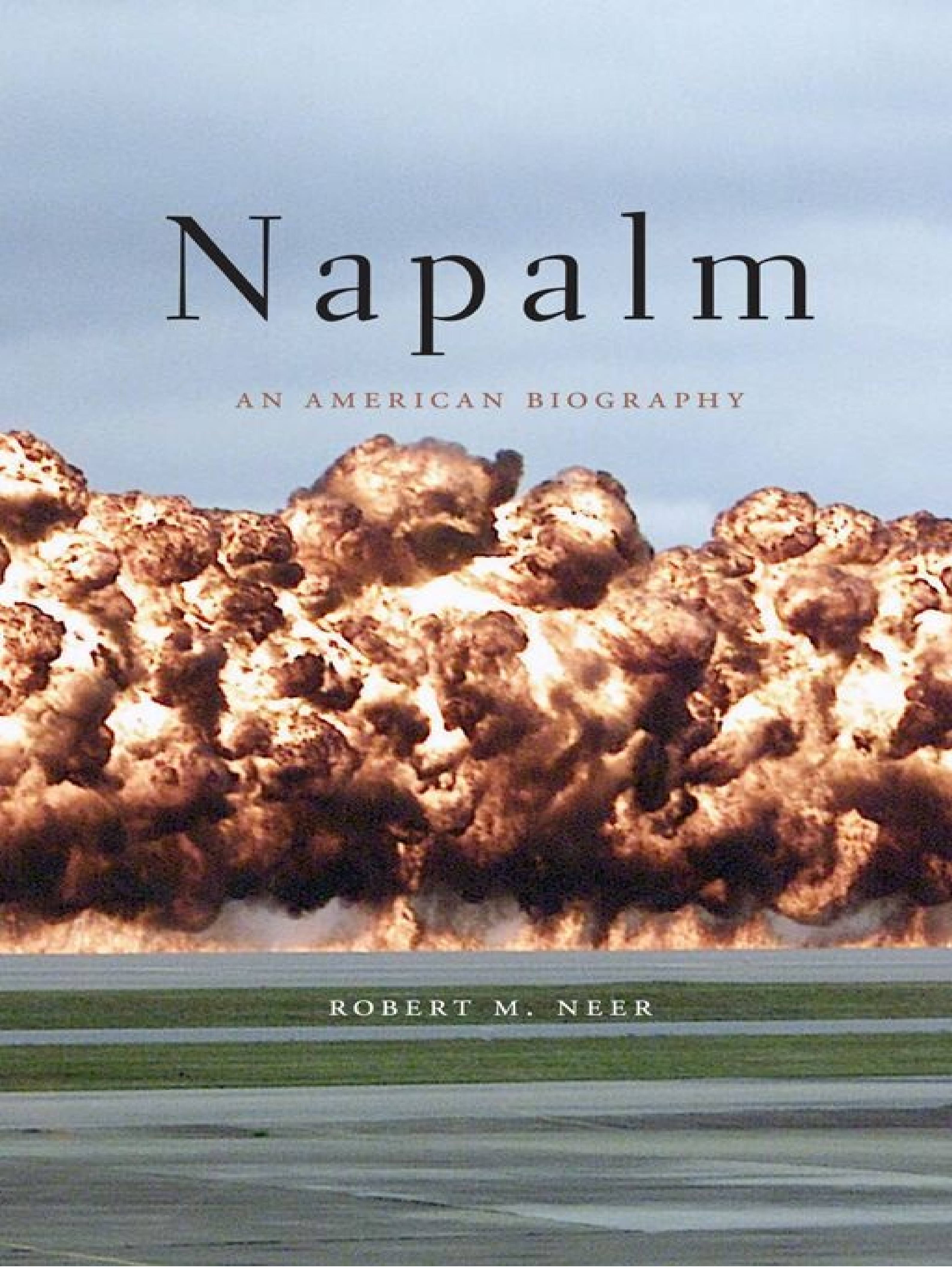

Napalm

AN AMERICAN BIOGRAPHY

ROBERT M. NEER

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For my father, a healer

Contents

Prologue

Trang Bang Village, South Vietnam, June 8, 1972

Trang Bang, thirty miles northwest of Saigon, shuddered under artillery shells on the morning of Ju 8, 1972. It was the third day of a fierce battle between Viet Cong and North Vietnamese arm infiltrators, who had seized the town, and South Vietnamese army units that had surrounded the Rotors thumped. Propellers roared. Machine guns echoed in the streets. Smoke filled the air. Phan T Kim Phúc, nine years old, huddled with her mother and father, aunts, young brothers, cousins, a neighbors, about thirty villagers in all, in two outbuildings at a temple complex on the edge of town. group of eight to ten South Vietnamese soldiers sheltered with them. Chips of masonry from near buildings rattled on their roof and clattered across the courtyard. On several occasions, napalm bom filled the air outside with flames, and turned the insides of the buildings red. “Fire is falling fro heaven!” the refugees lamented. A concertina wire roadblock on Route 1, the main national highw between Saigon and Cambodia which passed a few hundred yards to the south, had created a va traffic jam. Journalists watched from just in front of the wire. A boy sold ice cones.[1]

Kim Phúc’s family had fled to the temple three nights earlier, when Viet Cong soldiers took ov their home and began to dig tunnels under their living room. Further retreat was impossible. S pulled her favorite cousin, a chubby three-year-old named Danh, close to her. A light rain began lunch time.

"The Terror of War." Nine-year-old Phan Thị Kim Phúc, stripped by flames and still burning with napalm, runs from her village followed by South Vietnamese soldiers on June 8, 1972. *AP Photo/Nick Ut*

At around 1:00 p.m. the rain cleared and a spotter airplane that had been circling the town droppe low and blasted two phosphorus rockets into an area behind the temple. White smoke rose to mark suspected Viet Cong position. South Vietnamese troops near the front gate of the complex ran into th courtyard and tossed colored smoke grenades to indicate their own position. About 150 yar separated the two zones.

Suddenly, the soldiers decided an unreliable pilot might mark the temple outbuildings as a targe "Get out! Everybody get out! They are going to destroy everything!" they screamed. Kim Phúc father and mother prepared the children for a dash to the roadblock. Slowest left first: Kim Phúc grandmother, her aunt and nine-month-old baby, and the aunt's two other children, including Danh Children next: Kim Phúc and two of her brothers. Finally, the oldest siblings. "Run! Run fast, or yo will die!" yelled the soldiers, who were themselves in motion. A woman grabbed a child frozen wit fear. Sprinters made a rough line from the outbuildings, across the courtyard, through the gate, an onto Route 1.[2]

A slow-moving American-made South Vietnamese air force Skyraider propeller airplane appeare It was badly off course and far from the white smoke. Nonetheless, it dropped its bombs. They we duds. A second plane appeared, even more off course. It too released its payload. A quartet of silve canisters filled with napalm jelly tumbled in silence toward the ground, then hit with unbelievab suddenness and vicious "pops." Giant welts of flame, speckled with brilliant phosphorus flares, an coils of thick white and black smoke covered the highway between temple and roadblock. A brut wave of heat that felt like a giant had opened a furnace door swept over the journalists. A few secon later, small figures began to appear from the smoke.[3]

Flames enveloped Kim Phúc. Biographer Denise Chong described what happened next: "Her fir memory of the engulfing fires was the sight of flames licking her left arm, where there was an ug brownish-black glob. She tried to brush it off, only to scream out at the pain of the burn that had no spread to the inside of her other hand." Napalm had caught her as she ran, and splattered over th upper left side of her body. It carbonized her pony tail, and seared her neck, back, and left arm. Chon continued, "[A] tremendous fatigue and weariness overtook her, and as an intense heat seemed to e her from the inside out, she felt desperately thirsty." She screamed into the smoke: "Oh, Ma, it's to hot, too hot!' "[4]

Associated Press photographer Huynh Cong "Nick" Ut clicked off frame after frame as injure terrified children ran to the checkpoint. Then he ran to help. Kim Phúc was burned naked. Chon wrote, "Her body radiated heat, and chunks of pink and black flesh were peeling off." Indeed, her sk was still burning in places. Soldiers and reporters gave her water to drink and poured more on h wounds. Tragically, the fluid reacted with the napalm and phosphorus on her skin, and injured the gi further. About one third of her body was seared raw: her back, continuing to her chest on her left sid the back of her neck into her hairline, and her left arm. Deep burns from jellied splashes cut into h right arm, buttocks, and stomach. Her right palm was an open wound from where she had smeared with burning gel. Ut loaded Kim Phúc and her aunt, also scorched, into his van and drove them to hospital in the nearby town of Cu Chi. "Please, help them," he said to the nurse, then continued

Saigon to deliver his film. Kim Phúc’s photograph, titled “The Terror of War,” appeared i newspapers around the world the next day, won Ut a Pulitzer Prize for best spot news photograph c the year, and has passed into legend as an iconic image of the twentieth century.[5]

Napalm was born a hero but lives a pariah. Its invention is a chronicle of scientific discovery as old Yankee ingenuity and as modern as the military-academic complex. Its history illuminates America story, from victory in World War II, through defeat in Vietnam, to its current position in a globalizin world.

HERO

America's first Independence Day of World War II, July 4, 1942, was idyllic at Harvard University On campus tennis courts nestled between the college soccer field's verdant green and the golden dom of the Business School library, players in whites gathered for morning games. They volleyed a university maintenance workers armed with shovels arrived, cut into the field, and built a circul parapet a foot tall and sixty yards in diameter. Fire trucks from the City of Cambridge rumbled u and men flooded the circle to make a wide pool four to nine inches deep. Revelations 22.2—"On eac side of the river stood the tree of life.… And the leaves of the tree are for the healing of the nations"- bore mute witness from a plaque on a nearby bridge across the Charles River. By mid-morning, a was ready for the arrival of Sheldon Emery Professor of Organic Chemistry Louis Fieser, one of th university's most brilliant scholars and head of "Anonymous Research Project No. 4," a top secret w research collaboration between the school and the government.[1]

Fieser arrived. He was forty-three-years-old, tall, bald, with traces of the Williams College varsi football lineman he once was still present in his bearing. An octet of assistants followed. He equippe four of the young men with boots, buckets, long sticks, and gloves, and positioned them around th pool. With assistance from the others, he gingerly lugged a live seventy-pound napalm bomb, bolte nose down on a metal stand, to the center of the lagoon. A wire ran to a control box on dry groun Firemen and groundskeepers looked on. Players fifty feet away traded forehands.[2]

Fieser flipped a switch. High explosives blasted incendiary white phosphorus into forty-five poun of jellied gasoline. A spectacular, billowing 2,100-degree-Farenheit fire cloud rose over the fiel Lumps of searing, flaming napalm splashed into the water. Oily smoke filled the air. Assistan plunged into the muck, splashed water on burning blobs, and used their sticks to submerge an extinguish larger gobbets. They noted the location and size of chunks, and scooped salvageable jel into buckets for weighing. Tennis players scattered.[3]

World War II was just seven months old for the United States: close, and far away. *Boston Glob* newspaper headlines that day announced desperate battles at El Alamein in Egypt and Sevastopol the Crimea, an end to automobile and bicycle racing to conserve rubber, revised sugar rations, and th start of death penalty hearings for German saboteurs arrested on Long Island. Li'l Abner, in th comics section, explained what the struggle was about: "A world where a fella and his gal can look u at the moon just for the foolishness of it, and not because there may be planes up there coming to bla 'em both off the earth, a world where a fella is free to be as wise or as foolish as he pleases, bu mainly, a world where a fella is free! That world has disappeared, until we win this war."[4]

It had not completely disappeared. At 10:00 a.m. that morning a crowd gathered at Boston's Ci Hall, raised the Stars and Stripes, paraded to the Old Granary Burial Ground on Tremont Street, s flowers at the tombstones of John Hancock and Samuel Adams, and continued to the Old State Hous On a tiny colonial balcony flanked by wood carvings of England's lion and unicorn, an orator read th Declaration of Independence, just as at the same spot in 1776.[5]

Professor Fieser's firestorm was over in seconds. Hunks of gel hissed, flickered, and died. pungent aroma of phosphorus, like garlic or burning matches, mixed with the oily smell of gasolin hung in the air over the flooded field and empty tennis courts.[6] Napalm bombs had arrived in th world.

1

Harvard’s Genius

Harvard’s soccer-field test was one of the first progeny of the “military-academic” and “militar industrial” unions between academia, business, and the armed forces created after 1940 by th National Defense Research Committee (NDRC). Vannevar Bush, cofounder of armaments gian Raytheon and a Massachusetts Institute of Technology (MIT) electrical engineer, conceived th system. President Franklin D. Roosevelt established it on June 27, 1940, with a budget of about $10 million. In addition to napalm, the committee supervised creation of the atomic bomb, radar, sona proximity fuses, bazookas, amphibious landing craft, and some 200 other projects. By the war’s en five years later, Bush managed tens of thousands of scientists with practically unlimited funding.[1]

The “General of Physics,” as *Time* magazine called him in an April 1944 cover story, was tall an thin, with a wry smile, close-cropped hair, and round rimless glasses. He was born in 1890 in Everet Massachusetts, then as now a working-class town, and graduated from Tufts College in Medford 1913. After he lost his job as a test engineer at General Electric—a fire shut down the facility whe he worked—he taught elementary mathematics to women “not in the slightest degree interested,” an a “somewhat absurd” physics course for premedical students, then enrolled in 1915 in a joint Harvar MIT chemistry PhD program. He got married in 1916 and, under financial pressure, wrote his thesis one year and received his PhD in 1917. During World War I, he worked with the National Researc Council—a branch of the National Academy of Sciences and National Academy of Engineerin established in 1916 to coordinate war research—to develop a magnetic submarine detector. Bush group built a working device but bureaucratic mismanagement, in his estimation, prevented it fro being used. “That experience forced into my mind pretty solidly the complete lack of proper liaiso between the military and the civilian in the development of weapons in time of war, and what that lac meant,” he wrote later. He taught at MIT after the war, made important breakthroughs related to th development of analog computers, and rose to become vice president of the institute from 1932–193 a position roughly equivalent to chief operating officer. In 1939, he turned down an offer to be MIT president to lead the Carnegie Institution of Washington, a research institute that made grants fo basic scientific research.[2]

Adolf Hitler invaded Poland on September 1, 1939, and by mid-June 1940 German armies stoo triumphant across an arc that stretched from northern France to the Soviet frontier. Bush gathered ke leaders of the U.S. scientific research establishment, each of whom he had previously met individual or in small groups, for a collective lunch: Frank Jewett, newly elected president of the Nation Academy of Sciences and founding president of Bell Telephone Laboratories; James Bryant Conant, chemist and president of Harvard University; Karl Compton, a physicist and president of MIT; an

Richard Tolman, a physicist and professor at the California Institute of Technology. “We wer agreed,” he wrote, that America was sure to be drawn into the war, “that it would be a highly technic struggle, that we were by no means prepared in this regard, and finally and most importantly, that th military system as it existed … would never fully produce the new instrumentalities which we wou certainly need.” Universities, Bush believed, had to be integrated into the war effort. A coordinatin committee was required.[3]

Bush brought this idea to Secretary of Commerce Harry Hopkins, who was one of Roosevelt closest advisors and outspoken in his opposition to the Nazis. Hopkins was the fourth of five childre of a peripatetic Grinnell, Iowa, harness store owner and his devoutly Methodist wife. He graduated 1912 from Grinnell College. Mindful, perhaps, of town and college namesake Josiah Grinnell adjuration to community service, Hopkins spent the early part of his career working in New York Cit for social welfare organizations including the Board of Child Welfare and the Tuberculos Association. Later, he served the American Red Cross in New Orleans and Atlanta. In 1921, back i New York, he helped establish the American Association of Social Workers, and was elected it president in 1923. Hopkins came to the attention of Governor Franklin Roosevelt in 1931, when l directed New York’s Temporary Emergency Relief Administration for unemployed workers. Afte FDR was elected president, the social worker rose through New Deal bureaucracies to head the Work Progress Administration, the nation’s largest employer. Roosevelt appointed him secretary c commerce in 1938. He was sworn in on Christmas Eve.[4]

Hopkins immediately understood Bush’s proposal for a military-academic partnership. “We foun that we spoke the same language,” the Carnegie Institute’s director wrote. On June 12, 1940, th secretary arranged for Bush to meet Roosevelt. Britain’s desperate evacuation of its army fro Dunkirk was just eight days in the past. Italy declared war on France and Britain, and Norway’s la division surrendered to the Wehrmacht two days before the meeting. The NDRC plan was in fou paragraphs on a single sheet. “The whole audience lasted less than ten minutes (Harry had no dou been there before me). I came out with my ‘OK-F.D.R.’ and all the wheels began to turn,” Bus recalled.[5]

His remit was open-ended. “The Committee shall correlate and support scientific research on th mechanisms and devices of warfare … and may conduct research for the creation and improvement instrumentalities, methods, and materials of warfare,” read its establishing order. Ostensibly, the boc reported to the Council of National Defense, an assembly created for a similar purpose in August 191 and composed of the secretaries of war, navy, interior, agriculture, commerce, and labor. Thi designation made it part of the Executive Office of the President, which funded it. In practice, sinc the council’s work had ended after World War I and few knew of its continued existence, the grou reported directly to Roosevelt.[6]

“There were those who protested that the action of setting up N.D.R.C. was an end run, a grab b which a small company of scientists and engineers, acting outside established channels, got hold the authority and money for the program of developing new weapons. That, in fact, is exactly what was,” Bush wrote.[7]

The founder chose executives in his own image. Conant, from Harvard, got responsibility f “Division B,” in charge of bombs, fuels, gases, and chemical problems; Compton, from MIT, f detection, controls and instruments; and Tolman, from CalTech, for arms and ordnance. They serve as volunteers, like Bush, and kept their existing jobs. Lyman J. Briggs, director of the National Burea of Standards, added his Uranium Committee, which supervised atomic research, to the ne organization. Bush eased him out of power over the following year, in favor of Conant, whom h thought was more competent, as the significance of this area became apparent. Additional committe members joined *ex officio:* Jewett from the National Academy; the commissioner of patents; the hea of the Committee on Scientific Aids to Learning; and representatives from the army and navy.[8]

Perhaps the most extraordinary feature of the new committee was the way it planned to do its wor Rather than rely on government laboratories staffed by uniformed members of the military, or gran to individual researchers, as had been the practice for military research, the NDRC planned to contra its work to universities and private industry on a cost-plus basis. Bush conceived the ne administrative structure. “We proposed to contract with the university itself, thus placing on it th responsibility for all such [business] matters, and also giving it the authority necessary for prop performance. In return we proposed to pay its overhead costs,” he wrote. Harvard’s president Cona explained the consequences: “Creation of the committee marked the beginning of a revolution . [and] has had a transforming effect on the relationship of the university to the federal government.. The essence of the revolution was the shift in 1940 from expanding research in governme laboratories to private enterprise and the use of federal money to support work in universities ar scientific institutes through contractual arrangements.”[9]

Academic facilities were extensive and researchers did not require civil service certification, whic allowed for fewer administrative restrictions and greater speed. University administrators respond with enthusiasm to the new structure, which allowed faculty members to work on military projects their spare time and, in some cases, permitted students to submit NDRC projects as theses f advanced degrees. Private industry, the committee found, was less interested in cooperation in 194 when budgets were tight, than after 1941 when funds flowed more freely. Nonetheless, man companies did important work even in the early days of the NDRC.[10]

Disbursements followed the institutional affiliations of committee leaders. In its first year, fort one schools received 155 NDRC contracts. MIT led with twenty, followed by Harvard with thirte and the University of California and Princeton with ten each. CalTech and the Carnegie Institute eac received eight contracts. Division D, managed by Jewett at MIT, which was responsible for rad among other projects, received just over half of all funds: about $50 million in today’s dolla Division B under Conant was next with about $17 million. A total of twenty-two private businesse received fifty-two contracts. Uranium Committee projects got just $2.8 million in the first year.[11]

Conant leapt into action. Harvard’s president was nothing if not ambitious. When he was twent seven, he told his wife that his life goals were to be the premier organic chemist in the United State president of Harvard, and a cabinet member. He was born in Dorchester, Massachusetts, in 189 graduated from Harvard College in 1914 after three years of study, completed the work for his Ph with a dual concentration in organic and electrochemistry in 1916, and received his doctorate in 191 A foray with two friends into chemical manufacturing was unsuccessful: Conant and one of h partners started a fire that burned down the small building they had rented in Queens; a separa explosion later killed a third partner, and another man. In World War I, he led an army Chemica

Warfare Service (CWS) research team that researched Lewisite, the “Dew of Death” poison gas, the returned to Harvard in 1919 as an assistant professor of chemistry. With respect to gas warfare, h wrote later, it was unclear “why tearing a man’s guts out by a high-explosive shell is to be preferred t maiming him by attacking his lungs or skin.” As to civilian casualties, they were “not only a necessa consequence of bombing, but one might almost say an objective of the fleets of bombers directed b the British, the Germans and the Russians, as well as by the Americans.” This prodigy was appointe president of Harvard in 1933 at age forty and supervised sweeping reforms, from the use standardized aptitude tests and an embrace of admissions based on merit rather than social standin to modernization of the undergraduate curriculum away from Greek and Roman classics and towa the sciences.[12]

True to his penchant for fast action, by June 18, 1940—six days after Roosevelt’s OK of the NDRC and four days after his own appointment was made official—Conant recruited Roger Adams, chair o the Chemistry Department at the University of Illinois at Urbana-Champaign, and MIT profess Warren K. Lewis as vice chairmen of Division B. Adams was a fellow Bostonian, descendant o President John Adams, and a Harvard chemistry PhD and former professor at the university (his mov to Illinois created the vacancy that Fieser filled). France capitulated one week later, and the Battle o Britain began two weeks after that.[13]

Conant and his colleagues spent the summer and early fall of 1940 recruiting chemists for the ne organization. It was not easy. “Apparently there were very few chemists indeed in this country havin a knowledge of military explosives, which is quite a different subject than commercial explosive Hence it has been necessary for organic chemists to learn a somewhat new art,” the NDRC explaine in its first annual report. By mid-October, they had located enough to start. The Tripartite Pa launched the Axis alliance of Germany, Italy, and Japan at the end of September, and the United Stat began the first peacetime draft in its history in the second week of October. On October 23, Fieser an about twenty other top chemists gathered in Adams’s Illinois living room to begin the work o Division B.[14]

Conant laid out the program. He described the NDRC, summarized its innovative contractin system, outlined the War Department’s most pressing technical problems, and explained how eac researcher might help. Enthusiasm ran high. Fieser agreed to synthesize new compounds f evaluation as possible explosives.[15]

Harvard assigned him two secret rooms in the basement of the Converse Chemistry Laboratory 12 Oxford Street in Cambridge (off Divinity Avenue and within musket range of Memorial Hall, bui to honor university graduates who fought for the Union in the Civil War). A quartet of his graduat students, all in their early twenties, joined the forty-one-year-old professor as assistants. By the sprin of 1941, they had developed two new compounds more powerful than TNT.[16]

Louis Fieser was born on April 7, 1899, in Columbus, Ohio. His father was an engineer who trace his lineage to a village outside Heidelberg in Germany; his grandfather, a banker and one-time head o the Columbus school system, owned and published the first German-language newspaper in Ohi Louis attended the public East High School and adopted two mottos there which, he wrote forty-tw years later, summarized his life philosophy: *omnia possum* (anything is possible) and *labor omn vincit* (work conquers all). This ambitious, industrious student graduated in 1916 and headed east

Williams College in northwestern Massachusetts. He lettered in football, basketball, and track, and his senior year was a lineman on the unbeaten 1919 varsity football team. In 1920, he collected h college diploma and continued east to study chemistry at Harvard. His instructors included youn professor James Conant. In 1922, the two published a collaborative paper. Fieser received his PhD fo research on a related subject two years later. His eastern educational trajectory concluded with postdoctoral year at Frankfurt and Oxford.[17]

Fieser began his career as an assistant professor of chemistry at Bryn Mawr College for women 1925. "Girls can be very satisfactory students, or even superior ones; they also can have other qualiti appealing to a 26-year-old male instructor. I fell in love with a member of my second class at Bry Mawr," he wrote. He published some twenty academic papers during his years in Pennsylvania. 1930, Harvard, where Conant was then a full professor, offered Fieser a position as an assista professor. Mary Peters, his former student, enamored of both professor and profession, followed an enrolled in the university's chemistry PhD program. They were married in 1932. Peters, however, wa stifled by the sexism of the Harvard department—she was not allowed in the laboratory with ma students and forced to conduct her research, without supervision, in the deserted basement of separate building—and left the program after she received her MA degree in 1936. She went to wor as an assistant to her husband.[18]

At Harvard, Fieser concentrated on vitamin K, and developed a new interest in carcinogens. In th mid-1930s, with Mary's help, he published the first of a series of influential textbooks. In 1937, h became a full professor. In 1939, he was appointed to the prestigious Sheldon Emery Professorshi announced the first successful synthesis of vitamin K—a procedure that had important medic implications because of the role the vitamin plays in blood clotting—and received an honorary degre from his alma mater Williams. Fieser ultimately authored 341 research papers, including forty writte as a sole author and thirty-six that he wrote with his wife, and thirteen books, many also written wi his wife, of which five went through three editions. He was elected to the National Academy Sciences in 1940. Many thousands of students took his classes during his almost four decades Harvard.[19]

Fieser presented his work on explosives at an NDRC conference in Chicago on May 28. He the listened, intrigued, as Conant described a mysterious series of explosions at a DuPont paint factor Workers there produced divinylacetylene, a liquid that could be mixed with paint pigment and whic set to a tough, adhesive, protective film when exposed to air. Mishaps at the plant implied that th material was explosive and, since oxygen was excluded from the manufacturing process, perhap spontaneously combustible. Military possibilities seemed obvious. Conant asked for an investigato Fieser volunteered his laboratory for the task. He had just the man for the job.[20]

Emanuel Benjamin Hershberg drew his first breath on July 28, 1908, in Lynn, Massachusetts, nor of Boston. His father was a shoemaker who later owned a tobacco shop on the Boston waterfront. B., as he came to be known, was a master of invention with a Da Vinci-esque range of mechanic ability: "A masterful experimentalist in organic chemistry, he was also versed in engineering, mechanical drawing, in carpentry, in machining, in glass blowing, and in photography, and he ha invented and constructed a number of laboratory devices which later found wide use, for example, th Hershberg stirrer, the Hershberg stirring motor, the Hershberg melting-pot apparatus," Fieser wrot He received a degree in chemical engineering from MIT in 1929, and his PhD in chemistry from th institute in 1933, spent a year studying in Germany on a traveling fellowship, and joined Fieser laboratory in 1934 in the depths of the depression.[21]

Fieser put E. B., who was also an Army Chemical Warfare Service reserve officer, to work in th Converse basement. He then traveled to DuPont headquarters in Wilmington, Delaware, where pai chemists briefed him on the explosions and their manufacturing processes. In Cambridge, the tw researchers produced successive batches of divinylacetylene and exposed the liquid to air in pa placed in the window wells of their laboratory, shielded from wind and passersby. They watched as th material transformed into a gel that increased in viscosity over time. The experimenters poked at th pans with sticks, and dropped stones on them to try to produce an explosion or fire, but witho encouraging results.[22]

Because they couldn't get the gels to explode or burn on their own, the scientists did it themselve "At day's end we usually destroyed the gels … by setting fire to them with a match.… [T]hey burne with an impressive sputter and sparkle," Fieser wrote.[23]

This produced the crucial insight that led to napalm. Hershberg attributed their success to h mentor's inspiration. Fieser wrote that the men had the idea together. "We noticed also that when viscous gel burns it does not become fluid, but retains its viscous, sticky consistency," Fieser wrot "The experience suggested the idea of a bomb that would scatter large burning gobs of sticky gel."[24]

Hershberg made some improvised bombs from tin cans filled with divinylacetylene gel packe around gunpowder and the chemists tried them out in a remote section of Everett, "City of Prid Progress and Possibilities," just up the Mystic River from Boston. Results were promising: the stick gel ignited "with a sputtering, vicious-looking flame," Fieser remembered. "[T]hese probably were th first experiments on gelled fuels in this country," he wrote. As his colleague from the Harva Chemistry Department Robert Woodward later observed of Fieser's scientific philosophy, "Louis, th prototypical man of action, was impatient of sustained abstract thought. Facing any problem opportunity, his instinct was to dash into the laboratory, there to search for new facts, solidly base upon indefatigable experimentation—and Louis was par excellence a man to act without hesitation his always superbly robust instincts."[25]

Napalm is a devastating weapon because it is sticky and burns at an extremely high temperature. Fi in chemical terms, is the process of combustion, a complex and largely invisible sequence of even that occurs when molecules of oxygen combine with others. This releases heat and light in a directions. The most intense radiation takes place into whatever material the combustion occurs upo (which makes sticky incendiaries especially effective since they are in direct contact with whatev they burn), then upward, and finally, to the sides. Fire on a matchstick, for example, is hottest whe the stick is burning, then above and to the sides of the flame, and finally below it. Molecules abso radiated energy until they reach the temperature of the transmitting body or combust themselve whichever comes first. If enough energy is released, visible flames appear and the material is said burn. This process was first explained by the eighteenth-century French scientist Antoine-Laurent de Lavoisier who, as a result, is considered the founder of modern chemistry.[26]

Hotter things are more likely to combust. Molecules become agitated when heated, which causes a greater number to come into contact with the surface of the material they comprise and, in turn, heightens the probability they will combine with oxygen. As a general rule, an increase in temperature of eighteen degrees Fahrenheit doubles the chance of combustion. Coal, for example, will burn twice as fast at eighty-six degrees as at sixty-eight degrees—and 500,000 times faster at 400 degrees. To start a fire, place an incendiary in direct contact with whatever is to be burned—or below or next to it, in descending order of preference—and ensure there is plenty of oxygen. Thus, the best incendiaries ignite easily, burn hot, and stay close to their targets.[27]

A fearsome weapon results from this process. People and other animals dread fire, so it can induce panic: the flames of hell and fire-breathing monsters are common terrors. Almost everyone has experienced burns, so the pain of being burned to death is easy to imagine compared with less common injuries like a bullet wound. Most importantly, fire uses the energy contained in things themselves to destroy them. Larger targets mean greater potential devastation. Chicago's Great Fire of 1871 is illustrative: a conflagration that leveled much of a metropolis of approximately 324,000 people started, allegedly, when Mrs. Catherine O'Leary's cow knocked over a lamp. As Geoffrey Chaucer wrote with reference to ancient liquid incendiaries called "wildfire" in *The Canterbury Tales*, "Thou lykenest wommanes love … to wilde fyr/ The more it brenneth, the more it hath desyr." As a 1961 U.S. Air Force Air University textbook explained to Reserve Officer Training Corps students, in World War II "large targets (as an entire city) suffered more damage per ton of [incendiary] bombs than small targets, because fires had more opportunity to spread widely." Explosives, by contrast, carry all of their energy within themselves and seldom cause damage beyond the immediate area of impact. Nuclear weapons combine elements of both types of munitions but, arguably, inflict their greatest damage through heat. Explosives damage, fire annihilates: a shattered structure can perhaps be repaired, but an incinerated facility, its contents vaporized, melted, warped, or reduced to ash, is ruined.[28]

A few early examples give a sense of the antiquity and flexibility of this weapon. In 1400–1000 BC the biblical hero Samson, angered to find that his father-in-law had given away his wife, "went and caught three hundred foxes, and took firebrands, and turned tail to tail, and put a firebrand in the midst between two tails. And when he had set the brands on fire, he let them go into the standing corn of the Philistines, and burnt up both the shocks, and also the standing corn, with the vineyards and olives" (the Philistines responded by burning Samson's wife and father-in-law alive). Ninth-century BC Assyrian reliefs show combatants fighting with flaming arrows and pots filled with blazing material. India's *Mahabharata* and *Ramayana* epics, probably initiated around 800–750 BC, describe the use of fire arrows, as does the myth of Hercules, who used burning arrows to kill the Hydra monster and complete the second of his twelve labors. Chinese theorist Sun Tzu listed five ways to attack with fire in his circa 500 BC *Art of War*. Thucydides described a flamethrower in 424 BC: engineers from Boeotia, he said, routed an Athenian garrison with a bellows-driven fire pot when they "sawed a great log in half, hollowed it out, and fitted [it] together again like a pipe. They suspended a cauldron from chains at one end, attached to an iron tube that projected from the beam, rolled it on carts to part of the wall made of vines and timber, inserted a huge bellows into their end of the beam, and blew. The bla passed into the cauldron filled with lighted coals, sulfur and pitch, made a great blaze, and set fire the wall."[29]

Liquid and gel incendiaries have an equally ancient provenance. Hercules was consumed by flaming shirt, woven with centaur blood by his deluded wife, that could not be extinguished removed. Mythical Greek princess Glauke, popularized by Euripides in his 431 BC play *Mede* suffered a similar fate. According to the story, Jason promised to marry Medea, a princess fro Colchis, in modern Georgia, if she helped him win the Golden Fleece from her homeland. She did, ar they wed, but he then abandoned her for Glauke. Medea sent her rival a beautiful crown and gow perhaps impregnated with petroleum, which was common in surface deposits near Baku in th neighboring territory now known as Azerbaijan. When Glauke put on the garments and approached a altar—possibly illuminated by open flames—she ignited. "The chaplet of gold about her head [sen forth a wondrous stream of ravening flame, from her bones the flesh kept peeling off beneath th gnawing of those secret drugs, e'en as when the pine-tree weeps its tears of pitch, a fearsome sight see," Euripides wrote. More credibly, an Athenian attendant to Alexander the Great was severel burned during the Macedonian conquest of Mesopotamia when he agreed, at the suggestion of h inquisitive commander, to cover himself in *naptha*, or petroleum, in a bathhouse. The oil combusted- flames from nearby lamps, again, may have sparked volatile vapors—and the volunteer almost died.[3

Romans suffered the first recorded military attack with liquid fire. In 69 BC, the army of cons Lucius Lucullus attacked the city of Samosata on the Euphrates in what is now southeastern Turke According to Pliny the Elder, residents of the city poured *maltha*—flaming mud—on the soldiers. Th substance "adheres to every solid body which it touches, and moreover, when touched, it follows yo if you attempt to escape from it.… It is even set on fire in water. We learn by experience that it can b extinguished only by earth," he wrote. (Pliny distinguished *maltha* from *naphtha*, which he said w more liquid and used to treat Glauke's robe). Flames grilled the legionnaires in their armor, and brok the assault. Rome didn't capture Samosata for another 141 years.[31]

Legionnaires quickly incorporated incendiary liquids into their arsenal, and came to consider the divine in origin. In the tenth century, a millennium after Lucullus, Byzantine emperor Constantin Porphyrogenitus told his son that Constantine the Great, who ruled from 306 to 337 and moved th imperial capital from Rome to Constantinople, obtained the recipe for liquid fire directly from a angel. Flame weapons were holy, Porphyrogenitus explained, and it was anathema—punishable by lightning strike—to disclose their secrets. Imperial armorers who produced incendiaries, he sai practiced a "divine art."[32]

Byzantine craftsmen developed a pump system that allowed their soldiers to shoot "Greek fire," s called in their honor, onto their enemies. Constantinople was a center of mechanical innovation und the empire. Porphyrogenitus, for example, told of a golden tree with artificial birds that flapped the wings and sang, a model lion that moved and roared, and a jeweled lady who walked, powered b clockwork. Around 673, as the Muslim Arab armies of the Umayyad caliphate advanced from th south and west, a refugee named Kallinikos ("handsome winner") arrived in the capital from th Syrian town of Heliopolis. He adapted a pump, perhaps a double-action water pump, so that it could b mounted on a ship. A burning stream shot out through a moveable pipe, or "siphon," set into the bo

—often decorated like the head of a monster. As the emperor Leo wrote later: “The front part of th ship had a bronze tube so arranged that the prepared fire could be projected forward to the left or rig and also made to fall from above. This tube was mounted on a [platform] above the deck.… The fi was thrown either on the enemy’s ships or in the faces of the attacking troops.” This “sea-fire” Kallinikos, which like its predecessors could not be extinguished with water (but apparently could quenched with vinegar or urine), destroyed the Umayyad navy and saved the kingdom.[33]

Subsequent improvements miniaturized the technology so that it could be carried by soldiers in th field. Leo rhapsodized about “Small siphons discharged by hand from behind iron shields, which a called hand-siphons [and] have recently been manufactured in our dominions. For these can throw th prepared fire in the faces of the enemy.” This allowed a variety of delivery options. “Flexib apparatus with [artificial] fire, siphons, hand-siphons … are to be used, if at hand, against any tow that may be advanced against the wall of a besieged town,” Porphyrogenitus instructed. Commande in the 1100s deployed a breath-powered system. Anna Komnene, daughter of the emperor Alexios Komnenos, described a Byzantine incendiary attack in 1103 on a Pisan fleet near Rhodes: “This fi they made by the following arts. From the pine and certain such evergreen trees inflammable resin collected. This is rubbed with sulphur and put into tubes of reed, and is blown by men using it wi violent and continuous breath. Then in this manner it meets the fire on the tip and catches light an falls like a fiery whirlwind on the faces of the enemy.” The canny princess in all likelihood omitted key ingredient: petroleum. With this addition, her recipe is close to contemporary scholarly consensu about the composition of Greek fire: a “semi-liquid substance, composed of sulphur, pitch, dissolve nitre and petroleum boiled together and mixed with certain less important and more obscu substances,” in the words of scholar C. W. C. Oman.[34]

Arab armies also made extensive use of liquid incendiaries but used soldiers, catapults, trebuchets (slings powered by counterweights), rather than pump-powered jets, to deliver blazin munitions. Special “naphtha troops,” called *naffatun*, protected by asbestos clothing and armed wi copper *naffata* fire pots or ceramic hand grenades accompanied archer corps in Abbasid armies fro 750. Arabs who besieged the Greek port of Salonika in 904 left numerous small ceramic pots believe to have been fire grenades. A 1200s workshop that manufactured similar devices was found at the ci of Hama in Syria. Flamethrower technology spread east to China from Arabia around 919.[35]

Fire assaults created terror. The French crusader Jean de Joinville described an Arab *perronel* attac (literally, “stone thrower,” probably a trebuchet), that hurled blazing tubs of Greek fire during th 1250 siege of a fortified camp near the Egyptian city of Al Mansura: “This was the fashion of th Greek fire: it came on as broad in front as a vinegar cask, and the tail of fire that trailed behind it w as big as a great spear; and it made such a noise as it came, that it sounded like the thunder of heave It looked like a dragon flying through the air. Such a bright light did it cast, that one could see all ov the camp as though it were day, by reason of the great mass of fire, and the brilliance of the light th it shed,” he wrote. That battle ended with the capture of the French king Louis IX, the deaths of tens thousands of Europeans, and the collapse of the Seventh Crusade.[36]

Liquid incendiaries declined in importance after the mid-1200s as gunpowder spread across th world from China. Explosives dramatically increased the range of projectile weapons and made difficult or impossible to use traditional fire weapons, which had to be delivered at relatively clo

range. Heated shot, an ineffective incendiary compared to petroleum-based liquids, was the mo
gunnery officers could offer as an alternative. Rockets—used by Chinese and Mongolians from th
mid-1200s—delivered burning materials from a distance, but were inaccurate and unreliable. Gree
fire was not mentioned in Byzantine accounts after 1200, which has led some to speculate the recip
had been lost, perhaps because of excessive secrecy. This seems unlikely since the use of simil
incendiary weapons decreased everywhere at about the same time.[37]

Engineers attempted to break this paradigm for half a millennium by increasing the range of fi
weapons. It was not until 1805, however, that British designer William Congreve, inspired by India
rockets encountered in the 1767–1799 Anglo-Mysore Wars, invented a circular iron shell mounted o
a fifteen-foot wooden pole that could shoot a burning thirty-two-pound "carcass" warhead about
mile and a half, reliably and with some accuracy. For the first time in centuries, fire weapons had
greater range than artillery. England shot hundreds of fire missiles at the French port of Boulogne o
October 8, 1806—their first such attack—but met with limited success. In 1807, however, Brita
supplemented artillery and grenades with approximately 300 incendiary rockets during a three-da
bombardment of Copenhagen that left thousands dead and one-third of the city in ashes. This force
the surrender of virtually the entire Danish Navy. Red glare from British rockets fired at Baltimore
Fort McHenry on September 13, 1814, inspired Francis Scott Key to compose what is now the U.
national anthem. In the same year, also at Baltimore, Uriah Brown, one of the earliest America
incendiary engineers, produced a steam-powered flamethrower—a modern version of the mediev
Byzantine siphon—and demonstrated it to a "vast concourse" of citizens.[38]

Artillery, however, progressed even faster. Rifling inside gun barrels enhanced accuracy. Percussio
caps, which spark on impact, eliminated ignition systems that relied on smoldering fuses, an
improved reliability. Fire weapons, even those powered by rockets, couldn't keep up. Incendiar
deployments remained rare.

America's Civil War spurred a flurry of flame research but a similar result: few deployment
President Abraham Lincoln urged aggressive research. In 1861, he ordered the army to help New Yor
inventor Robert L. Fleming develop a proposed firebomb. On January 14, 1862, the president met wi
Levi Short of Buffalo, who claimed to have rediscovered the recipe for Greek fire. Short test-fired
pair of thirteen-inch shells later that month on the Ellipse, just south of the White House. They ble
fire forty to fifty feet into the air, and covered a fifty-foot radius with flames for ten minutes.[39]

General George McClellan found the weapons barbaric—"Such means of destruction are hard
within the category of those recognized in civilized warfare," he wrote—but others thought more lik
Lincoln. General Benjamin Butler invited Short to display his devices over Boston Common, an
subsequently purchased one hundred shells for use against New Orleans. Rear Admiral David I
Porter rented part of his family mansion on the Delaware River to Short to produce "Solidified Gree
Fire" in tin cylinders three inches long and five-eighths of an inch in diameter. He then ordered te
gross (1,440) and used them to bombard Vicksburg, Mississippi, in May 1863. Defenders expresse
outrage over this indiscriminate use of fire, despite the fact that just three significant conflagration
resulted. A "Greek fire" incendiary attack on Charleston on August 22–23, carried out on the dire

order of Lincoln himself, produced similarly disappointing results. “My conscience will not perm me to recommend his greek fire, which I know to be good for nothing,” Porter later wrote of Short invention in a letter to his mother.[40]

World War I sustained the essential paradigm of the previous eight centuries, but offered harbinger of things to come. German engineers introduced gas-powered *Flammenwerf* (flamethrowers) that shot gasoline, or fuel oil, thickened with rubber about twenty yards. Artiller shells, now equipped with streamers to ensure a straight descent, continued in the tradition of U. Civil War fire experimenters. Zeppelin airships motored over London and launched incendiar bombardments. In all of these cases, however, principle was more impressive than practice: th weapons did relatively little damage.

Germany first attacked French troops with flamethrowers at Malencourt, in northeastern Franc north of Verdun, on February 26, 1915. An observer applauded “The fiery serpents which, as if risin out of the earth, fell roaring and hissing on the enemy’s trenches and drove him to precipitate flight That summer, British field marshal Sir John French reported “A new device has been adopted by th enemy for driving burning liquid into our trenches with a strong jet.… Most of the infantry occupyin these trenches were driven back, but their retirement was due far more to the surprise and tempora confusion caused by the burning liquid than to the actual damage inflicted.” A U.S. Chemical Warfar Service official history observed, “After the initial terror had subsided, however, Allied soldiers foun that their own circuitous trenches provided them with adequate protection, since flame throwers that time could not project fuel around corners or into most underground passages.” It conclude “The maximum range of the portable German weapon was 20 yards; its small tanks were quick exhausted of fuel, and its operator, after firing, became a helpless target out in No Man’s Lan defenseless and hampered with a heavy load.” Over 90 percent of the fuel burned in vast clouds black smoke before it reached its target.[41]

“Unthickened fuel made a great show,” the NDRC wrote, “There were many who believed that th almost sole effect of the portable flame thrower was psychological.” British, French, and U. engineers developed similar devices in response, but they were used on only a handful of occasion and never by U.S. troops. After the war, the CWS abandoned the program and destroyed its stock weapons. “In general, it was not considered a successful munition,” the service concluded of the early flamethrowers.[42]

German Zeppelin airships firebombed London on May 31, 1915. Bombs, however, were few- ninety incendiaries and thirty explosives from a single dirigible in the first attack. Many did n ignite, and firefighters easily contained the conflagrations that did result. German engineers lat produced a bucket-shaped bomb that contained a core of thermite (a mixture of powdered aluminu or magnesium and metal oxides, often iron, that burned white-hot at around 5,000 degrees) packed cotton, doused with naptha and tar, and bound with tarred rope. Flaming bullets, invented in 1916 b the British in response to the air attacks, however, effectively defeated the dirigibles. British, Frenc and U.S. scientists also developed firebombs—respectively the “Baby Incendiary” bomb filled with “Thermalloy” blend of thermite and powdered aluminum; the Chanard dart, intended to be droppe from an airplane; and the Mark I and II bombs and darts—but the small devices played insignificant role in the conflict.[43]

Airplanes restored incendiary weapons to their medieval pride of place. On April 26, 1937, th German Condor Legion, a volunteer force that supported fascist allies of the Nazis in the Spanis Civil War, demonstrated modern fire warfare when it deployed forty-three airplanes to drop fifty ton of thermite incendiaries and explosive bombs on the Basque town of Guernica. The municipalit jammed with people on a market day, was devastated: about three-quarters of its buildings burned, least 300 people died, and thousands were injured. *Times of London* correspondent George Ste described the new kind of warfare: "First, small parties of aeroplanes threw heavy bombs and han grenades all over the town, choosing area after area in orderly fashion. Next came fighting machin which swooped low to machine-gun those who ran in panic from dugouts, some of which had alread been penetrated by 1,000 lb. bombs, which make a hole 25 ft. deep." He continued, "Many of the people were killed as they ran. A large herd of sheep being brought in to the market was also wipe out. The object of this move was apparently to drive the population under ground again, for next many as 12 bombers appeared at a time dropping heavy and incendiary bombs upon the ruins Japanese commanders underlined the point in August when they attacked Shanghai with firebomb and killed tens of thousands.[44]

Then, on September 7, 1940, Germany launched the first sustained incendiary bombing campaign history: the London Blitz. During the Battle of Britain as a whole, the Luftwaffe dropped about 23,50 clusters of thirty-six one-kilogram magnesium shells packed with thermite. Bombs burned so hot the ignited their magnesium casings, which burned for up to fifteen minutes and threw lumps of molte metal up to fifty feet. They could not be extinguished with water. Larger German firebombs combine up to 500 pounds of thermite, oil, and magnesium shavings. Luftwaffe bombers attempted to do cities with fire what many, after World War I, feared might be done with poison gas.[45]

A triptych of images from the period illustrate the new paradigm. Pablo Picasso painted *Guernica*, grey-and-white vision of the disaster that befell the city, in June 1937. In Shanghai, rescuers plucked burned baby from the rubble of the main railway station and set it, sobbing, by a track. H. S. Won snapped a photo. Japanese authorities alleged that because the baby was placed in position the pho was not a faithful depiction of events. Its fame, however, was indisputable. In England, news camera recorded a grim prime minister Winston Churchill in 1942 as he walked through the charred remain of Coventry Cathedral, gutted in November 1940 by an attack of over 1,000 firebombs. Britis analysis of the London Blitz concluded that a ton of the new incendiaries produced about five tim more damage than the same amount of conventional high explosives. Churchill agreed about th potential for ruination from the air. "The Navy can lose us this war, but only the Air Force can win it he said, just before German bombardments began.[46]

Given this history, the British were interested in Fieser's research on incendiary gels. In August 194 two months after the Everett tin-can tests, Major Gerrard Rambaut of the Air Ministry, who helpe develop the United Kingdom's magnesium incendiary, arrived at the Oxford Street laboratory for visit. His key piece of advice was to establish a measurement system to allow quantitativ comparisons between alternative gels. "An obviously sound suggestion," Fieser noted. Harvard's tea built a structure with four upright pieces of wood attached to a wooden base and connected by tw sample content of Napalm: An American Biography