrialization, when people were pleading with him to go slower because the country couldn't stand it:

> To slacken the pace would mean to lag behind; and those who lag behind are beaten. We do not want to be beaten. No, we don't want to be. Old Russia was ceaselessly beaten for her backwardness. She was beaten by the Mongol khans, she was beaten by Turkish beys, she was beaten by the Swedish feudal lords, she was beaten by Polish-Lithuanian pans, she was beaten by Anglo-French capitalists, she was beaten by Japanese barons, she was beaten by all—for her backwardness. For military backwardness, for cultural backwardness, for agricultural backwardness. She was beaten because to beat her was profitable and went unpunished. You remember the

* St. Petersburg, renamed Petrograd by Czar Nicholas in 1914 and Leningrad by the new Soviet government in 1924.

> words of the pre-revolutionary poet: "Thou art poor and thou art plentiful, thou art mighty and thou art helpless, Mother Russia."
>
> We are fifty or a hundred years behind the advanced countries. We must make good the lag in ten years. Either we do it or they crush us.

Soviet scientists felt a special burden of responsibility in the midst of such desperate struggle; the heat and light that radioactive materials such as radium generate for centuries without stint mocked their positions of privilege. Vernadski, who founded the State Radium Institute in Petrograd in 1922, wrote hopefully that year that "it will not be long before man will receive atomic energy for his disposal, a source of energy which will make it possible for him to build his life as he pleases." World leaders such as England's Ernest Rutherford, who discovered the atomic nucleus, and Albert Einstein, who quantified the energy latent in matter in his formula $E = mc^2$, disputed such optimistic assessments. The nuclei of atoms held latent far more energy than all the falling water of the world, but the benchtop processes then known for releasing it consumed much more energy than they produced. Fiztekh had spun off provincial institutes in 1931, most notably at Kharkov and Sverdlovsk; in 1932, when the discovery of the neutron and of artificial radioactivity increased the pace of research into the secrets of the atomic nucleus, Ioffe decided to divert part of Fiztekh's effort specifically to nuclear physics. The government shared his enthusiasm. "I went to Sergei Ordzhonikidze," Ioffe wrote many years later, "who was chairman of the Supreme Council of National Economy, put the matter before him, and in literally ten minutes left his office with an order signed by him to assign the sum I had requested to the Institute."

To direct the new program, Ioffe chose Igor Vasilievich Kurchatov, an exceptional twenty-nine-year-old physicist, the son of a surveyor and a teacher, born in the pine-forested Chelyabinsk region of the southern Urals in 1903. Kurchatov was young for the job, but he was a natural leader, vigorous and self-confident. One of his contemporaries, Anatoli P. Alexandrov, remembers his characteristic tenacity:

> I was always struck by his great sense of responsibility for whatever problem he was working on, whatever its dimensions may have been. A lot of us, after all, take a careless, haphazard attitude toward many aspects of life that seem secondary to us. There wasn't a bit of that attitude in Igor Vasilievich. . . . [He] would sink his teeth into us and drink our blood until we'd fulfilled [our obligations]. At the same time, there was nothing pedantic about him. He would throw himself into things with such evident joy and conviction that finally we, too, would get caught up in his energetic style. . . .
>
> We'd already nicknamed him "General." . . .

Within a year, justifying Ioffe's confidence in him, Kurchatov had organized and headed the First All-Union (i.e., nationwide) Conference on Nuclear Physics, with international attendance. With Abram I. Alikhanov, he built a small cyclotron that became, in 1934, the first cyclotron operating outside the Berkeley, California, laboratory of the instrument's inventor, Ernest O. Lawrence. He directed research at Fiztekh in 1934 and 1935 that resulted in twenty-four published scientific papers.

Kurchatov was "the liveliest of men," Alexandrov comments, "witty, cheerful, always ready for a joke." He had been a "lanky stripling," his student and biographer Igor N. Golovin writes, but by the 1930s, after recovering from tuberculosis, he had developed "a powerful physique, broad shoulders and ever-rosy cheeks." "Such a nice soul," an Englishwoman who knew him wrote home, "like a teddy bear, no one could ever be cross with him." He was handsome, Sergei Frish says—"a young, clean-shaven man with a strong, resolute chin and dark hair standing straight up over his forehead." Golovin mentions lively black eyes as well, and notes that Kurchatov "worked harder than anyone else.... He never gave himself airs, never let his accomplishments go to his head."

When Igor was six, his father, a senior surveyor in government service, took a cut in pay to move west over the Urals from the rural Chelyabinsk area to Ulyanovsk, on the Volga, where the three Kurchatov children could attend a proper academic *gymnasium*. Three years later, in 1912, Igor's older sister Antonina sickened with tuberculosis. For her health the family moved again, to the balmier climate of Simferopol on the Crimean Peninsula. The relocation proved to be a forlorn hope; Antonina died within six months.

The two surviving Kurchatov children—Igor and his brother Boris, two years younger—thrived in the Crimea. Both boys did well in *gymnasium*, played soccer, traveled into the country with their father during the summer on surveying expeditions. Igor ran a steam threshing machine harvesting wheat the summer he was fourteen. Another summer he worked as a laborer on the railroad.

A chance encounter with Orso Corbino's *Accomplishments of Modern Engineering* encouraged the young *gymnasium* student to dream of becoming an engineer. The Italian physicist would influence Kurchatov's career again indirectly in the 1930s when Corbino sponsored Enrico Fermi's Rome group that explored the newly discovered phenomenon of artificial radioactivity. The discoveries of the Rome group would inspire and challenge Kurchatov's Fiztekh research.

The Great War impoverished the Kurchatov family. Igor added night vocational school to his heavy schedule, qualified as a machinist and worked part-time in a machine shop while taking nothing but 5's—straight A's—during his final two years of *gymnasium*.

After the Revolution, in 1920, when he was seventeen years old, Kurchatov matriculated in physics and mathematics at Crimean State, one of about seventy students at the struggling, recently nationalized university. None of the foreign physics literature in the university library dated past 1913 and there were no textbooks, but the rector of the school was a distinguished chemist and managed to bring in scientists of national reputation for courses of lectures, among them Abram Ioffe, theoretical physicist Yakov I. Frenkel and future physics Nobel laureate Igor E. Tamm.

In the wake of war and revolution there was barely enough to eat. After midday lectures, students at Crimean State got a free meal of fish soup thickened with barley so flinty they nicknamed it "shrapnel." The distinction of an assistantship in the physics laboratory in the summer of 1921 gratified Kurchatov in part because it won him an additional ration of 150 grams—about five ounces—of daily bread.

Kurchatov finished the four-year university course in three years. He chose to prepare a thesis in theoretical physics because the university laboratory was not adequately equipped for original experimental work; he defended his dissertation in the summer of 1923. His physics professor, who was leaving for work at an institute in Baku, invited the new graduate to join him. Drawn from childhood to ships and the sea, Kurchatov chose instead to enroll in a program in nautical engineering in Petrograd. He suffered through a winter short on resources in the bitter northern cold, eking out a living as a supervisor in the physics department of a weather station, sleeping on a table in the unheated instrument building in a huge black fur coat. "This is no life I'm living," he wrote a friend that winter, uncharacteristically depressed, "but a rusted-out tin can with a hole in it." But the station director gave him real problems to solve, including measuring the alpha-radioactivity of freshly fallen snow, and the work finally won him for physics. He returned to the Crimea in 1924 to help his family—his father had been sentenced to three years of internal exile—and later joined his former teacher in Baku.

In the meantime, one of Kurchatov's physics classmates, his future brother-in-law Kirill Sinelnikov, had caught Ioffe's eye and accepted his invitation to work at Fiztekh. Sinelnikov told the institute director about his talented friend. Off went another invitation. Kurchatov returned to Leningrad, this time to take up his life's work. (He married Sinelnikov's sister Marina in 1927.)

Kurchatov quickly impressed Ioffe. "It was almost routine to chase him out of the laboratory at midnight," the senior physicist recalls. In the interwar years Ioffe sent twenty of his protégés abroad "to the best foreign laboratories where [they] could meet new people and familiarize [themselves] with new scientific techniques." Like a young entrepreneur too busy to bother going to college, Kurchatov never found time for foreign study. "He kept putting off taking advantage of [this opportunity]," Ioffe adds.

"Everytime it was time to leave he was on an interesting experiment that he preferred to the trip."

Others left and won international reputations. Peter Kapitza explored cryogenics and strong magnetic fields at Cambridge University and became a favorite of Ernest Rutherford, the New Zealand–born Nobel laureate who directed the Cavendish Laboratory there; Kapitza would earn a Nobel in his turn. So would theoretician Lev Landau, who worked in Germany during this period with his young Hungarian counterpart Edward Teller. The German emigré physicist Rudolf Peierls remembers a walking tour of the Caucasus with Landau after Landau had returned home when the Soviet theoretician pointed out that a nuclear reaction that produced secondary neutrons, if it could be found, would make possible the release of atomic energy—"remarkably clear vision in 1934," comments Peierls, "just two years after the discovery of the neutron." Less conspicuously, but with more enduring influence on Soviet history, Yuli Borisovich Khariton, the youngest son of a St. Petersburg journalist and an actress in the Moscow Art Theater —"compact, ascetically slight and very sprightly," a friend describes him—worked at Fiztekh on chemical chain reactions with Semenov, their discoverer, before earning a doctorate in theoretical physics at the Cavendish in 1927. Alarmed by the growing mood of fascism he found in Germany on his return passage, Khariton at twenty-four organized an explosives laboratory in the new Institute of Physical Chemistry, a Fiztekh spinoff. These were only a few of Ioffe's talented protégés.

Their talents barely protected them from the Great Terror that began in the Soviet Union after the assassination of Central Committee member Sergei Mironovich Kirov in December 1934 as Stalin moved to eliminate all those in power whose authority preceded his imposition of one-man rule. "Stalin killed off the founders of the Soviet state," writes the high-level Soviet defector Victor Kravchenko. "This crime was only a small part of the larger blood-letting in which hundreds of thousands of innocent men and women perished." According to a Soviet official, the slaughter claimed not hundreds of thousands but millions: "From 1 January 1935 to 22 June 1941, 19,840,000 enemies of the people were arrested. Of these 7 million were shot in prison, and a majority of the others died in camp." Exiled Soviet geneticist Zhores Medvedev notes that "the full list of arrested scientists and technical experts certainly runs into many thousands." Kharkov, where Kirill Sinelnikov had moved to direct the high-voltage laboratory after studying at Cambridge, lost most of its leaders, though Kurchatov's brother-in-law himself was spared.

The British Royal Society had funded an expensive laboratory in its own dedicated building in the courtyard outside the Cavendish for Peter Kapitza. Perhaps suspecting that he intended to defect, the Soviet government detained him during a visit home in the summer of 1934 and barred him from returning abroad. His detention shocked the British, and for a time he was too depressed to work, but the Soviet government bought his Cambridge laboratory equipment and built a new institute for him in Moscow. (A frustrated Kapitza had to order such unavailable consumer goods as wall clocks, extension telephones and door locks from England.) Eventually he went back to work, as he wrote People's Commissar Vyacheslav Molotov, "for the glory of the USSR and for the use of all the people." Niels Bohr, the Danish physicist, after visiting him in Moscow in 1937, observed that "by his enthusiastic and powerful personality, Kapitza soon obtained the respect and confidence of Russian official circles, and from the first Stalin showed a warm personal interest for Kapitza's endeavors."

Kapitza's golden captivity was not yet terror, but he needed all his connections when Lev Landau was arrested in April 1938, convicted of being a "German spy" and sent to prison, where he languished for a year and became ill. Landau had been working at Kapitza's Institute for Physical Problems. Kapitza determined to save him, writes Medvedev:

> After a short meeting with Landau in prison, Kapitza took a desperate step. He presented Molotov and Stalin with an ultimatum: if Landau was not released immediately, he, Kapitza, would resign from all his positions and leave the institute. . . . It was clear that Kapitza meant business. After a short time Landau was cleared of all charges and released.

In old age, Edward Teller would cite his friend's arrest and imprisonment as one of three important early influences on his militant anti-Communism (the other two, Teller said, were the Great Terror itself and Arthur Koestler's novel *Darkness at Noon*): "Lev Landau, with whom I published a paper, was an ardent Communist. Shortly after he returned to Russia, he went to prison. After that he was no longer a Communist." Communist or not, Landau continued to work at Kapitza's institute in Moscow.

Not even Ioffe escaped the general harrowing. "Although the majority of [Soviet] scientists realized the importance of work in the field of nuclear physics," writes Alexandrov, "the leadership of the Soviet Academy of Sciences and of the Council of People's Commissars believed that this work had no practical value. Fiztekh and Ioffe himself were heavily criticized at the 1936 general assembly of the Academy of Sciences for 'loss of touch with practice.' " With the Great Terror destroying lives all around them, Soviet physicists understandably learned caution from such charges. "In those years," writes Stalin's daughter Svetlana Alliluyeva, "never a month went by in peace. Everything was in constant turmoil. People vanished like shadows in the night." Her father brooded over it all, reports the historian Robert Conquest: "Stalin personally ordered, inspired and organized the operation. He received weekly reports of . . . not only steel production and crop figures, but also of the numbers annihilated." Shot in the back of the head at Lubyanka prison, truckloads of bodies to the crematorium at the Donskoi Monastery, smoking ashes bulked into open pits and the pits paved over. That was the era when Osip Mandelstam suffered three years' exile and then five years in a gulag camp—five years that killed him—for writing a poem, "The Stalin Epigram," the most ferocious portrait of the dictator anyone ever devised:

Our lives no longer feel ground under them.
At ten paces you can't hear our words.

But whenever there's a snatch of talk
it turns to the Kremlin mountaineer,

the ten thick worms his fingers,
his words like measures of weight,

the huge laughing cockroaches on his top lip,
the glitter of his boot-rims.

Ringed with a scum of chicken-necked bosses
he toys with the tributes of half-men.

One whistles, another meows, a third snivels.
He pokes out his finger and he alone goes boom.

He forges decrees in a line like horseshoes,
one for the groin, one the forehead, temple, eye.

He rolls the executions on his tongue like berries.
He wishes he could hug them like big friends from home.

Igor Kurchatov organized the initial Soviet study of nuclear fission at Fiztekh in the early months of 1939, following Joliot-Curie's letter to Ioffe and confirmation of the discovery in scientific journals. Landau's remark to Peierls in 1934 about secondary neutrons points to one universal line of inquiry: examining whether the fission reaction, which a single neutron could initiate, would release not only hot fission fragments but additional neutrons as well. If so, then some of those secondary neutrons might go on to fission other uranium atoms, which might fission yet others in their turn. If there were enough secondary neutrons, the chain reaction might grow to be self-sustaining. Joliot-Curie's team in Paris set up an experiment to look for secondary neutrons in late February; in April the French reported 3.5 secondary neutrons per fission and predicted that uranium would probably chain-react. Enrico Fermi, now at Columbia University in flight from anti-Semitic persecution (his wife Laura was Jewish), and emigré Hungarian physicist Leo Szilard, also temporarily working at Columbia, soon independently confirmed fission's production of secondary neutrons. At a Fiztekh seminar in April, two young members of Kurchatov's Fiztekh team, Georgi Flerov and Lev Rusinov, reported similar results—between two and four secondary neutrons per fission. (In 1940, Flerov and Konstantin A. Petrzhak would make a world-class discovery, the spontaneous fission of uranium, a consequence of uranium's natural instability and a phenomenon that would prove crucial to regulating controlled chain reactions in nuclear reactors. Before the young Russians succeeded, the American radiochemist Willard F. Libby, later a Nobel laureate, had tried two different ways unsuccessfully to demonstrate spontaneous fission.)

Down the street at the Institute of Physical Chemistry, Yuli Khariton and an outstanding younger colleague, theoretician Yakov B. Zeldovich, began exploring fission theory. "Yuli Borisovich notes a curious detail," Zeldovich recalled: "we considered the work on the theory of uranium fission to be apart from the official plan of the Institute and we worked on it in the evenings, sometimes until very late." Zeldovich was a brilliant original—"not a university graduate," comments Andrei Sakharov; "... in a sense, self-educated"—who had earned a master's degree and a doctorate "without his ever bothering about a bachelor's degree." "We immediately made calculations of nuclear chain-reactions," Khariton remembers, "and we soon understood that on paper, at least, a chain-reaction was possible, a reaction which could release unlimited amounts of energy without burning coal or oil. Then we took it very seriously. We also understood that a bomb was possible." Khariton and Zeldovich reported their first calculations in a seminar at Fiztekh in the summer of 1939, describing the conditions necessary for a nuclear explosion and estimating its tremendous destructive capacity—one atomic bomb, they told their colleagues, could destroy Moscow.

Theoretical physicist J. Robert Oppenheimer at Berkeley, Fermi, Szilard, Peierls in England, all quickly came to similar conclusions. "These possibilities were immediately obvious to any good physicist," comments Robert Serber. But it was also soon obvious from work by Niels Bohr that a formidable obstacle stood in the way of making bombs: only one isotope of uranium, U235, would sustain a chain reaction, and U235 constituted only 0.7 percent of natural uranium; the other 99.3 percent, chemically identical, was U238, which captured secondary neutrons and effectively poisoned the reaction.* There were then two difficult technical questions that needed to be resolved by any nation that proposed to explore building an atomic bomb: whether it might be possible to achieve a controlled chain reaction —to build a nuclear reactor—using natural uranium in combination with some suitable moderator, or whether the U235 content of the uranium

* An atomic bomb and a nuclear reactor exploit different circumstances using significantly different arrangements: a bomb creates a chain reaction using fast neutrons, a nuclear reactor using slow neutrons.

would have to be laboriously enriched; and how to separate U235 from U238 on an industrial scale for bomb fuel when the only exploitable distinction between the two isotopes was a slight difference in mass. Enrichment and separation were essentially identical processes ("separated" bomb-grade uranium is natural uranium enriched to above 80 percent U235) and would use the same massive, expensive machinery that no one yet knew how to build; while a reactor fueled with natural uranium, if such would work, might be a straightforward enterprise.

Khariton and Zeldovich approached these questions from first principles, as it were, carefully calculating what was not possible as well as what might be. In the first of three pioneering papers they published in the Russian *Journal of Experimental and Theoretical Physics* in 1939 and 1940 (papers that went unnoticed outside the Soviet Union) they demonstrated that a fast-neutron chain reaction was not possible in natural uranium. Isotope separation would therefore be necessary to build a uranium bomb.

A second, longer paper, delivered a few weeks later on October 22, 1939, developed important basic principles of reactor physics. Khariton and Zeldovich correctly identified the crucial bottleneck that experimenters would have to bypass to build a natural-uranium reactor that worked. Visualize a stray neutron in a mass of natural uranium finding a U235 nucleus, entering it and causing it to fission. The two resulting fission fragments fly apart; a fraction of a second later they eject two or three secondary neutrons. If these fast secondary neutrons encounter other U235 nuclei they will continue and enlarge the chain of fissions. But there is much more U238 than U235 in the mass of natural uranium, making an encounter with a U238 nucleus more likely, and U238 tends to capture fast neutrons. It is particularly sensitive to neutrons moving at a critical energy, twenty-five electron volts (eV), a sensitivity which physicists call a "resonance." On the other hand, U238 is opaque to slow neutrons. To make a reactor, then, Khariton and Zeldovich realized, it would be necessary to slow the fast secondary neutrons from U235 fission quickly below U238's twenty-five eV resonance. The way to do that, they proposed, was to make the neutrons give up some of their energy by bouncing them off the nuclei of light atoms such as hydrogen. "In order to accomplish [a chain] reaction [in natural uranium]," they wrote, "strong slowing of the neutrons is necessary, which may be practically accomplished by the addition of a significant amount of hydrogen."

The simplest way to mix uranium with hydrogen would be to make a slurry—a homogeneous mixture—of natural uranium and ordinary water. But Khariton and Zeldovich demonstrated in this second paper that such a mixture would not sustain a chain reaction, because hydrogen and oxygen also capture slow neutrons, and in a reactor fueled with natural uranium such capture would subtract too many neutrons from the mix. Important consequences followed from this conclusion. One was that instead of hydrogen in ordinary water it would apparently be necessary to use heavy hydrogen—deuterium, H^2 or D, an isotope of hydrogen with a smaller appetite for neutrons than ordinary hydrogen—perhaps in the form of rare and expensive heavy water. (In a review article published in 1940, Khariton and Zeldovich proposed carbon and helium as other possible moderators, both materials that later proved to work.) Alternatively, wrote the two Soviet physicists, "another possibility lies in the enrichment of uranium with the isotope 235." They calculated that natural uranium enriched from 0.7 percent U235 to 1.3 percent U235 would work in a homogeneous solution with ordinary water.

In a third paper submitted in March 1940, Khariton and Zeldovich identified two natural processes that would make it easy and "completely safe" to initiate and control a chain reaction in a nuclear reactor. The fissioning process would heat the mass of uranium and cause it to expand, which in turn would increase the distance the neutrons would have to travel to cause additional fissioning and would therefore slow down the chain reaction, allowing the mass of uranium to cool and the chain reaction to accelerate. This natural oscillation could be controlled by increasing or decreasing the volume of uranium. Another natural process—delayed neutrons released in fission which would "significantly increase" the oscillation period—subsequently proved more significant for reactor control. (Apparently critics within the Soviet scientific community had made safety a point of attack; in this third paper Khariton and Zeldovich vigorously disputed what they called "hasty conclusions . . . on the extreme danger of experiments with large masses of uranium and the catastrophic consequences of such experiments." Because of the natural processes they had identified, they scoffed, such conclusions "do not correspond to reality.")

Khariton and Zeldovich summarized these early and remarkable insights in the introduction to their third paper:

> It would appear (the lack of experimental data precludes any categorical assertions) that by applying some technique, creating a large mass of metallic uranium either by mixing uranium with substances possessing a small capture cross-section (e.g., with heavy water) or by enriching the uranium with the U^{235} isotope . . . it will be possible to establish conditions for the chain decay of uranium by branching chains in which an arbitrarily weak radiation by neutrons will lead to powerful development of a nuclear reaction and macroscopic effects. Such a process would be of much interest since the molar heat of the nuclear fission reaction of uranium exceeds by $5 \cdot 10^7$ [i.e., 5,000,000] times the heating capacity of coal. The abundance and cost of uranium would certainly allow the realization of some applications of uranium.
>
> Therefore, despite the difficulties and unreliability of the directions indicated, we may expect in the near future attempts to realize the process.

At the annual All-Union Conference on Nuclear Physics, held in 1939 in November at Kharkov in the Ukraine, Khariton and Zeldovich reported their conclusion that carbon (graphite) and heavy water were possible neutron moderators. They also reported that a controlled chain reaction even with heavy water would be possible in a homogeneous reactor only with uranium enriched in U235. Since uranium enrichment was notoriously difficult, and would require the development of an entirely new industry, their conclusion made the possibility of building a working nuclear reactor within a reasonable period of time and for a reasonable amount of money appear remote. But there are other possible arrangements of natural uranium and graphite or heavy water that they overlooked, even though their second 1939 paper had offered an important clue. Why two such outstanding theoreticians should have overlooked more promising alternative arrangements is a question worth exploring.

The effectiveness of a moderator such as graphite or heavy water is limited crucially by its probability of capturing rather than reflecting neutrons. That probability, called a "cross section," can only be determined by experiment. Physicists quantify capture cross sections (and other such probabilities) in extremely small fractions of a square centimeter, as if a cross section were the surface area of a target the incoming neutron might hit. The two theoreticians had calculated that to achieve a chain reaction in a mixture of ordinary uranium and heavy water, the cross section of deuterium for neutron capture must not be larger than $3 \cdot 10^{-27}$ cm^2. They lacked the laboratory equipment they needed—a powerful cyclotron and a large quantity of heavy water—to measure the actual capture cross section of deuterium (the entire Soviet supply of heavy water at that time amounted to no more than two to three kilograms). For the 1939 All-Union Conference they must have offered an approximation drawn from the international physics literature.

Apparently they continued to search the literature to see if someone had determined a more accurate value for the deuterium capture cross section. They found an estimate in a letter to the editor of the American journal *Physical Review* published in April 1940. In that letter, University of Chicago physicists L. B. Borst and William D. Harkins noted a "quantitative estimate" of $3 \cdot 10^{-26}$ cm^2, a full order of magnitude too large ($^{-26}$ rather than $^{-27}$). "Thus," Igor Kurchatov would explain in 1943 in a top secret report, "we came to the conclusion that it is impossible to achieve a chain reaction in a mixture of [ordinary] uranium and heavy water." And if not in heavy water without investing expensively in isotope enrichment, then also not in carbon, where tolerances were even closer. "Contrary to the opinion of a small group of enthusiasts," Khariton would comment late in life, "the dominant opinion in our country was that a technical solution to the uranium problem was a matter for the remote future, and that success would require fifteen to twenty years." Khariton and Zeldovich's disappointing conclusion must certainly have contributed to that conservative assessment. But the "small group of enthusiasts," which included Khariton, Zeldovich, Kurchatov and Flerov, was not deterred. "In the case of a homogeneous reactor, the enterprise looked doomed," Khariton would note, "but there was still some hope that a loophole was possible. The cross sections were not very reliable and we felt that we had to dig through the material."

Believing that a nuclear reactor as well as a bomb would require increasing the U235 content of natural uranium, Kurchatov's group examined various methods of uranium enrichment. Gaseous diffusion—pumping a gaseous form of uranium against a porous barrier through which the lighter U235 isotope would diffuse faster than the heavier U238, selectively enriching the product—the physicists discounted as impractical. Instead they recommended separating U235 from U238 in gaseous form in a high-speed centrifuge, a method Khariton had studied in detail in 1937 but one for which the technology had not yet been developed.

These early discussions caught the attention of Leonid Kvasnikov, the head of the science and technology department of the state security organization, the People's Commissariat of Internal Affairs, known by its Russian initials NKVD. The NKVD, which had orchestrated the Great Terror (which then swallowed up some 28,000 of its own), had been headed since 1938 by Stalin's brutally efficient fellow Georgian Lavrenti Pavlovich Beria. It maintained a network of spies throughout the world run by NKVD *rezidents* stationed in Soviet consulates and embassies. One important field of *rezidency* work was industrial espionage—stealing industrial processes and formulas to save the Soviet Union the expense of licensing these technologies legitimately from their developers. The American industrial chemist Harry Gold, who began a long career of espionage for the Soviet Union in 1935, mentions among such information "the various industrial solvents used in the manufacture of lacquers and varnishes . . . , such specialized products as ethyl chloride (used as a local anesthetic) and in particular, absolute (100%) alcohol (used to blend, i.e., 'extend,' motor fuels)." These commonplace products, Gold understood, "would be a tremendous boon to a country [that was] back in the 18th century, industrially speaking (in spite of some localized advances)." They "could go toward making the harsh life of those who lived in the Soviet Union a little more bearable."

Early in 1940, Kvasnikov alerted the *rezidency* network to collect information on uranium research. According to Georgi Flerov, the early focus of Soviet concern was on German more than on Anglo-American work, just as it was in England and America:

> It seemed to us that if someone could make a nuclear bomb, it would be neither Americans, English or French but Germans. The Germans had brilliant chemistry; they had technology for the production of metallic

> uranium; they were involved in experiments on the centrifugal separation of uranium isotopes. And, finally, the Germans possessed heavy water and reserves of uranium. Our first impression was that Germans were capable of making the thing. It was obvious what the consequences would be if they succeeded.

Espionage, then, accompanied the Soviet development of nuclear energy from its earliest days.

In the spring of 1940, George Vernadsky, who taught history at Yale University, sent his father, V. I. Vernadski, an article about atomic energy published in the *New York Times.* Vernadski wrote a letter to the Soviet Academy of Sciences about the article, following which the academy created a Special Committee for the Problem of Uranium. Khlopin, who had succeeded Vernadski as director of the State Radium Institute, was appointed to head the Uranium Committee, which also included Vernadski, Ioffe, the distinguished geologist A. Y. Fersman, Kapitza, Kurchatov and Khariton as well as a number of senior Soviet scientists. The committee was directed to prepare a scientific research program and assign it to the necessary institutes, to oversee the development of methods of isotope separation and to organize efforts toward achieving a controlled chain reaction—that is, building a nuclear reactor. The decree that established the committee also ordered the construction, completion or improvement of no fewer than three Soviet cyclotrons, two already at hand in Leningrad and one to be built in Moscow; set up a fund for the acquisition of uranium metal, which Soviet industry at that time did not have the technology to produce; and appointed Fersman to lead an expedition into Central Asia to prospect for uranium. ("Uranium has acquired significance as a source of atomic energy," Vernadski wrote a colleague in July. "With us uranium is a scarce metal; we extract radium from deep brine [pumped from oil wells], and any quantity can be obtained. There is no uranium in these waters.")

Kurchatov was disappointed with the committee's plan, which the Academy of Sciences approved in October 1940. He believed it to be unduly conservative. Despite the expectation that uranium would have to be enriched, he wanted to move directly to building a nuclear reactor. At the Fifth All-Union Conference on Nuclear Physics in Moscow in late November, he analyzed fission studies published throughout the world to demonstrate that a controlled chain reaction was possible and listed the equipment and materials he would need. Asked if a uranium bomb could be built, he said confidently that it could and estimated that a bomb program would cost about as much as the largest hydroelectric plant that had been built in the Soviet Union up to that time—an estimate low by several orders of magnitude, but comparable to one Rudolf Peierls and Austrian emigré physicist Otto Robert Frisch had prepared in England eight months earlier for the

British government. In any case, as Frisch commented later, the cost of a plant for separating U235 "would be insignificant compared with the cost of the war."

Golovin was an excited eyewitness to the November debate:

> The situation... during Kurchatov's talk was rather dramatic. The workshop took place at the Communist Academy on Volkhonka Street, in a large hall with an amphitheater overcrowded by numerous participants. In the course of the presentation the excitement of the audience kept growing and by the end of it the general feeling was that we were on the eve of a great event. When Kurchatov finished his talk, and, together with the chairman of the meeting, Khlopin, went to the adjacent room from the rostrum, Ioffe, Semenov, [A. I.] Leipunski, Khariton and others started to move there one after the other. Meanwhile, the discussion over Kurchatov's talk was continued in the hall.... The break was delayed. Instead of the ordinary five or ten minutes between talks, the chairman, Khlopin, didn't return even in twenty minutes.... A noisy discussion was taking place [in the adjacent room].

The Great Terror had taught its survivors wary circumspection. In the fifteen months since the beginning of the Second World War on September 1, 1939, Germany had overrun Europe. To buy time, Stalin had concluded a nonaggression pact with Hitler, but the Soviet Union was gearing up for the war with Germany that Stalin understood was coming; in May 1941 he would tell his inner circle, "The conflict is inevitable, perhaps in May next year." The Soviet leadership had made clear its suspicion of "impractical" science, and Stalin had ordered the scientists in no uncertain terms to roll up their sleeves and get down to practical work. Nor had Khariton and Zeldovich's calculations encouraged optimism in an older generation still suspicious of the new physics. Surprisingly, even Ioffe was skeptical. He was not a nuclear physicist, and after the discovery of fission he had taken a long view of its potential, predicting that "if the mastering of rocket technology is a matter of the next fifty years, then the utilization of nuclear energy is a matter of the next century." All these factors would have influenced the noisy discussion going on in the adjacent room at the Communist Academy. Golovin:

> A quarter of an hour later, Khlopin returned to the rostrum and declared that he had come to the conclusion that it was too early to ask the government for large grants since the war was going on in Europe and the money was needed for other purposes. He said that it was necessary to work a year more and then make the decision whether there would be some grounds to involve the government.... The audience was disappointed.

The development of a capacity to build atomic bombs required a massive commitment of government funds, funds that would have to be diverted from the conventional prosecution of the war. If atomic bombs could be built in time they would be decisive, in which case no belligerent could afford *not* to pursue them. But making that judgment depended critically on how much scientists trusted their governments and how much governments trusted their scientists.

Trust would not be a defining issue later, after the secret, the one and only secret—that the weapon worked—became known. This first time around, however, it was crucial, as the Russian physicist Victor Adamsky emphasizes in a discussion of why Nazi Germany never developed an atomic bomb:

> The tension [between scientists and their governments] stemmed from the fact that there existed no *a priori* certainty of the possibility of creating an atomic bomb, and merely for clarification of the matter it was necessary to get through an interim stage: to create a device (the nuclear reactor) in order to perform a controlled chain reaction instead of the explosive kind. But the implementation of this stage requires tremendous expenses, incomparable to any of those previously spared for the benefit of scientific research. And it was necessary to tell this straight to your government, making it clear that the expenses may turn out to be in vain—an atomic bomb may not result. . . . .

Scientists and their governments developed confidence and mutual understanding in England and the United States, Adamsky concludes, but not in Germany. At the end of 1940, such confidence and mutual understanding had not yet developed in the USSR.

The overwhelming German surprise attack along the entire western border of the Soviet Union at dawn on June 22, 1941, one month after Stalin's prediction that a shooting war would not begin for another year, mooted the issue of how large an effort should be devoted to what Soviet physicists called the "uranium problem." Stalin met with military and other leaders for eleven hours that first day and almost continuously for several days thereafter, Beria at his side. The Wehrmacht decimated the Soviet Air Force, rolled over Belorussia and the Ukraine and thrust up through the Baltic states toward Leningrad. Once the magnitude of the disaster sank in, says Stalin biographer and General of the Soviet Army Dmitri Volkogonov, the dictator "simply lost control of himself and went into deep psychological shock. Between 28 and 30 June, according to eyewitnesses, Stalin was so depressed and shaken that he ceased to be a leader. On 29 June, as he was leaving the defense commissariat with Molotov, [Kliment] Voroshilov, [Andrei] Zhdanov and Beria, he burst out loudly, 'Lenin left us a great inheritance and we, his heirs, have fucked it all up!' " Stalin retreated to his dacha at Kuntsevo; it took a visit from the Politburo, led by Molotov, to mobilize him. "We got to Stalin's dacha," Anastas Mikoyan recalled in his memoirs. "We found him in an armchair in the small dining room. He looked up and said, 'What have you come for?' He had the strangest look on his face. . . ."

By the time the Soviet dictator rallied, the Germans were bombing Moscow. Volkogonov chronicles the debacle:

> Soviet losses were colossal. Something like thirty divisions had been virtually wiped out, while seventy had lost more than half of their numbers; nearly 3,500 planes had been destroyed, together with more than half the fuel and ammunition dumps. . . . Of course, the Germans too had paid a price, namely about 150,000 officers and men, more than 950 aircraft and several hundred tanks. . . . The [Red] army was fighting. It was retreating, but it was fighting.

Stalin finally rallied the Soviet people on July 3. Molotov and Mikoyan had written the speech and they almost had to drag Stalin to the microphone. The Soviet writer Konstantin Simonov, a front-line correspondent throughout the war, recalled the momentous occasion in his postwar novel *The Living and the Dead:*

> Stalin spoke in a toneless, slow voice, with a strong Georgian accent. Once or twice, during his speech, you could hear a glass click as he drank water. His voice was low and soft, and might have seemed perfectly calm, but for his heavy, tired breathing, and that water he kept drinking during the speech. . . .
>
> Stalin did not describe the situation as tragic; such a word would have been hard to imagine as coming from him; but the things of which he spoke—*opolcheniye* [i.e., civilian reserves], partisans, occupied territories, meant the end of illusions. . . . The truth he told was a bitter truth, but at last it was uttered, and people now at least knew where they stood. . . .

"It was an extraordinary performance," reports the Russian-born journalist and historian Alexander Werth, who covered the war in the USSR for the London *Times,* "and not the least impressive thing about it were these opening words: 'Comrades, citizens, brothers and sisters, fighters of our Army and Navy! I am speaking to you, my friends!' This was something new. Stalin had never spoken like this before."

But Stalin's secret police had surprises in store for any of his newfound "friends" whose loyalty might be suspect, particularly if their background was German. "In every village, town and city," notes Victor Kravchenko, "long blacklists were ready: hundreds of thousands would be taken into custody.... The liquidation of 'internal enemies' was, in sober fact, the only part of the war effort that worked quickly and efficiently in the first terrible phase of the struggle. It was a purge in the rear in accordance with an elaborate advance plan, as ordered by Stalin himself...." Half a million people—the entire population of the Volga German Republic—were transported to internal exile in Siberia. "In Moscow alone thousands of citizens were shot under martial law in the first six months," Kravchenko concludes. "...The magnitude of the terror inside Russia cannot be overstated. It amounted to a war within the war."

In the course of his July 3 speech, Stalin announced the formation of a State Defense Committee (GKO), in which he vested "all the power and authority of the State." He appointed himself chairman of the five-man committee, Molotov deputy chairman, and as members Red Army Marshal Kliment Voroshilov ("an utterly mindless executive with no opinion of his own," scoffs Volkogonov), the assiduous bureaucrat Georgi Malenkov and Beria.

Thus Lavrenti Beria came into his own. Born in the Sukhumi district of Georgia in 1899, he had worked his way to power first as police chief and then party chief of Georgia and the Transcaucasus (where he had personally organized the terrible purges) and now at the center in Moscow. Stalin had summoned him from Georgia in 1938 to purge the NKVD itself. "By early 1939," according to a biographer, "Beria had succeeded in arresting most of the top and middle-level hierarchy of [his predecessor's] apparatus...." He inherited a gulag slave-labor force of several million souls. "Camp dust," he liked to call them. "A magnificent modern specimen of the artful courtier," Svetlana Alliluyeva mocks; she blamed Beria for her father's excesses. The Yugoslavian diplomat Milovan Djilas met Beria in the course of the war: a short man, Djilas says, "somewhat plump, greenish pale, and with soft damp hands," with a "square-cut mouth and bulging eyes behind his pince-nez" and an expression of "a certain self-satisfaction and irony mingled with a clerk's obsequiousness and solicitude." Beria's brutality extended to casual rape—of teenage girls plucked off the street and delivered to his Lubyanka office—and official torture and murder. He was nevertheless an exceptional administrator. Stalin gave him huge responsibilities: for evacuating wartime industry eastward over the Urals, for mobilizing gulag labor, for overseeing industrial conversion and for moving troops and matériel to the front. "Beria was a most clever man," Molotov testified, "inhumanly energetic and industrious. He could work for a week without sleep." In the early months of the war he almost certainly did.

"Beria was no engineer," observes Victor Kravchenko, a factory manager in those days. "He was placed in control for the precise purpose of inspiring deadly fear. I often asked myself—as others assuredly did in their secret hearts—why Stalin had decided to take this step. I could find only one plausible answer. It was that he lacked faith in the patriotism and national honor of the Russian people and was therefore compelled to rely primarily on the whip. Beria was his whip."

According to Marshal K. S. Moskalenko, who told a group of senior military officers in 1957 that he heard it from Beria himself, Stalin colluded with Beria and Molotov in late July to offer a surrender, "agreeing to hand over to Hitler the Soviet Baltic republics, Moldavia, a large part of the Ukraine and Belorussia. They tried to make contact with Hitler through the Bulgarian ambassador. No Russian czar had ever done such a thing. It is interesting that the Bulgarian ambassador was of a higher caliber than these leaders and told them that Hitler would never beat the Russians and that Stalin shouldn't worry about it."

The war emptied out the Leningrad institutes. The scientists crated up their movable equipment and shipped it on tracks crowded with troop trains to the other side of the Urals, out of range of German bombers. Fiztekh went to Kazan, four hundred kilometers east of Moscow on the Volga. Whole factories moved east,* reports Sergei Kaftanov, minister of higher education and deputy for science and technology to the State Defense Committee:

> How long would it take today to move a big industrial enterprise to a new site? Two years? Three years? During the war it took only months for plants that had been moved a thousand kilometers to start up again. The regular order of construction is: walls—roof—machines. We were doing it this way: machines—roof—walls. War pressed us for quick solutions.

Quick solutions meant solutions, including scientific solutions, that contributed immediately to the defense of the beleaguered country. In the late summer of 1941, Kurchatov and Alexandrov set up a laboratory together in the Crimean port of Sevastopol, on the Black Sea, organized a test site for demagnetizing ships to protect them against magnetic mines and trained Navy crews in the lifesaving technology until September, when the Germans began bombing Streletskaya Bay. Alexandrov went north then to work with the Northern Fleet; Kurchatov stayed on in Sevastopol demagnetizing submarines.

Boris Pasternak compacted the mood that terrible autumn into a shudder of dread:

* "Altogether, between July and November 1941 no fewer than 1,523 industrial enterprises, including 1,360 large war plants, had been moved to the east—226 to the Volga area, 667 to the Urals, 244 to Western Siberia, 78 to Eastern Siberia, 308 to Kazakhstan and Central Asia. The 'evacuation cargoes' amounted to a total of one and a half million railway wagon-loads." Werth (1964), p. 216.

Do you remember that dryness in your throat
When rattling their naked power of evil
They were barging ahead and bellowing
And autumn was advancing in steps of calamity?

In October there was panic in Moscow. The Germans had advanced to within a hundred kilometers of the city and it seemed they might succeed in seizing it. A young Red Army cipher clerk stationed in training nearby, Igor Gouzenko, had been given a pass into Moscow on October 16 and witnessed the debacle. "The street was crowded with people carrying bundles, sacks and suitcases," Gouzenko recalled after the war. "They were scurrying in all directions. No one seemed to know where they were fleeing. Everyone was just fleeing. Most astounding of all was the strange silence hanging over the scene. Only the stamp of hurrying feet created an undertone of frantic rhythm." Andrei Sakharov, who was then a young university student, remembered that "as office after office set fire to their files, clouds of soot swirled through streets clogged with trucks, carts, and people on foot carrying household possessions, baggage, and young children. . . . I went with a few others to the [university] Party committee office, where we found the Party secretary at his desk; when we asked whether there was anything useful we could do, he stared at us wildly and blurted out: 'It's every man for himself!' "

At the Scientific Research Institute where Igor Gouzenko's sister had been working, a notice had been posted on the door on the authority of the chairman of the Moscow Soviet: "The situation at the front is critical. All citizens of the City of Moscow, whose presence is not needed, are hereby ordered to leave the city. The enemy is at the gates."

Gouzenko thought the notice qualified as "the most panicky document of World War II." Warranted or not, Moscow emptied out; by the end of October, more than two million people had been evacuated officially and many more had simply fled. Stalin stayed. The counterattack outside Moscow, the first major Soviet offensive, began early in December and saved the city. "West of Moscow," observes Alexander Werth, ". . . miles and miles of road were littered with abandoned guns, lorries and tanks, deeply embedded in the snow. The comic 'Winter Fritz,' wrapped up in women's shawls and feather boas stolen from the local population, and with icicles hanging from his red nose, made his first appearance in Russian folklore." But the siege of Leningrad had begun, and that winter nearly half the population of the city, a million people, died of starvation.

Georgi Flerov had been drafted into the Soviet Air Force at the beginning of the war and assigned to the Air Force Academy in Ioshkar-Ola to train as an engineer. He was a stubborn man; he suspected that other nations, including the fascist enemy, were working on a uranium bomb; he believed passionately that his country should develop such a weapon first. He said as much in a letter to the State Defense Committee in November, but the letter went unanswered.

That month German bombs and artillery barrages finally drove the Soviet Navy from the Sevastopol harbor. Kurchatov left ruined Sevastopol then, evacuating first by boat to Poti, south of Sukhumi on the eastern shore of the Black Sea, then beginning the long journey by train to Kazan, seven hundred kilometers east of Moscow, to resume work at the temporary Fiztekh installation there. On his way, the Soviet physicist spent a night on a below-zero station platform and caught cold. Suzanne Rosenberg, a daughter of Canadian Communists who had returned to the Soviet Union to support the Revolution, describes a similar railroad ordeal evacuating Moscow during the October panic:

> So crammed with evacuees was the train that we spent the first twenty-four hours standing on the wind-swept platform between the carriages. Later we took brief turns sitting down on the benches inside. Our journey lasted nineteen days: normally it took forty-six or fifty hours. We learned to sleep standing up, like horses, to do without water and with little food for whole days. The German Messerschmitts were on our trail. Hearing their approach we would jump off the train, tumbling over one another, and scurry off in all directions. If there were woods we made a dash for their cover. If not, we fled into the open fields and stretched out in the frozen grass, faces buried in the icy ground.

In December Flerov won leave to present a seminar on the uranium problem to the Academy of Sciences, which, like Fiztekh, had been evacuated to nearby Kazan. He missed Kurchatov, who was still in transit, but wrote him a long letter in a school notebook that repeated the gist of his report. One of the participants remembers:

> Flerov's report was well-argued. As usual, he was vivid and enthusiastic. We listened to him attentively. Ioffe and Kapitza were present. . . . The seminar left the impression that everything was very serious and fundamental, that work on the uranium project should be renewed. But the war was going on. And I don't know what the outcome would have been if we'd had to decide whether to start work immediately or to delay beginning for another year or two.

Flerov was proposing work on a fast-neutron chain reaction: a bomb. He argued that an atomic bomb was possible and that 2.5 kilograms of pure U235 would yield 100,000 tons of TNT equivalent. "He suggested developing a 'cannon' design," reports Khariton, "that is, quickly driving together two hemispheres made of U235. He also expressed the important idea of the use of 'compression of the active material.' " The record is silent on how Flerov proposed to achieve such compression in a uranium gun, which assembles but does not compress. Flerov's 2.5 kilograms was at best a rough approximation, far below the minimum quantity of U235 necessary to sustain a chain reaction,* but it compares with the 1 kg that Rudolf Peierls and Otto Frisch in England had first roughly estimated and was probably derived similarly from the known cross section of uranium for neutron capture, the geometric cross section, 10^{-23} cm^2.

By the time Kurchatov arrived behind the Urals, at the end of December 1941, his cold had turned to pneumonia. He took to his bed. His wife Marina Dmitrievna joined him in Kazan and nursed him. Abram Ioffe nursed him. During his illness he chose not to shave. When he recovered, early in 1942, he emerged into Russian winter with a full-blown beard, "which," says Golovin, "he declared no scissors would touch till after victory." It was unusual in those days for a young Russian to wear a beard. Kurchatov would make his famous.

Khariton says Kurchatov cherished Flerov's report, saving it in his desk to the end of his life. Admiring Flerov's enthusiasm was not the same as trusting his judgment, however. "Kurchatov knew," comments Golovin, "that Flerov did not and indeed could not have proofs; he only had a passion for experimentation and would not back down from his ideas. . . . Cares of the day distracted Kurchatov. He was recalled to fleet duty and left for Murmansk."

"Scientific work which is not completed and produces no results during the war," Peter Kapitza explained in a lecture in 1943, "may even be harmful if it diverts our forces from work which is more urgently required." With ships to demagnetize, tank armor to harden and radar to invent, the Soviet scientific establishment concluded once again, that hard winter of 1941, that it would be imprudent to undertake expensive, problematic and long-term nuclear-fission research in the midst of war.

* Critical mass for a bare U235 sphere, 56 kg; for a U235 sphere surrounded by a thick uranium tamper, 15 kg. King (1979), p. 7.

2

Diffusion

"I THINK THAT THE WORLD in which we shall live these next thirty years will be a pretty restless and tormented place," Robert Oppenheimer wrote his younger brother Frank from Berkeley in 1931; "I do not think that there will be much of a compromise possible between being of it, and being not of it." Many thoughtful men and women felt that way in the decades between the two world wars, and for some of them, Communism seemed to promise what the *Time* essayist and Communist agent Whittaker Chambers called a "solution." "In the West," Chambers observed of that period, "all intellectuals [who] become Communists [do so] because they are seeking the answer to one of two problems: the problem of war or the problem of economic crises." Chambers explained:

> The same horror and havoc of the First World War, which made the Russian Revolution possible, recruited the ranks of the first Communist parties of the West. Secondary manifestations of crisis augmented them—the rise of fascism in Italy, Nazism in Germany and the Spanish Civil War. The economic crisis which reached the United States in 1929 swept thousands into the Communist Party or under its influence.

But commitment to Communism was also always personal, Chambers emphasized, the resolution of a crisis of faith; "his decision to become a Communist seems to the man who makes it as a choice between a world that is dying and a world that is coming to birth." Partisan observers then and since have ridiculed such commitment, judging it naive or even delusional, but it was no more so than any other religious conversion seen from outside the circle of faith.

For committed Communists it followed that the Soviet Union was the new world's vanguard. Some acknowledged its unparalleled violence, its rule by terror; some did not. "The Communist Party presents itself," Chambers noted, "as the one organization of the will to survive the crisis. . . . It is in the name of that will . . . that the Communist first justifies the use of terror and tyranny . . . which the whole tradition of the West specifically repudiates." "We were defending the first socialist country," insisted Ruth Kuczynski, a German Communist who lived in exile in England. "We didn't know—I didn't know—about Stalin's crimes," she told an interviewer late in life. "We knew how the capitalist West wanted to destroy the Soviet Union. It really seemed possible that they had managed to insert all these agents [who were purged during the Great Terror] into high places. . . . I believed Stalin."

Blindered or open-eyed, some among the faithful invested the raw, brutal, revolutionary new nation with their hopes of connection. Through its instrumentalities, they hoped that they could fight fascism, anti-Semitism, ignorance, inequality. Harry Gold believed he was attacking a universal and all-encompassing anti-Semitism:

> In only the Soviet Union was anti-Semitism a crime against the State. . . . Here, too . . . was the one bulwark against the further encroachment of that monstrosity, Fascism. To me Nazism and Fascism and anti-Semitism were identical. This was the ages-old enemy of the Roman Arena, the ghetto, of the inquisition, of Pogroms, and now of concentration camps in Germany. Anything that was against anti-Semitism I was for, and so the chance to help strengthen the Soviet Union seemed like a wonderful opportunity.

Soviet intelligence networks made productive use of Communist Party members even though such volunteers were not trained agents and even though their Party affiliation made them suspect to their own governments; they were such people as money could not buy.

Recruiting usually followed a standard pattern. Committed Party members looked out for potential converts with useful skills or affiliations, made them welcome, proselytized them, obligated them with favors and gifts. Out of work in the depths of the Great Depression, Harry Gold got a job with the help of a Party recruiter, Tom Black. "That wonderful $30.00 every Saturday kept our family off relief. . . . I was grateful to Black, very much so." A 1946 Royal Commission investigating Soviet intelligence operations in Canada found that there were "numerous . . . groups where Communist philosophy and techniques were studied. . . . To outsiders these groups adopted various disguises, such as social gatherings, music-listening groups and groups for discussing international politics and economics. . . . These study groups were in fact 'cells' and were the recruiting centres for agents, and the medium of development of the necessary frame of mind which was a preliminary condition to eventual service of the Soviet Union in a more practical way." Besides commitment to the cause, the "necessary frame of mind" was secrecy:

> This object is to accustom the young Canadian adherent gradually to an atmosphere and an ethic of conspiracy. The general effect on the young man or woman over a period of time of *secret* meetings, *secret* acquaintances, and *secret* objectives, plans and policies, can easily be imagined. The technique seems calculated to develop the psychology of a double life and double standards.

A candidate dropped out of Party activity when he agreed to become an agent, dividing and isolating him still further.

This theme of recruiting had significant variations. Morris Cohen, a native New Yorker born in 1910 to immigrant Russian parents and a high school football star, had joined the Communist Youth League in 1933 at the University of Illinois and subsequently volunteered to fight with the Abraham Lincoln International Brigade in the Spanish Civil War. While recovering from wounds in a hospital in Barcelona, Cohen was invited to attend the Republican Army's nearby Barcelona Intelligence School, which operated under the code name Construction. There he was recruited for US espionage by a Soviet intelligence officer. "In April 1938," Cohen wrote in his NKVD autobiography, "I was one of a group of various nationalities sent to a conspiratorial school in Barcelona. Our chief commissar and leaders were Soviets." Cohen completed his course of espionage training in February 1939 and returned to the United States to begin a productive career.

Ruth Kuczynski's older brother Jurgen was the political leader of the German Communist Party in England. Jurgen had escaped Nazi Germany in 1933 through Czechoslovakia and taken up teaching at the London School of Economics. Ruth, born in Berlin in 1907, came west by a different route; trained in Moscow as a clandestine radio operator, she had already worked out of Czechoslovakia, Trieste, Cairo, Bombay, Singapore, Hong Kong, Shanghai, Peking and Poland. By the time she settled in England in 1938 she was a major in Red Army intelligence (GRU as opposed to secret police intelligence, NKVD; the two entities maintained parallel and independent networks).

The most productive cell in the history of Soviet espionage developed at Cambridge University in the 1930s. While physicists at the Cavendish Laboratory probed the real world of the atomic nucleus with the new tool of neutron bombardment, a brilliant and fanatic group of young Cambridge intellectuals at Trinity College lauded the certainties of Marxian metaphysics. The majority of the group were homosexual or bisexual in a society that branded homosexual acts as felony crimes; sexual orientation contributed to affiliation even as it taught the young conspirators double standards and a double life. But Communism in any case was intensely fashionable at English universities between the world wars. Michael Straight, an American student at Cambridge at the time, estimates that "the Socialist Society had two hundred members when I went to Cambridge and six hundred when I left. About one in four of them belonged to Communist cells."

The nucleus of the Cambridge group was Guy Burgess, recruited in 1933 by a Russian agent who worked in London as a journalist under the alias Ernst Henri. Burgess, the handsome son of a well-married naval commander, took prizes at Eton and first-class honors in history at Cambridge. His brilliance and charm won him election to the Cambridge Conversazione Society, an elite secret society whose members were known as the Apostles. He enlisted at least two of the members of his cell by seduction. "At one time or another," wrote a don who adored him, "he went to bed with most of [his] friends, as he did with anyone who was willing and was not positively repulsive, and in doing so he released them from many of their frustrations and inhibitions." Of the four other men who came to be known as the Cambridge Five, Anthony Blunt and Donald Maclean certainly count among Burgess's sexual conquests. Kim Philby and John Cairncross were already dedicated Communists, but Cairncross at least acknowledged finding Burgess "fascinating, charming and utterly ruthless."

John Cairncross was a tall, rangy Scotsman from Glasgow, born in 1913. He studied at Glasgow University for two years beginning in 1930, when he was seventeen, took a year at the Sorbonne in Paris, then won a scholarship to Cambridge. Anthony Blunt was one of his Trinity supervisors there and directed him to Burgess, who recruited him for espionage in 1935. In the autumn of 1936, after he graduated from Cambridge with first-class honors in modern languages, Cairncross joined the British Foreign Office. Maclean, the tall, athletic namesake of the Liberal politician Sir Donald Maclean, was already on staff. "It's like being a lavatory attendant," Maclean would say later of espionage; "it stinks, but someone has to do it."

Though he worked at making friends, Cairncross was not a success in the Foreign Office. "Cairncross was always asking people out to lunch," one of his colleagues, John Colville, remembers. ". . . He ate very slowly, slower than anyone I've ever known." Colville judged him "a very intelligent, though sometimes incoherent, bore." In 1938, Cairncross transferred from the Foreign Office to the Treasury, probably at the request of the NKVD. Cairncross's real espionage breakthrough came in September 1940, a year into the European war, when Lord Hankey, minister without portfolio in Winston Churchill's War Cabinet, appointed him his private secretary. Hankey had full access to top secret War Cabinet papers and oversight of British intelligence. He also chaired the Scientific Advisory Committee.

It was probably John Cairncross who first passed information on Anglo-American atomic-bomb research to "Henry," the Cambridge Five's London NKVD control Anatoli Borisovich Gorsky, at the end of September 1941, when the Wehrmacht was besieging Leningrad and Igor Kurchatov was demagnetizing ships in Sevastopol. Gorsky—"a short, fattish man in his midthirties, with blond hair brushed straight back and glasses that failed to mask a pair of shrewd, cold eyes" according to one of his wartime agents—was "Vadim" to Moscow Center, the NKVD home office. Cairncross was probably "List." Vadim's report, "#6881/1065 of 25.IX.41 from London," summarized a meeting of the British Uranium Committee held on September 16. The information corresponds to information contained in the secret "Report by MAUD Committee on the Use of Uranium for a Bomb" prepared that summer for the British Cabinet and transmitted to the United States. At some time Moscow Center acquired a complete copy of the MAUD report.

"The uranium bomb may very well be developed within two years," Vadim's report began dramatically. Measurements of U235 cross sections would be accomplished by December. The British firm Metropolitan Vickers had been commissioned to develop a twenty-stage gaseous-diffusion pilot plant, a task which had "high priority," construction to begin "immediately." The government had contracted with Imperial Chemical Industries (ICI) for uranium hexafluoride, the gaseous form of uranium, which the Vickers plant would process.

Some of the information in this first transmission was garbled. A second transmission sent October 3 cleared up the confusion. "It is thought that the critical mass [of U235] falls within the range from 10 to 43 kg," the document reported. ICI had already produced three kilograms of uranium hexafluoride. "Production of U235 is realized by diffusion of uranium hexafluoride in a vaporized state through a number of membranes consisting of a grid of very fine wire." (This configuration was German emigré chemist Franz Simon's first approximation of a diffusion "membrane" or "barrier"—he had pounded out a kitchen strainer to demonstrate the idea to his Oxford staff.) In 1939, Yuli Khariton and Yakov Zeldovich had dismissed gaseous diffusion as an impractical method of separating U235; here was information that the British considered it superior. The document reported problems, however. "Development of the separation plant design is meeting with serious difficulties." Vadim enumerated the perverse physical characteristics that made "hex" hellish stuff—the heavy, corrosive gas destroyed lubricant, dissociated in the presence of water vapor and attacked equipment. A gaseous-diffusion plant would be huge, the British had calculated, 1,900 ten-stage units occupying a plant area of some twenty acres.

From gaseous diffusion the report then veered back to the bomb, echoing Peierls and Frisch's early realization that a weapon that derived its explosive force from nuclear fission would have unique characteristics: "It should be noted that besides the uranium bomb's tremendous destructive effect, the air at the site of the explosion will be saturated with radioactive particles capable of killing everything alive."

September 1941 was a banner month for Soviet nuclear espionage. While Vadim was reporting from London, Morris Cohen weighed in from New

York. Cohen had married a fellow Communist, Leontine Patka, known as Lona, the day Germany invaded the USSR. The invasion had depressed him, but after he had mulled it over for a few days he had revealed his affiliation to his wife and convinced her to join him in espionage work. Together they had already collected and passed along information from an engineer in Hartford on a new aircraft machine gun, even delivering a prototype of the machine gun to Morris's Soviet contact, the long barrel concealed in a bass viol case. Now Cohen reported a remarkable development. An American physicist whom he knew from Spanish Civil War days had contacted him for an introduction to Amtorg, the Soviet trading corporation in New York that clandestinely organized North American espionage. The physicist told Cohen he had been invited to work on a secret project to develop an American atomic bomb. Cohen wanted to know if he could recruit the man. Moscow Center approved.

Lavrenti Beria received these independent reports of Allied nuclear-research activity with his habitual cynicism. Anatoli Yatzkov, the NKVD's New York *rezident* during the Second World War, notes that "from the very beginning [Beria] suspected that these materials contained disinformation and thought that our adversaries [sic] were trying to drag us into tremendous expenditures and efforts on dead-end work. He gave them to a group of physicists for review. The scientists concluded that even if nuclear weapons were possible, they could only be built in the remote future."

Early in 1942, a new GRU volunteer began contributing to the volume of information reaching the Soviet Union. He was a refugee in England from Nazi Germany, a devoted Communist already gone underground and an exceptional young physicist and he worked for Rudolf Peierls:

> I . . . found many problems piling up on the theoretical side, and I could not deal with all of them fast enough. . . . I needed some regular help—someone with whom I would be able to discuss the theoretical technicalities. I looked around for a suitable person, and thought of Klaus Fuchs.

Born in 1911 in Rüsselsheim, in the Rhine Valley south of Frankfurt, Fuchs at thirty-one had already seen enough conflict and tragedy for a lifetime. He claimed later that he had "a very happy childhood," but it culminated with his mother's violent suicide—she drank hydrochloric acid—when he was nineteen. His elder sister Elizabeth would also be a suicide, though her act may have been protective: a Communist who was active politically against the Nazis, she jumped in front of a train when she was about to be arrested. Fuchs's father Emil was a politically contentious parson who left the Lutheran Church when Fuchs was fourteen and became a Quaker. "My father always told us that we had to go our own way," Fuchs remembered, "even if he disagreed. He himself had many fights because he did what his conscience decreed, even if these [sic] were at variance with accepted convention." Klaus Fuchs would become his father's son, but he broke away from his father's philosophy, he said, over pacifism.

Fuchs joined the Socialist Party at the University of Leipzig, where he began studying physics and mathematics in 1930. After two politically active years he went on to the University of Kiel. There he quit the Socialists over the party's decision to support the presidency of Paul von Hindenburg, the conservative field marshal who would pass the chancellorship of Germany to Adolf Hitler. "At this point," Fuchs recalled, "I decided to oppose the official policies openly, and I offered myself as a speaker in support of the Communist candidate." He joined the Communist Party soon afterward and worked actively on its behalf in student politics, his work culminating in a strike which the Nazi leaders called in SA brownshirts to break. "In spite of that I went there every day to show that I was not afraid of them. On one of these occasions they tried to kill me and I escaped."

After the Reichstag fire early in 1933 that gave Hitler an excuse to invoke a state of emergency and round up the opposition, Fuchs went underground:

> I was lucky because on the morning after the burning of the Reichstag I left my home very early to catch a train to Berlin for a conference of our student organization, and that is the only reason why I escaped arrest. I remember clearly when I opened the newspaper in the train I immediately realized the significance and I knew that the underground struggle had started. I took the badge of the hammer and sickle from my lapel. . . .

"I was ready to accept the philosophy that the Party is right," Fuchs continues, "and that in the coming struggle you could not permit yourself any doubts after the Party had made a decision." Long afterward, Rudolf Peierls would ask Fuchs how a scientist could accept Marxist orthodoxy and would be shaken by the "arrogance and naiveté" of his answer. "You must remember what I went through under the Nazis," Peierls reports Fuchs answering. "Besides, it was always my intention, when I had helped the Russians to take over everything, to get up and tell them what is wrong with their system."

Fuchs remained underground until he left Germany for Paris in July 1933. He was then twenty-one years old. "I was sent out by the Party, because they said that I must finish my studies because after the revolution in Germany people would be required with technical knowledge to take part in the building up of the Communist Germany." To Harry Gold, who would meet him later in America, Fuchs's dedication would always be "noble":

> Here: While Klaus was a mere boy of 18 he was head of the student chapter of the Communist Party at the University of Kiel . . . and Klaus, a frail, thin boy, led these boys in deadly street combat against the Nazi storm troopers

> . . . and later, when the Nazis had put a price on his head, he barely managed to escape with his life to England. . . . For a man of such convictions who fought this horror of Fascism at the risk of his life, I cannot help but express my admiration.

Student friends helped Fuchs find his way to England, where a Bristol family with Communist connections took him in. Theoretical physicist Nevill Mott, a professor at Bristol University, gave him an assistantship. Mott thought Fuchs "shy and reserved," but saw another side at meetings of the Bristol branch of the Society for Cultural Relations with the Soviet Union, which sometimes staged dramatic readings of the texts of the purge trials then underway in Moscow. Fuchs chose to read the part of the prosecutor, shrill Andrei Vyshinsky, "accusing the defendants with a cold venom that I would never have suspected from so quiet and retiring a young man."

After four years at Bristol, Fuchs moved in 1937 to Edinburgh to work with Max Born, one of the pioneers of quantum mechanics and himself an emigré. In Edinburgh, says Peierls, Fuchs "did some excellent work in the electron theory of metals and other aspects of the theory of solids." Like Mott, Born also found the young German "a very nice, quiet fellow with sad eyes"; after Bristol Fuchs seems to have dissembled his political radicalism and swallowed his rage, although he did organize sending propaganda leaflets from Scotland to Germany.

He must have had trouble containing himself when he was interned as an enemy alien in May 1940 and sent to a camp on the Isle of Man. From there, jammed in with hundreds of other undesirables, he was deported by ship to internment in Canadian army camps that were short on latrines and running water. England was in a jingoist mood; by July, it had interned more than twenty-seven thousand Germans and Italians, many of them refugees from fascism, and would ship more than seven thousand abroad. Shattered by this second deportation, some of them committed suicide. A German U-boat torpedoed the *Arandora Star,* one of the passenger liners carrying the unlucky internees to exile; of 1,500 aboard, only 71 survived. Everyone's papers went down with the *Arandora Star* and for a time in Canada, as a result, Fuchs was billeted among Nazis. "I felt no bitterness by the internment," he claimed later, "because I could understand that it was necessary and that at the time England could not spare good people to look after the internees, but it did deprive me of the chance of learning more about the real character of the British people." How he assessed the British people in ignorance of their real character he chose not to say, but he did say, of his state of mind during the next several years, that he "had complete confidence in Russian policy and . . . believed that the Western Allies deliberately allowed Russia and Germany to fight each other to the death." No less a figure than Missouri Senator Harry S. Truman argued publicly for just such a policy when Germany invaded the USSR in June 1941. "If we see that Germany is winning we ought to help Russia and if Russia is winning we ought to help Germany and that way let them kill as many as possible," Truman told the Senate, "although I don't want to see Hitler victorious under any circumstances. Neither of them think anything of their pledged word." This early expression of Truman's hostility to the Soviet Union suggests that his move to a hard line after the war was a move from the Roosevelt policy of cooperation and accommodation back to long-standing conviction more than simply a response to Soviet intransigence.

After inquiries and the intercession of friends, Fuchs was returned to England and released from internment on December 17, 1940, twelve days before his twenty-ninth birthday. He went back to Edinburgh and Max Born and his chosen work of physics, a thin, pale, stoop-shouldered young man of average height with prominent forehead and Adam's apple, myopic brown eyes watchful behind thick glasses, a habit of swallowing hard, frequently and audibly, a chain-smoker with stained fingers. Someone eventually wrote a clerihew about him:

Fuchs
Looks
Like an ascetic
Theoretic.

Rudolf Peierls requisitioned Fuchs from Born sometime after the first of the year and took him in as a lodger; Peierls's wife Genia was exuberantly Russian and a great mother of young men, having previously taught Otto Frisch to shave daily and dry dishes faster than she could wash them. "[Fuchs] was a pleasant person to have around," Peierls recalls. "He was courteous and even-tempered. He was rather silent, unless one asked him a question, when he would give a full and articulate answer; for this Genia called him 'Penny-in-the-slot.' "

Since Fuchs was still an enemy alien, and was known to have been an active Communist in his homeland, clearance was delayed. The quiet young German started work on the atomic bomb at Birmingham in May 1941.

"When I learned the purpose of the work," Fuchs testified later, "I decided to inform Russia and I established contact through another member of the Communist Party." Fuchs went up to London in late 1941 and talked to Jurgen Kuczynski. "On his first contact with Kuczynski," an FBI report paraphrases his testimony, "he informed him of his desire to furnish information to the Soviet Union." Kuczynski put Fuchs in touch with a man he would come to know as "Alexander": Simon Davidovitch Kremer, secretary to the military attaché at the Soviet Embassy, who became his GRU control. In the next six months, Fuchs met with Alexander two or three times, once at the embassy, and gave him copies of the reports he was writing for Peierls. These included studies of isotope separation and calculations of critical mass as well as reviews of published German work in the field.

By early 1942, Lavrenti Beria's agents had bombarded him with so much information about British, French, German and American research toward an atomic bomb that he could no longer discount it. He ordered the British documents that the NKVD had received gathered together and a report prepared for Stalin. Copy No. 1 of that report, KZ-4, went to Stalin over Beria's signature in March 1942.

"Study of the question of military use of nuclear energy has begun in a number of capitalist countries," Beria began cautiously. Work on the development of new explosives using uranium was being carried out in an atmosphere of "strict secrecy" in France, England, Germany and the US. Top secret documents obtained by the NKVD from its agents in England revealed that the British War Office was intensely interested in the problem of military use because of concern that Germany might solve the problem first.

Drawing directly on the MAUD report, Beria noted that "well-known English physicist G. P. Thomson" was coordinating the work in England and that U235 was the explosive isotope involved, extracted from ores of which there were large reserves in Canada, the Belgian Congo, Sudetenland and Portugal. In a significant garble, Beria reported that the French scientists Hans Halban and Lew Kowarski had developed a method for extracting U235 using uranium oxide and heavy water; in fact, Halban and Kowarski (using most of the world's supply of heavy water, fifty gallons spirited out of France just ahead of the Germans in tin cans by car and boat) had determined that a controlled chain reaction was possible using such materials without enrichment, information Yuli Khariton and Yakov Zeldovich would benefit in the course of time from learning.

Beria went on to discuss gaseous diffusion, noting that the British hoped to cooperate in development with the United States. Then he took up the bomb itself.

Peierls, Beria reported, had determined that ten kilograms of U235 would form a critical mass. "Less than this amount is stable and absolutely safe, but a mass of U235 greater than 10 kilograms develops in itself a fission chain reaction, leading to an explosion of tremendous force." The British therefore proposed to design a bomb in which the "active part consists of two equal halves" and to drive them together at around six thousand feet per second. "Professor Taylor"—presumably Geoffrey Taylor, the English hydrodynamicist—"has calculated that the destructive action of 10 kg of U235 would correspond to 1,600 tons of TNT."

Imperial Chemicals had estimated that a plant to separate U235 "using Dr.

Simon's system" would cost £4.5 to £5 million, Beria went on. Then he offered a justification for bomb building that demonstrates how little anyone yet understood the revolutionary nature of the potential new explosive:

> Given production of 36 bombs per year by such a plant, the cost of one bomb would be £236,000 compared to the cost of 1,500 tons of TNT at £326,000.

Beria concluded that the British leadership considered the military application of uranium solved in principle and that the War Office was laying plans to produce uranium bombs. He recommended: (1) forming a special scientific committee attached to the State Defense Committee to coordinate Soviet work on atomic energy and (2) passing the espionage documents along to "prominent specialists and scientists" for assessment and use.

Coincidentally, the timing of Beria's report to Stalin matched within a few days a report US science czar Vannevar Bush sent to Franklin Roosevelt describing an American program that was then in the process of expanding from laboratory research to industrial development. "If every effort is made to expedite [research and production]," Bush concluded, an American bomb could be delivered in 1944. On March 11, 1942, Roosevelt responded enthusiastically, "I think the whole thing should be pushed.... Time is of the essence." In contrast, Stalin moved cautiously. He acted on Beria's second recommendation but not yet his first. The Soviet leader sent the file of espionage documents to Molotov with instructions to pass it for evaluation in turn to Mikhail Georgievich Pervukhin, the newly appointed People's Commissar of the Chemical Industry.

Molotov called him in, Pervukhin later told an interviewer, and expressed concern that other countries "might have achieved a major advance in the field, so that if we didn't restart our work we might seriously lag behind.... Then he said: 'You should talk to the scientists who know the field and then report on it.' That's what I did."

April 1942 brought further confirmation that the giant of nuclear fission was stirring. A Red Army colonel who commanded partisan detachments behind the German lines sent a captured document to Sergei Kaftanov, the State Defense Committee deputy for science. "Ukrainian partisans had brought him the notebook of a dead German officer," Kaftanov recalls. "... The notebook contained certain chemical formulae ... [which] appeared to concern the nuclear transformations of uranium. The notes in general showed that the officer had a professional interest in nuclear energy. It seemed he'd come to the occupied territories specifically to look for uranium." Kaftanov gave a Russian translation of the German officer's notes to A. I. Leipunski, a senior Ukrainian physicist on the staff of the ill-fated institute at Kharkov. Leipunski responded with the safe and standard litany, says Kaftanov: "In three days the answer came. Leipunski believed that in the coming fifteen to twenty years the problem of developing nuclear energy would hardly be solved and that it wasn't worth spending money on it in the midst of war." Pervukhin heard much the same message.

Georgi Flerov had lost patience with timid Academicians and stodgy bureaucrats. He was a lieutenant in the Air Force now, assigned to a reconnaissance squadron in Voronezh, near the confluence of the Voronezh River and the Don some five hundred kilometers south of Moscow, but he was still strafing the government with letters and telegrams—no fewer than five telegrams to Kaftanov in recent months, with no response. Nor was official indifference to the cause of uranium research his only resentment. Although he and Konstantin Petrzhak had been nominated for a Stalin Prize for their 1940 discovery of spontaneous fission—an honor that customarily included tangible gifts—the nomination had not been confirmed because scientists in other countries had not welcomed the discovery in print or cited it in their publications. The university at Voronezh had been evacuated eastward, leaving behind its library. Flerov decided to check the scientific journals there to see if any new citations had turned up.

He found more missing from the foreign journals he consulted than merely references to his own work. Nuclear physics itself was missing; all the leading American nuclear physicists had stopped publishing. Flerov immediately understood that their work must have been classified. To Flerov that meant that the United States must be developing an atomic bomb. Twenty-nine years old and a mere lieutenant, but a physicist who understood the energy that matter might release if it were properly arranged, he notched his sights up then from assaulting the bureaucracy and in April 1942 appealed directly to Stalin:

> Dear Josef Vassarionovich:
>
> Ten months have already elapsed since the beginning of the war, and all the time I have felt like a man trying to break through a stone wall with his head.
>
> Where did I go wrong?
>
> Am I overestimating the significance of the "uranium problem"? No, I am not. What makes the uranium projects fantastic are the enormous prospects that will open up if a successful solution to the problem is found. . . . A veritable revolution will occur in military hardware. It may take place without our participation—due simply to the fact that now, as before, the scientific world is governed by sluggishness.
>
> Do you know, Josef Vassarionovich, what main argument has been advanced against uranium? "It would be too good if the problem could be solved. Nature seldom proves favorable to man."

> Perhaps, being at the front, I have lost all perspective. . . . I think we are making a big mistake. . . .

Flerov went on to propose a conference where he might state his case, with Stalin and a jury of ranking physicists present—he asked for Ioffe, V. G. Khlopin, Kapitza, Leipunski, Landau, Kurchatov, Khariton, Zeldovich and others. "I see this as the only means to prove that I am right," he argued, ". . . because other means . . . are simply being passed over in silence. . . . That is the wall of silence which I hope you will help me break through. . . ."

Stalin enjoyed springing traps. "To choose one's victim," he mused once, "to prepare one's plans minutely, to slake an implacable vengeance, and then to go to bed . . . there is nothing sweeter in the world." After he received Flerov's letter and consulted with Kaftanov he called in four of his Academicians—Ioffe, Kapitza, Khlopin and Vladimir I. Vernandski—and berated them, indignant that a young tyro like Flerov had recognized a danger to the country that they had ignored. Golovin says he "asked them bluntly how serious the information he had was concerning the possibility of developing the atom bomb in the next few years. . . . His guests unanimously confirmed the importance of this work."

The expense of building a new industry in the midst of war mobilization worried the Soviet dictator. Two of his advisers predicted that a bomb would cost as much again as the entire war effort. Kaftanov defended the expense:

> I said that of course a degree of risk was involved. We would risk tens, perhaps hundreds of millions of rubles. In the first place, we would have to spend money on science anyway, and investment in a new field of science is always fruitful. But if we did not take the risk, a much greater risk would then emerge: that we might one day face an enemy possessing nuclear weapons while we ourselves were unarmed.

After some hesitation, adds Kaftanov, "Stalin said: 'We should do it.' "

It was then May 1942 and the Wehrmacht was still smashing its way across the western USSR. The possibility that Germany might develop an atomic bomb had strongly influenced the Anglo-American decision to go forward. The possibility that Germany was working on an atomic bomb and the certainty, confirmed by espionage, that England and the United States were, had now catalyzed the Soviet decision as well.

Deciding was one thing. Embodying the decision in difficult research and fantastic, extravagant technology would be quite another. "The Stalingrad victory was far ahead," write Golovin and Russian physicist Yuri Smirnov of the desperate spring and summer of 1942. ". . . Moscow was the front line and nearly depopulated. Anti-aircraft batteries stood on alert, the Kremlin stars had been covered with canvas, barrage balloons guarded the approaches, German and Soviet planes were dogfighting over the city. A curfew began at dusk and the streetlights had been shut off; automobiles found their way with headlights dimmed and narrowed to blue beams. . . . Food and goods were rationed. Many ministries and departments were still in evacuation." On a train ride from Murmansk to Moscow during the first week in June, Alexander Werth observed the results of wartime shortages and German successes:

> Civilians were badly underfed, and many suffered from scurvy; old women especially were tearful and pessimistic, and thought the Germans were terribly strong. . . . Morale among soldiers and officers was rather better. . . . All the same, they were far from underrating the power of the Germans, and in their game of dominoes, they called the double-six "Hitler"—"because it's the most frightening of them all."

As of June 22, official Soviet combat casualties, probably underestimated, totaled 4.5 million; German totals approached 1.6 million. On July 28, Stalin issued his notorious Order No. 227 acknowledging the loss of the Ukraine, Belorussia and the Baltics to the German advance. "We now have fewer people and industrial plants, less bread and metal," Stalin declared. ". . . Any further retreat will be fatal for us and for the Motherland. . . . Not a step backward! At any cost, we must stop the enemy, push him back and defeat him!"

One tried, effective way to save time and expense was industrial espionage. A coded radio message went out from Moscow Center on June 14, 1942, to NKVD *rezidents* in Berlin, London and New York:

> Top secret.
>
> Reportedly the White House has decided to allocate a large sum to a secret atomic bomb development project. Relevant research and development is already in progress in Great Britain and Germany. In view of the above, please take whatever measures you think fit to obtain information on:
>
> —the theoretical and practical aspects of the atomic bomb projects, on the design of the atomic bomb, nuclear fuel components, and the trigger mechanism;
>
> —various methods of uranium isotope separation, with emphasis on the preferable ones;
>
> —transuranium elements, neutron physics, and nuclear physics;
>
> —the likely changes in the future policies of the USA, Britain, and Germany in connection with the development of the atomic bomb;
>
> —which government departments have been made responsible for co-

> ordinating the atomic bomb development efforts, where this work is being done, and under whose leadership.

Morris Cohen was drafted into the US Army in July and left New York for basic training and service in Europe. It took Anatoli Yatzkov two months clandestinely to reestablish contact with Morris's wife Lona, but she agreed to replace her husband as a courier.

Fuchs's arrangements also changed that summer. Traveling to London was awkward in wartime; to deceive Genia Peierls, Fuchs had to fake illnesses and pretend to be visiting a physician. At his third meeting with "Alexander," the Russian proposed a more convenient link. Fuchs would not quite remember if Alexander also told him he was leaving England; in any case the new arrangement would give Fuchs a contact closer to Birmingham.

Fuchs's courier would be a woman this time. Her code name was "Sonia." He knew her as Ruth Kuczynski, the sister of the man whom he had first approached to propose espionage. She was living in Oxford under the name Ruth Brewer with her children and her English husband Len, a fellow spy, clandestinely broadcasting coded espionage information to Moscow using a shortwave radio she had built herself. She was tall, slender and attractive, and at their meetings in Banbury and in the countryside near Birmingham —Fuchs rode out on a bicycle—she offered Fuchs a welcome change from what he would later call the "controlled schizophrenia" of his double life. "It was a great relief for him to have someone he could talk to openly," she told an interviewer many years afterward. "He never met any comrades in Britain with whom he could talk about things." He was, she thought, "a good, decent man." For his part, Fuchs confessed, he had "no hesitation in giving all the information I had."

In Moscow, the search went forward for someone to direct the new project. According to Golovin, Stalin consulted with Beria. Beria suggested Ioffe or Kapitza. Stalin disagreed; they were world-famous scientists, he argued, they were already burdened and their disappearance into secret work would be noticed. "He said that it was necessary to promote a young, not well-known scientist," writes Golovin, "for whom such a post would be . . . his life work." Kaftanov describes a different, or perhaps a complementary, sequence:

> I got the job of finding people, finding a place and organizing the necessary institutions. I began with Ioffe. The most important issue was who would head this extraordinary project. I suggested that he himself should head it. He said that he was already too old (he was then sixty-three), and that we needed a young, energetic scientist. He proposed a choice of two [physicists]: thirty-nine-year-old [Abram] Alikhanov and forty-year-old Kurchatov.

Yuli Khariton's wife Maria Nikolaevna encountered Kurchatov in Kazan that summer. "After the epic events in Sevastopol I saw Kurchatov with a beard. I asked him, 'Igor Vasilievich, what are you doing with that pre-Petrine ornamentation on your face?'* He answered with two lines of a popular song: 'First we're gonna beat back Fritz, then, when there's time, we'll all shave.'... The beard suited that tall and imposing man very well." Bearded Kurchatov traveled to Moscow for consultations. So, presumably, did Alikhanov.

"Alikhanov," Kaftanov explains, "was by that time quite famous. He was already a corresponding member of the Soviet Academy of Sciences and winner of a Stalin Prize. He was known for his discovery of positron-electron pairs and his work in the field of cosmic rays. Kurchatov was less well-known." But Kurchatov, Kaftanov continues, had worked with uranium and with nuclear fission. He had not only participated in this work but directed it. "It was also in his favor that he had joined the Navy, which showed that he was willing to work where he was most needed."

The government chose its man sometime in September 1942. A Kaftanov senior aide, S. A. Balezin, recalls Kurchatov's final interview:

> We invited Kurchatov to Moscow simply to meet him before rejecting his candidacy. But he entered the room and immediately impressed everyone with his modesty and charm: he had a very good smile. He also appeared to be a thorough man. I had shown him translations of the German officer's notebook and he had read them through. I didn't tell him that the decision to restart uranium work had already been made. I only asked him: if such work should start, would he accept the leadership? He became thoughtful for a while, smiled, patted his beard—it was a short one then—and said, "Yes."

Apparently the interview made the difference. "The outcome of any enterprise," says Kaftanov, "is finally determined by competence, energy, organizing skills and devotion to the cause." He offered Kurchatov the job. Kurchatov asked for a day to think it over. "On the next day he came and said, 'If it is necessary, I'm ready. This is a tremendously difficult task. But I hope that the government will help, and of course that you will help too.' "

One other version of how Kurchatov was chosen has surfaced. Molotov, who notes that he "was in charge" of atomic-bomb research, says he picked Kurchatov:

> I had to find a scientist who would be able to create an A-bomb. The [NKVD] gave me a list of names of trustworthy physicists.... I summoned Kapitsa, an Academician. He said we were not ready, that it was a matter

* In the eighteenth century, Peter the Great had made shaving compulsory as part of his program to Europeanize his subjects.—RR

> for the future. We asked Ioffe. He too showed no clear interest. To make a long story short, I was left with the youngest and least-known scientist of the lot, Kurchatov; they had been holding him back. I summoned him, we chatted, and he impressed me.

Kurchatov returned to Kazan and told Alexandrov. "The work on nuclear physics will continue. There's information that the Americans and the Germans are making nuclear weapons." "How is it possible for us to develop a thing like that in wartime?" Alexandrov asked. "They said don't be shy," Kurchatov told him. "Order what you need and begin work immediately."

3

'Material of Immense Value'

VYACHESLAV MOLOTOV—"Stalin's shadow," says Dmitri Volkogonov, "a harsh man"—assumed overall direction of the Soviet atomic bomb program at its inception in autumn 1942. Molotov had earned Lenin's contempt in the early years of the new state for "generating the most shameful bureaucratism and the most stupid." "His leadership style," Yuli Khariton reports, "and correspondingly, its results, were not terribly effective." Born in northwestern Russia in 1890 and one of the few Old Bolsheviks to survive the purges, Molotov was square and dark, with close-cropped curly hair and a strip of black mustache pasted across his upper lip. Like Beria, he affected pince-nez; when he grimaced at Stalin in devotion, baring his teeth, he looked like Teddy Roosevelt, but a Russian poet who had occasion to work with him found him not exuberant but "modest, precise and thrifty," the kind of man who could not pass an empty room without turning off the lights.

If Molotov told Kurchatov not to be shy and to order all he needed, the vice-premier did not yet give the new project carte blanche. The atomic-bomb program in the United States, which the US Army Corps of Engineers was now administering and had code-named the Manhattan Engineer District, was awarded first priority for materials and personnel over any other program of the war. In the Soviet Union, to the contrary, atomic-bomb research began ad hoc, Kurchatov and his colleagues pulling together whatever resources they could find.

The vicissitudes of war partly determined the Soviet program's modest initial priority. Molotov had assigned chemical industry commissar Mikhail Pervukhin to work with Kurchatov and with Sergei Kaftanov of the State Defense Committee. "It was difficult to organize the works to the desired scale," Pervukhin recalls, "because the country was in the heaviest period of the war; the nation's full potential was already mobilized to defeat the enemy." Research institutes had been evacuated to the east, Pervukhin adds;

the cyclotron under construction in Leningrad had to be moved with its big magnet to Moscow; Kurchatov needed time to prepare a feasibility study.

But bureaucratic politics interfered as well. Kurchatov's lack of scientific rank, which Stalin had counted in his favor, worked against him in council. "Our suggestion to the State Defense Committee was to form an institute," says Pervukhin, "but we were told that we should start in a more modest way, with a laboratory, since Kurchatov had been only a laboratory director up to that time. Start with a laboratory, they said, and develop a program of works to be done."

Nor was it easy to corral the necessary organizations and personnel. "There were many difficulties in those years," Pervukhin continues:

> For instance, we had problems drawing institutes into our work. We asked Academician Ilia Iliich Chernyayev of the Institute for Inorganic Chemistry to develop some chemical methods for us, but he refused: "Why should we do it? It's not our work. We have our own job to do." We couldn't agree to that and we got a decision obliging the institute to do the work. Then . . . along came the deputy director of the institute and the secretary of its Party organization, complaining that we were interfering with their scientific programs and ruining the institute's specialization. We had to explain to these comrades that they were wrong.

Bureaucrats similarly resisted aiding the new enterprise. "It was very difficult to negotiate with Ministers," complains Pervukhin. "They said, 'You're taking our people from us when we have our own state plans to fulfill. We won't give our people away!' " Pervukhin had to invoke the State Defense Committee to enforce his requisitions. "Until 1945," Khariton confirms, "this program was carried out by only a few researchers who had scarce resources."

Everyone was preoccupied with the Battle of Stalingrad, which raged through the autumn and early winter. "Stalingrad was the key to the rest of the country still in Russian hands," comments Alexander Werth—"the whole of European Russia east of Moscow, the Urals and Siberia." Blocked in the north at Leningrad, stopped and pushed back before Moscow, the Germans had launched a major summer offensive up through the Crimea and eastward through central Russia southeast of Moscow intended to capture or destroy Stalingrad and then turn south to claim the vital oil areas of the Caucasus at Maikop, Grozny and Baku. Soviet industry had not yet revived sufficiently to supply the Red Army with the equipment it needed to match the German onslaught; "with 1,200 planes in this area of the front," writes a Soviet historian, "the enemy had great superiority in aircraft, as well as in guns and tanks."

On August 23, 1942, a raid of six hundred German bombers on Stalingrad killed forty thousand civilians. The Wehrmacht began a major ground assault on September 13. "Whole columns of tanks and motorized infantry were breaking into the center of the city," writes the commander of one of the defending Soviet armies. "The Nazis were now apparently convinced that the fate of Stalingrad was sealed, and they hurried towards the Volga.... Our soldiers—snipers, anti-tank gunners, artillerymen, lying in wait in houses, cellars and firing-points, could watch the drunken Nazis jumping off the trucks, playing mouth organs, bellowing and dancing on the pavements." Stalingrad with its suburbs and factories, war correspondent Konstantin Simonov wrote back from the front, was one "whole, huge, thirty-seven-mile-long strip along the Volga":

> This city is no longer as we saw it from the Volga steamer [before the war]. It has no white buildings climbing the mountain in a merry throng, no little landing piers on the Volga, no quays with rows of baths, kiosks, and small buildings running along the river. At present this city is smoke-filled and grey and the fire dances about it and the soot whirls day and night. This is a soldier-city, scorched in battle, with strongholds of self-made bastions built from the stones of its heroic ruins....

The Wehrmacht pushed the Soviets back east across the river—the Soviets were able to maintain only about twenty thousand troops on bridgeheads on the west bank—but "the other side of the Volga," says a Red Army lieutenant who fought there, "was a real ant-heap. It was there that all the supply services, the artillery, air force, etc., were concentrated. And it was *they* who made it hell for the Germans." Artillery shells and Katyusha rockets roared over the bridgeheads and smashed into the city. Fighting went on day to day and hand to hand. The Germans began another all-out offensive on October 14 that the Soviet Army commander characterizes as "a battle unequalled in its cruelty and ferocity throughout the whole of the Stalingrad fighting." The Germans wanted to make a hell out of the city, Simonov wrote: "The sky burns overhead, and the earth shudders underfoot." Wehrmacht forces drove their way to within four hundred yards of the Volga, close enough to rake the bridgeheads with machine-gun fire; the Soviets had to build stone walls under fire to protect their positions.

In November, the Red Army was able at last to mount a great counteroffensive. Forces from the Don and Northwest Fronts pushed down from the north while Stalingrad Front armies pushed up from the south; in four days they sealed off the Germans in what they named a "cauldron." It was cold by then and it got bitterly colder in December, as much as forty degrees below zero. Until too late the German high command had withheld winter clothing from its armies in Stalingrad, afraid the realization that they would have to fight through the winter would damage the soldiers' morale. A Luftwaffe attempt to airlift supplies foundered on bad weather and poor organization. But the starving Germans refused to surrender and in January 1943 Soviet forces liquidated the cauldron, barraging the ruined city from seven thousand mortars and guns, bombing, crashing in with tanks and infantry. They had encircled 330,000 men; they took fewer than 100,000 prisoners. They stacked up the frozen German bodies like cordwood. "Funny blokes," a boy told Werth. ". . . Coming to conquer Stalingrad, wearing patent-leather shoes." Werth heard that children in a nearby village were using one dead German for a sled.

One night after the liquidation of the cauldron, when it was minus forty-four degrees, Werth drove shivering toward Stalingrad in a van full of journalists through the victorious armies:

> All the forces in Stalingrad were now being moved. . . . About midnight we got stuck in a traffic jam. And what a spectacle that road presented. . . . [There were] lorries, and horse sleighs and guns, and covered wagons, and even camels pulling sleighs. . . . Thousands of soldiers were . . . walking in large irregular crowds, to the west, through this cold deadly night. But they were cheerful and strangely happy, and they kept shouting about Stalingrad and the job they had done. . . . In their *valenki* [wool felt boots], and padded jackets, and fur caps with the earflaps hanging down, carrying tommy-guns, with watering eyes, and hoarfrost on their lips, they were going west. How much better it felt than going east!

Stalingrad was the turn of the tide.

Moving and other preliminaries kept Kurchatov busy until early 1943; in January the Navy even ordered him to Murmansk to work on German mines. The State Defense Committee (GKO) officially awarded him authority over the uranium project on February 11, 1943. "At that time it required special permission from the GKO to enter Moscow," Kaftanov recalls. "We obtained permission for approximately a hundred people and a respective number of apartments and began inviting the chosen specialists."

Working out of a room at the Moscow Hotel, on Marx Prospekt within sight of the Kremlin, Kurchatov assembled a core team of talents to prepare a feasibility study: theoretical physicists Georgi Flerov, Yuli Khariton and Yakov Zeldovich, experimentalists Isaak Konstantinovich Kikoin and Abram Alikhanov. Kikoin was a specialist in diffusion processes; Alikhanov, the young Academician and cosmic-ray expert, had competed with Kurchatov to head the project. Golovin:

> In no hurry to expand his staff, [Kurchatov] tried to determine the main lines of attack and clearly formulate the scientific and engineering task ahead. He made numerous estimates and gave more detailed consideration to the possible ways of achieving a uranium fission chain reaction, carefully discussing them all. The group soon decided to build a [nuclear reactor] powered by [slow] neutron fission and simultaneously to work out means for separating large quantities of uranium isotopes. . . . Kurchatov did not settle for half measures but at once boldly got started on estimates for a uranium bomb whose explosive power would come from fast-neutron fission, though he did not yet have so much as a microgram of pure U-235 and though neither he nor the other members of the group had an inkling as to the possibility of producing . . . plutonium. . . .

At the beginning of 1943, that is, Igor Kurchatov and his colleagues in the Soviet Union were planning to build a nuclear reactor to prove that a chain reaction was possible in uranium and then to build a uranium bomb using U235 separated laboriously from natural uranium by physical means.

That would be a long, slow, expensive route to a bomb, one that Kurchatov certainly would not have chosen if he had known any shorter, faster and cheaper approach. The Soviet Union had only limited known reserves of uranium ore. It had only a few kilograms of heavy water and no facilities for making more, but a reactor moderated with heavy water would require several tons. It lacked the technology to make large quantities of pure graphite, an alternative to heavy water. It lacked the technology to make uranium metal or uranium hexafluoride. U235 had not yet been separated from U238 in the Soviet Union even at laboratory scale, and separating enough U235 for a bomb—tens of kilograms—would require developing a vast new industrial plant based on one or more new and difficult technologies. The gun bomb that Flerov had proposed and that Kurchatov had in mind would be prodigal of material, requiring several critical masses of U235 in its design.

The Soviet scientists had not yet appreciated that a reactor would transmute a portion of its larger inventory of U238 into a new man-made element heavier and less stable than uranium. Early in 1941, a team of American scientists at Berkeley led by radiochemist Glenn T. Seaborg had transmuted the first millionth of a gram of the new element in the big sixty-inch Berkeley cyclotron; the team had isolated the first sample on March 28, but the discovery was classified and would not be announced until after the war. In 1942, Seaborg had named the new element plutonium. By then, the Americans had determined what the Soviets did not yet know: that plutonium was even more fissionable than U235, with a fission cross section for fast neutrons 3.4 times as large as natural uranium. Since it could be separated chemically from the matrix of natural uranium in which it was bred, and since chemical separation was a far less difficult and therefore less costly process than physical separation, plutonium would probably be a shortcut to a bomb. So the leaders of the American program had come to believe. As a result, the Manhattan Project was now gearing up to breed plutonium in graphite and heavy-water reactors as well as to separate U235 using gaseous diffusion, thermal diffusion and electromagnetic means. A new secret laboratory that would open its doors on a mesa in the northern New Mexico wilderness in April 1943 would begin developing gun designs for both uranium and plutonium.

With its high priority and unlimited resources, the American program could afford to hedge its bets. At that early point in any case it would be prudent to explore alternatives, as Kurchatov also understood—when Ukrainian physicist Anatoli Petrovich Alexandrov asked him why he wanted thermal diffusion explored when there were better methods and it wouldn't be used, Kurchatov shot back, "The Devil knows what will be used. We have to try this way just in case." But given a choice, a country with fewer resources might do better to give priority to plutonium. As of early 1943, Igor Kurchatov was evidently not aware of the existence of such a choice.

Then he saw the accumulated NKVD espionage. "He said he still had a lot to clear up," Molotov remembers. "I decided then to provide him with our intelligence data. Our intelligence agents had done very important work. Kurchatov spent several days in my Kremlin office looking through this data. . . . I asked him, 'So what do you think of this?' I myself understood none of it, but I knew the material had come from good, reliable sources. He said, 'The materials are magnificent. They add exactly what we have been missing.' "

On March 7, 1943, Kurchatov finished drafting a fourteen-page review for Mikhail Pervukhin of the documents and transmissions that Moscow Center had collected. He only refers to British material—most of it probably passed by Klaus Fuchs—which almost certainly means that no American technical information had yet come in. But the British knew enough, and Kurchatov learned enough, to transform the Soviet program.

"Having reviewed the material," Kurchatov began directly, "I came to the conclusion that it is of immense value for our science and our country. Its value cannot be overestimated."

The material "shows what serious and intensive research and development work on the uranium problem has been undertaken in England," Kurchatov explained. It also, he wrote, "provides some quite important reference points for our research, informing us of new scientific and technical approaches and enabling us to skip labor-intensive phases of development."

Kurchatov judged at that point that the most valuable information in the espionage material dealt with isotope separation. The Anglo-American preference for gaseous diffusion as a means of separating U235 from U238 was