from Washington in the fall of 1931 to study decay throughout communities in the South departure planted a seed for the government's everal years later, another seed would take root. 1939, Gerald Cox, the researcher at the Mellon most radical suggestion yet at a meeting of the Vorks Association in Johnstown, Pennsylvania. k place at a historic moment. The world stood on other world war. German tanks had just entered n aircraft and steel armor plate would be critical nflict. Pittsburgh's great blast furnaces and alu- grown cold during the Depression, were being wing a fresh funereal smoke against the autumn e already flooding war factories, eager for work. at America should now consider adding fluoride er supply.

lth authorities had sought only to remove fluoride , the Mellon man told the Water Works Associa- t trend toward complete removal of fluorine from may need some reversal."[76]

a global conflagration, a nuclear bomb, and an lop by the Public Health Service for water fluori- old—yet Gerald Cox's 1935 rat study and Dean's stigations would be the germ for a vaccine provid- s new immunity in the postwar years. Touted as a tection against dental cavities, water fluoridation etly help to inoculate American industry against a lawsuits from workers and communities poisoned lustrial fluoride emissions.

4

General Groves's Problem

On the edge of the marsh water, near the monumental K-25 factory at Oak Ridge, Tennessee, stands a solitary blue heron, its head angling for prey. "Danger. No Fishing. Radiation," reads a sign. Across the pond, the gray walls of the plant glitter in the late evening sun. The smokestacks are cold now, the big machines silent and patient as the heron, waiting to be dismantled and hauled away. Close your eyes and the ghosts return. Mausoleum now, this half-mile-long steel colossus was once among the biggest industrial buildings in the world. Here, in the spring and summer of 1945 and throughout the cold war, tens of thousands of women and men worked through the night in a cacophony of heat and smoke, their backs bent to the purpose of a nation. Here, in the shade of Tennessee's Black Oak Ridge, lay America's biggest wartime secret, where nature was rendered in man's image more powerfully than ever before. Here, on the banks of the Clinch River, exotic ore and minerals from the corners of the globe were transfigured with an elemental genius by scientists, farm laborers, and migrants from across the United States, punching time clocks, sculpting the future, and enriching uranium for the Hiroshima atomic bomb.

IT WAS A cold December morning in 1943 in northwest Washington, DC, and Brigadier General Leslie C. Groves had another problem on his desk. The portly, tough-talking engineer was in charge of the United States' biggest and best-kept wartime secret. He was the army's chief of the Manhattan Project, and its staff was building an industrial infrastructure to manufacture the world's first atomic bomb.

It was a gargantuan task. In complete secrecy Groves and the Army Corps of Engineers were overseeing the work of tens of thousands of laborers, scientists, and engineers who in just three years would create factories and laboratories rivaling the size of the entire U.S. automobile industry. The budget of the Manhattan Engineer District, as the project was officially known, eventually would run to over $2 billion and would be concealed almost entirely from the U.S. Congress.[1]

The General's days were a blur of covert action. There were secret flights to mysterious giant new factories being carved from virgin sites in Tennessee, New Mexico, and Washington State; huddled conferences in the Manhattan Project's New York and Washington, DC, offices; and endless telephone calls, trouble-shooting with top military lieutenants. The United States was in a nuclear arms race with Germany, Groves believed. Yet some of the key industrial processes needed to make the U.S. weapon had not even reached pilot-plant stage. Much of the nation's atomic program, he knew, was still mired in laboratory development.

Groves had a new headache that December morning. There were disturbing reports of workers and scientists being gassed and burned in the bomb project's laboratories and factories. Colonel Stafford L. Warren, chief of the Manhattan Project's Medical Section, needed help. He wanted General Groves to use his authority to pry loose some secret information from the army's Chemical Warfare Service. Warren wanted to know what the military's poison-gas experts could tell the Manhattan Project about the toxicity of fluoride.[2]

General Groves immediately agreed to help. Getting more information about fluoride toxicity was vital. Despite the many uncertainties facing the Manhattan Project that bleak winter of 1943, Groves was sure of one thing: fluoride was going to be essential in making the United States' atomic bomb. Manhattan Project scientists were planning to use a "gaseous diffusion" technology to refine uranium. In that process uranium is mixed with elemental fluorine, forming a volatile gas called uranium hexafluoride, which is then "enriched" by diffusing that gas through a fine barrier, or membrane. The lighter molecules containing fissionable uranium

needed for a nuclear explosion pass though the membrane more quickly and are captured on the other side. But because only a handful of the lighter molecules make it through the membrane each time, many hundreds of tons of fluorine, and thousands of stages of progressive enrichment, would be needed to produce enough uranium for a single atomic bomb.[3] By January 20, 1945, when the K-25 gaseous diffusion plant on the banks of the Clinch River was loaded with fluoride for the first time, the plant's fantastic appetite would include a work force of 12,000, a hunger for electricity that rivaled the city of New York, and a diet of some 33 tons of uranium hexafluoride each month.[4]

The hunger for fluorine was one of the most closely guarded military secrets of World War II. A special office of the Manhattan Project in New York City, known as the Madison Square Area, coordinated much of the fluoride work. Elemental fluorine was designated simply "the gas" or "fresh air." Scientists at the University of Chicago were advised in a secret 1942 memo that "all fluorides are to be disguised . . . in that they give definite clues to the chemistry involved."[5]

Dragooning fluoride into military service was also one of the central technological challenges of the war, requiring the full resources of academia and industry.[6] While the idea behind gaseous diffusion was simple, elemental fluorine and uranium hexafluoride were extraordinarily corrosive and toxic.[7] Fluorine was easily the Earth's most reactive element, scientists knew, often combining violently with other chemicals even at room temperature, vaporizing steel in a flash of white heat, for example, and presenting bomb-program engineers with extraordinary challenges and nightmarish hazards. So dangerous was the pure element that industry had avoided fluorine before the war, regarding it as "a laboratory curiosity."[8]

Wartime necessity became the mother of invention. Thousands of researchers in crowded laboratories worked to enlist fluoride in the fight against fascism. Scientists from Columbia, Princeton, Johns Hopkins, Purdue, Ohio State, Penn State, Duke, the University of Virginia, MIT, Cornell, and Iowa State studied the chemical, alongside engineers from some of the biggest industrial companies in wartime America. The companies included DuPont, Chrysler, Allis-Chalmers, Westinghouse, Standard Oil, the American Telephone and Telegraph Company (AT&T), Mallinckrodt, Eastman Kodak, the Electro Metallurgical Company, Linde Air Products, Hooker Chemical, Union Carbide, and Harshaw Chemical.[9]

Columbia University scientists made an early technological breakthrough. In December 1940 a tiny two-cubic-centimeter capsule of a liquid, code-named "Joe's Stuff," was delivered to the campus in New York City. Researchers handled it with care. Inside was virtually the entire world's existing supply of a radical new chemical compound known as a "fluorocarbon"—in which carbon atoms were bonded not with hydrogen, as in conventional "hydrocarbon" oil, but entirely with fluorine atoms.[10] The Columbia researchers soon confirmed that the liquid had Herculean strengths. The fluoride atom was bound to the carbon atom so tightly that even the hyperaggressive elemental fluorine gas was held at bay. The discovery was crucial. Inside the Oak Ridge gaseous-diffusion plant, hundreds of huge compressors and blowers would be needed to push the uranium hexafluoride gas through the multiple "enrichment" stages. If regular oils were used to grease these engines, however, the predatory fluorine atom stripped the hydrogen from the hydrocarbon, destroying the lubricant and the machinery.[11]

The bomb-program scientists could now fight fire with fire. Fluoride, bonded to carbon atoms in fluorocarbons, would protect the machinery from the fluoride in the uranium hexafluoride gas. In other words, fluoride would protect the machinery from fluoride's uniquely corrosive powers. A crash research program at Columbia—led by a brilliant Russian immigrant, Aristide V. Grosse—soon found a way of mass-producing the top-secret compounds.[12] By 1945 thousands of pounds of fluorocarbon oils and seals were being delivered to Oak Ridge.[13]

DuPont mass-produced the fluorocarbons. Their prewar expertise in manufacturing Freon was vital to the U.S. nuclear program. Thousands of pounds of similar refrigerants were now needed to cool the K-25 diffusion plant. DuPont's fluoride-based plastic called Teflon also gave the United States a key wartime advantage. Japan's atomic scientists had struggled to manufacture and handle small amounts of the corrosive uranium hexafluoride. But Teflon—which had been first fabricated in a DuPont lab in 1938—allowed U.S. companies to move enormous quantities of fluoride around the country.[14]

"The basic problem" in making the bomb, General Groves wrote, "was to arrive at an industrial process that would produce kilograms of a substance that had never been isolated before in greater than sub-microscopic problems."[15]

Solving that problem required fluorine scientists. Without their inventions, the United States' atomic bomb "would have been impossible," noted the Manchester University scientist and historian Eric Banks. Most historians have focused on the physics of the atomic bomb, chronicling how the atom was split. The vast contribution of chemical engineers to the Manhattan Project—and the radical debut of a powerful chemical element onto the global stage—has largely been ignored. "It is a striking omission," pointed out Banks. "American fluorine chemists had a huge impact on the production of the bomb."

But exploiting fluoride was a double-edged sword, as the bomb program's scientists soon discovered. On January 20, 1943, the senior Manhattan Project doctor, Captain Hymer L. Friedell, paid a visit to the sprawling New York campus of Columbia University, where a small-scale gaseous diffusion plant had already been built. Almost a thousand researchers would eventually work on bomb-related projects at Columbia's War Research Laboratory.[16] After his visit Captain Friedell warned of possible health problems: "The primary potential sources of difficulty may be present in the handling of uranium compounds, as noted above, and the coincident use of fluorides which are an integral part of the process."[17]

His warning was accurate. A fluoride-gas release at Columbia later that year produced "nausea, vomiting and some mental confusion"; in 1944 another researcher, Christian Spelton, developed pulmonary fibrosis after repeatedly fleeing clouds of uranium hexafluoride gas.[18] Other health problems were also reported. Dr. Homer Priest, a leading Columbia University fluoride scientist, complained that his "teeth seemed to be deteriorating rapidly." Dr. Priest told a doctor that he bled more freely and that "there has been a progressive increase in the degree of slowness of healing and of pain in the period he has been doing this work."[19]

The epidemic spread. At Princeton leaking fluoride gas left scientists feeling "more easily fatigued." There were multiple reports of illness at Iowa State and of fluoride acid burns at Purdue, where two researchers were badly gassed with carbonyl fluoride in 1944.[20] Health problems hit industry scientists too. At DuPont "rather severe weakness" was reported in 1943 by three chemists who had received "heavy exposures" to fluorine. "The symptoms were ascribed by them to the oxyfluorides formed," a report said.[21]

Accounts of fluoride injury mushroomed as the laboratory work moved into full-scale industrial production. At Oak Ridge in September 1944, 190 pounds of hexafluoride gas escaped into a room, drifted outdoors, and formed a chemical cloud "20 yards by 20 yards." Nine workers were exposed "for periods of twenty seconds to five minutes," injuring "the mouth, salivary organs, pharynx, skin, eyes and lungs."[22] The news got worse: that same year, 1944, General Groves got shocking new reports of multiple deaths in the nuclear program. Details of those fatalities and fluoride's role have remained hidden, often for a half-century or more.

The stories of the DuPont workers, who may have been fluoride's first wartime fatalities, have not been made public until now. (And they remain anonymous: once-secret military documents describing the deaths do not record their names.) On January 15, 1944, a laboratory assistant, a chemist, and "a girl technician" producing the fluorinated plastic Teflon for the bomb program were exposed to waste gases. Shortness of breath followed twelve hours later and "by the end of 36 hours, all three were in the hospital," Colonel Warren was informed.[23] The chemist recovered but the other two died terrible deaths, turning purple and unable to breathe.[24] When the twenty-three-year-old female "expired at the end of ten days," her autopsied lungs resembled a victim of a World War I poison gas attack. Colonel Warren's deputy, Captain John L. Ferry, suspected that the DuPont fumes contained "certain oxyfluorides" and suggested the military "investigate the possibilities of this material being used as a poisonous gas."[25]

Although the army ordered up fresh toxicity studies, fearing "similar compounds may be formed in some of the other fluoride manufacturing operations," DuPont dragged its feet, investigators suggested, perhaps seeking to protect Teflon's postwar commercial potential. "The manufacturer considers that we were buying a 'packaged product' and is not interested in our investigating the toxicity of the materials involved," reported Captain Ferry. "Several of the

components thus far identified give good promise for commercial uses other than that contemplated here," explained a second army official.[26] (Subsequently there were additional reports of sickness associated with Teflon. British scientists visiting a DuPont factory just after the war confirmed that heated Teflon fumes were linked with "excessive weakness, tiredness, nausea and sore throat.")[27]

A Philadelphia Story

THE SECRET DEATHS continued. Arnold Kramish is tormented by injuries sustained in perhaps the worst fluoride accident of World War II. Sitting in a New York hotel eating breakfast one October 2001 morning, pastry crumbs sprinkling his shirt, Kramish described how he still endures "painful" fluoride skin eruptions on his legs—fifty-seven years after surviving an explosion that killed two of his colleagues. In the 1970s he sought medical help for the recurring sores. A Navy doctor explained to him that fluoride "stalks you the rest of your life."

He is stalked, too, by memories of the chemical "hell" that erupted in South Philadelphia in September 1944. After the war Kramish became a top nuclear scientist and government diplomat, well-versed in the ways of government secrecy. But half a century after the fluoride accident, in a bid to gain recognition for the victims, Kramish broke his silence and revealed details of that disaster, including the names of the men who were killed and why General Groves kept the deaths secret.[28]

On the morning of September 2, 1944, twenty-one-year-old Private Kramish and engineers Peter Bragg and Douglas Meigs reported for duty at the sprawling Philadelphia Navy Yard. The Yard housed a super-secret facility using hot liquid fluoride and pressurized steam to enrich uranium for the atomic bomb.[29] Kramish was one of ten volunteers who had arrived to train on the new equipment. Just three days earlier, at the Manhattan Project's vast construction site at Oak Ridge, Tennessee, Harvard University president James Conant had gathered the men and asked for volunteers. Conant warned them that their work in Philadelphia would be "one of the more dangerous parts of the Project," remembers Kramish.

James Conant was acutely aware of the dangers the men faced from fluoride. The chemist was one of President Roosevelt's top atomic advisers. He knew about the DuPont Teflon deaths. And he had seen the secret army reports on fluoride toxicity that General Groves had requested in December 1943.[30] The reports explained that the military was carrying out wartime human experiments with fluoride gases at the army's Edgewood Arsenal in Maryland, searching for chemical warfare agents.[31] The army had received data about fluoride experiments on humans in England that had produced powerful central-nervous-system effects.[32] And there were reports from captured prisoners of war suggesting that the Nazis, too, were investigating fluoride as a war gas.[33] Harvard's president was so disturbed by the "extraordinary" toxicity of certain fluoride compounds, especially those used in the human experiments, that he issued a secret warning to a senior U.S scientist about the atomic industrial fluoride work. "As an organic chemist," Conant wrote, "I think I should point out to you . . . it is conceivable that similar effects would occur with any fluorinated organic acid, although probably the compounds would be less striking in their action. It is further conceivable that these compounds could be formed in small amounts by the action of fluorine gas on the acids or related compounds."[34]

That fall day at Oak Ridge, however, as he asked for volunteers, Conant did not mention fluoride. All ten men raised their hands. "Any mildly inquisitive guy was not going to opt out," said Kramish.

At first the Philadelphia mission was more Keystone Kops than cloak and dagger. When they arrived at the Thirtieth Street train station, a military official in street clothes ordered them into Wanamaker's department store to replace their uniforms with anonymous civilian garb. But the Navy did not give them enough money, and all the men could find were cheap Hawaiian shirts, says Kramish. He remembers ten men furtively changing into their new "outfits" in a nearby subway station, emerging into the sunlight wearing brightly colored shirts and GI boots.

Two days later Kramish, Bragg, and Meigs were at the Navy Yard, working on the secret machinery. At lunch Kramish received a two-dollar bill in his change. "Give it back," his friend told him, warning that it was an omen of bad luck. Kramish pushed the bill into his pocket.

That afternoon, back at the plant, at 1:20 PM a massive explosion suddenly tore at the machinery. Boiling steam and fluoride jetted

onto Kramish's legs and back, clawing at his lungs and eyes. He fell backward, temporarily blinded. A trained scuba diver, Private John Hoffman ran into the smoking chaos holding his breath, pulling the injured men from the room and slicing Kramish's clothes from his burned body. This act of bravery would win Hoffman a Soldier's Medal, although the award was kept secret. "I pulled three guys out. Everybody was shell-shocked," Hoffman told me. "Fluorine gas had gotten loose—it was pretty pungent. I had to watch what the hell I was doing."[35]

The afternoon detonation echoed across South Philadelphia. A giant white plume of uranium hexafluoride gas drifted over the dockyard and into the nearby battleship USS *Wisconsin*. Douglas Meigs and Peter Bragg lay in their death throes. A priest attempted last rites on Kramish, whose wife was told that he had been killed. A once secret report of the disaster makes gruesome reading: twenty-six men had been exposed to 460 pounds of fluoride and uranium in a "huge chemical cloud." Douglas Meigs was "sprayed with live steam containing liquid, solid and gaseous material in large quantities"; he died after sixteen minutes. Peter Bragg expired an hour later with third-degree burns over most of his body. He "seemed in a great deal of pain," the report noted, and "became violent shortly before death and resisted all attention."

The remaining men survived, although many had serious and slow-healing wounds. Some experienced "intense pain in the scrotum, penis, or about the anus, probably because of the hydrolysis of the chemicals in these moist areas," the report notes. Survivors also suffered unusual "nervous system" effects. One man was temporarily rendered "almost incoherent." This "altered mental state" was "more than could be explained on a purely fear reaction basis," the report said. "In all probability the injurious effects observed on the skin, eye, mucous membranes of upper respiratory tract, esophagus, larynx and bronchi were all directly caused by the action of the fluoride ion on the exposed tissues," concluded a military doctor.[36]

Kramish reports that at a closed wartime inquiry, he learned that part of his suffering had been unnecessary. The head of the Navy project, Dr. Philip H. Abelson, had known how to treat fluoride burns, according to Kramish. But fluoride and uranium were considered so secret that Abelson refused to give the medical facts to the arriving doctors, telling them, "I'm not sure you guys are cleared," Kramish recalls. As a result, he adds, the doctors walked among the injured and dying men that afternoon "guessing what the burns might be." (Fifty years after the accident, Kramish reports he cornered Abelson one lunchtime in the Cosmos Club in Washington. Abelson refused to talk about the accident, Kramish says. "It was clearly a trauma for him.")

The Philadelphia explosion traumatized the entire Manhattan Project. In addition to the fluoride strewn over south Philadelphia, it was perhaps the largest release of man-made radiation that had ever occurred. General Groves feared that a nuclear fission accident had taken place. The military quickly suppressed media coverage. The Philadelphia coroner was not told the cause of the men's death.[37]

That disaster night, roused by Groves, the Manhattan Project's top doctor, Colonel Stafford Warren, drove through the darkness from Oak Ridge, Tennessee. He arrived at the Philadelphia Navy Hospital in time to seize the organs of the dead men, stuffing the heart and lungs of Meigs and Bragg into his briefcase before returning home, he later told Kramish. (Warren and Kramish became friends after the war.) Warren explained to him that the organs "had become classified material," Kramish recalled, and that they were sent to the University of Rochester for examination. "The deceased were buried without them," Kramish added.

Family members, such as Elizabeth Meigs, who was on her way to meet her husband in Philadelphia for Labor Day, would never learn that fluoride may have killed their relatives. General Groves kept silent about the fatalities. In his book about the Manhattan Project, *Now It Can Be Told*, Groves tells only that several persons "were injured" in Philadelphia and that the investigation "held up the work for a while."[38] Groves's fear of admitting the deaths, Kramish says, was "not only that the atomic bomb project might be compromised, but that if project workers learned of the true hazards of working with uranium, they might balk."[39] Suppressing toxicity information "would extend to fluoride," added Kramish. "Working with it was dangerous."

Arnold Kramish still has the two-dollar bill he received that lunchtime. He keeps it wrapped in lead; it remains contaminated.

Although fluoride played a nearly fatal part in Arnold Kramish's wartime experiences, he believes that few people have any idea of the chemical's wartime importance. "It is not as exotic as the atom," he says. For most historians, radiation is "all they want to talk about."

The Fear Mounts

FEAR NOW GRIPPED wartime fluoride workers across the U.S. atomic complex, and with good reason.[40] Thousands of them were entering an abominable work environment, beyond even Victorian horror, with daily exposure to a witch's brew of fluoride chemicals—including, for the first time in human history, the ferociously reactive elemental fluorine gas.[41]

"When a jet of pure fluorine strikes most non-metallic materials," began one 1946 secret memo detailing occupational hazards, "the surface of the material is instantly raised to an incandescent white heat. Personnel may be severely burned by heat radiated from the surface even when they are not directly exposed to fluorine at all. . . . NO PERSONAL PROTECTIVE EQUIPMENT HAS BEEN DEVISED TO DATE WHICH WILL RELIABLY AFFORD EVEN TEMPORARY PROTECTION AGAINST A HIGH PRESSURE JET OF PURE FLUORINE," emphasized the memorandum.[42]

Incredibly, fluorine was *not* the most toxic gas to which workers risked exposure. When excess fluorine was vented to the atmosphere (a common procedure, as we shall see) a truly venomous family of even deadlier compounds—"oxyfluorides"—were formed. One of these chemicals, oxygen fluoride, "a bi-product of fluorine disposal," was probably "the most toxic substance known," bomb program researchers bluntly reported.[43]

Another common workplace hazard was hydrogen fluoride acid (HF), which had the fiendish property, if splashed on skin, of initially escaping detection but then slowly and painfully eating into a victim's bones.[44] One especially fearsome compound called chlorine trifluoride, which was used to "condition" or clean machinery, was so reactive that Allied intelligence agents suspected Hitler's SS had also experimented with it, as an incendiary agent.[45] U.S. atomic worker Joe Harding, who used chlorine trifluoride at the Paducah gaseous diffusion plant in Kentucky, described the compound as a "violent monster that makes [pure] fluorine look mild by its side."

Working with chlorine trifluoride was "more dangerous than handling TNT while you was climbing a tree," said Harding.[46]

Fluoride posed another hazard. It dramatically boosted the toxicity of other cold war chemicals. The biological havoc wreaked by beryllium, for example—a key metal that makes nuclear weapons more powerful—was at least doubled by the synergistic presence of fluoride, bomb program scientists found.[47] By 1947 there had been nineteen or more deaths reported in the nation's beryllium plants, with the carnage spreading rapidly.[48] (When newspaper reporters got wind of the fact that families living near the beryllium plants were also getting sick, the Atomic Energy Commission tried to suppress the story.)[49]

Beryllium smelters were felled with an especially devastating one-two punch, said the Manhattan Project scientist Robert Turner. Men became ill with a "foundry fever" marked by shivering, high temperatures, and "profuse perspiration." The knockout blow from fluoride fumes followed sometimes days later, the scientist noted, with workers turning purple, gasping for breath, and coughing up blood.[50] Turner was critical of other scientists. Investigators studying fluoride had shown "a disregard of the fundamental principles of modern toxicology." Discovering how workers were being hurt required considering a range of factors, including the size of the particles involved, ways the poison entered the body, and awareness "that the action of a compound is not equivalent to the sum of the action of its component parts," he wrote.[51] Turner described the pathways by which tiny fume-sized particles of beryllium oxyfluoride penetrated deep into lungs "with missile-like force." When the molecules arrived inside the alveoli, the atoms of fluorine and beryllium separated "like a charge bursting." Both beryllium and fluoride were poisonous, the scientist said, but it was the liberation of fluoride deep inside the lung that produced the most catastrophic health problems, destroying tissue, choking breath, and leaving permanent lung scarring.[52]

Similarly, when uranium was converted into hexafluoride gas, that poisonous metal also got a deadly new punch. This enhanced toxicity of uranium presented nuclear planners with perhaps their most diabolical quandary. Enormous quantities of uranium hexafluoride "process gas" were required for even a single atomic bomb. But when the "hex" was exposed to air, it rapidly formed a dense white cloud of HF gas and fume-sized particles of a "highly toxic" compound known as uranyl fluoride or uranium oxyfluoride (chemical symbol UO_2F_2). The compound injured laboratory animals in microscopic quantities, while even "a few milligrams" ingested daily proved fatal, bomb program doctors reported.[53]

Exposure to these two chemicals would be a daily fact of life in the diffusion plants.[54] In the hidden chambers of the massive K-25 plant, where precious uranium for the Hiroshima atomic bomb was first captured, "there will be a continuous escape of UO_2F_2 in the cold trap rooms," officials warned. Those workers would be exposed "8 hours per day regularly," explained Medical Captain John Ferry in a secret June 16, 1944 letter to an Oak Ridge contractor.[55]

"Just Watch Anyone That Has a Tie On"

AS PREDICTED, WHITE fluoride smoke became a familiar sight and smell to generations of workers in America's gaseous diffusion plants. "I have never seen it that there wasn't a thick haze of process gas smoke in the air," said Joe Harding, remembering his almost thirty years inside the gaseous diffusion plant at Paducah, Kentucky.[56]

"It does have a pungent odor," confirmed another worker, Sam Vest, who in 1970 followed his father and two uncles into the Oak Ridge nuclear factories. In a 2001 interview in his home near Oak Ridge the fifty-four-year-old Vest tugged on a never-ending cigarette, recalling his own three decades at America's first gaseous diffusion plant. His soft Tennessee drawl transported a visiting writer back inside the cacophonous K-25 building and to the apprentice electrician's first encounter with uranium hexafluoride gas. Vest watched one morning as clouds of smoke belched from equipment he was replacing. He asked a more experienced worker about the strange white fog.[57] "I said, 'What is that stuff?' And he said, 'That is process gas.' And I said, 'Should we be here? I don't see anybody with respirators on.'" The older worker explained an Oak Ridge safety rule: "Just watch anyone that has a tie on." He added, "And if he leaves hurriedly, you leave behind him." "That was my first indoctrination," Vest said. "I was just a kid."

Medical advice given to men who had been in a chemical release, said Vest, was to "go home and drink a six pack of beer."[58] Vest remembered thinking, "I don't know anything about chemicals or uranium hexafluoride or anything like that. But none of this looks on the level to me. These men are standing in this fog with no respirators. I thought 'My God, what kind of a place is this?'"

On another occasion Vest found himself high above the plant in the "pipe gallery," replacing electrical heaters. "We were wading though this yellow powder," he recalled. "I asked [a colleague] Clyde, I said, 'Clyde, what is all this yellow lying around here?' And he said, 'That is product.' I said, 'What do you mean?' And he said, 'Well, that is UO_2F_2. After it cools down, it solidifies and that is enriched uranium.' And I said, 'Shouldn't we have some kind of breathing apparatus or something?' And he said, 'Hell no, we work in this all the time. It won't hurt you.'"[59]

Similar official safety reassurances, from the highest levels of the United States government, were given to tens of thousands of fluoride workers throughout the cold war. The assurances were false. Fluoride was a state secret. Workers were neither told what chemicals they were handling nor of the warned dangers. "The people hired by the contractors were not, because of security, told of the hazards involved in their work," Colonel Stafford Warren wrote to a deputy, Dr. Fred Bryan, in September 24, 1947.[60]

Despite an early awareness that cancer and occupational injuries were extraordinarily frequent at the gaseous diffusion plants, workers could never prove that such was the case. "All medico-legal and insurance statistics which refer directly to process hazards" were classified "secret," an AEC document noted.[61] In data that were declassified only in 1997, for example, it was revealed that during the earliest months of the K-25 plant's operation, from June 1945 to October 1946, there were 392 "chemical injuries" from uranium hexafluoride, 58 injuries from fluorine, 21 from hydrogen fluoride, and six injuries from fluorocarbons.[62]

Area C

WORKERS QUICKLY GREW suspicious at the endless medical testing. Behind a barbed wire fence at a secret plant in downtown Cleveland, Ohio, known as Area C, segregated young African Americans—who loaded a chalky "green salt" into furnaces—gave regular urine samples to government doctors.

"You had to be tested all the time," said Allen Hurt, an employee of the Harshaw Chemical Company, which ran the secret plant under contract for the Manhattan Project. He was one of five former workers who agreed to talk about his experiences.

The industrial complex on the Cuyahoga River was one of the Manhattan Project's most important sites. Harshaw engineers had invented a way to add extra fluoride molecules to uranium tetra fluoride—the "green salt" the workers were handling—manufacturing the vital hexafluoride "process" gas needed for uranium enrichment. ("Hex" means six and "tetra" means four.) By June 1944, the plant was capable of producing a ton of "hex" each day for shipment by truck to Oak Ridge for the K-25 gaseous diffusion plant.[63]

The government reassured the workers about the tests. In a 1948 visit to Cleveland, for example, a Manhattan Project senior doctor, Bernard Wolf, gathered the workers together to tell them that "all our records indicate that no unusual hazard existed." The truth was very different. Secretly, on August 5, 1947, the AEC's W. E. Kelly had informed Harshaw's senior manager, K. E. Long, that "the status of health protection at Area C is unsatisfactory is several respects." He cited in particular:

1. Contamination of the Area C plant, Harshaw plant area and an unknown amount of contamination of the surrounding neighborhood with uranium and fluoride compounds.
2. Exposure of operating personnel to uranium and fluorine compounds by direct contact and inhalation.[64]

Harshaw workers knew *something* was in the air. "The moment you stepped out of the time clock office, there would be an odor, a burning sensation," recalled Henry Pointer. "It would sting your face, you would inhale it too." Union organizer John L. Smith was sick one day after repairing a pipe. "It was the fumes—next thing I felt breathing difficulty and started vomiting and went to the first aid and started shitting in front of them at the same time," he said. (Although he never knew what had poisoned him, Smith's symptoms were of acute fluoride poisoning.)[65]

There were fluoride fatalities at Harshaw as well. Young black women made up about half of the Area C workforce. Twenty-two-year-old Gloria Porter started at the Cleveland works in 1943, filling hydrogen fluoride tanks. On October 9, 1945, she saw a man eaten alive by the fluoride acid when a storage tank at Area C exploded.[66] "I heard this rumble," remembers Porter, who had just finished her shift. "All of a sudden this cast iron [storage tank] just burst open and the smoke, the fumes from the acid, you just couldn't see nothing, and that stuff was rolling and the more it rolled the further we would run."

A male worker helped Porter to scramble over the barbed wire fence that surrounded Area C. As she stared back, a horrific image was seared in her mind. She watched men struggling through a giant cloud of hydrofluoric acid. "I saw all of them coming out with hunks of flesh just falling off of them, and the stomach, and their arms, and I said 'My God, I can't look at that. That man can't live.' He looked just liked bone, but he fell right then." Two men were killed in the accident, and a good friend was badly burned, recalls Porter, who left Area C the following year.[67] "After the explosion, I just wanted to get out," she added

African Americans may have been hired for fluoride work in order to conceal the chemical's toxic effects. "Most fair complexioned men could not be employed in the production plant," reported a once classified wartime study of Harshaw fluoride workers.[68] Acid fumes produced skin that was "dehydrated, roughened and irritated," the report noted. Some workers had "hyperemia" or acute reddening of the face. When that report was published, however, the black- and-white language of segregation had grown less stark. The chemical sensitivity to the fluoride was now more subtly described as "more severe in fair complexioned men."[69]

Harshaw veterans confirmed that only African Americans were employed inside the heavily guarded Area C plant. Outside, white male supervisors oversaw the big cylinders being hoisted onto trucks for the journey to Oak Ridge, remembered a former worker, James Southern. "Yeah, but they weren't pulling," interjected worker Henry Pointer, "the labor people were all black."

One young white laborer, John Fedor, who joined the company in 1939 with a tenth-grade education, was never permitted to enter the

Area C complex. He had no idea that the plant was performing secret war work for the government. "To work there you had to be cleared and I was not cleared to go in," he explained. Nevertheless Fedor grew worried about fluoride exposure at Harshaw's big hydrogen fluoride (HF) plant, which supplied Area C, and about the "terrible" conditions those workers endured. (He became a union organizer after the war.) His Safety Committee invited state inspectors inside the HF plant. Inside, fluoride levels as high as 18 parts per million were measured, six times the permitted safety standard.[70] "There were men walking around with rags over their noses, there were no respirators, there was no safety program," Fedor remembered. Burns and acid splashes were common. "The good Lord knows what it did to the inside of a person's body. How many people may have suffered fatalities over the years I have no idea," he added.[71]

Allen Hurt carries visible reminders of his years at Harshaw Chemical. He pulled a trouser leg up to reveal fifty-year-old scars he blamed on fluoride. "They didn't give you protection," he said. "It would eat the clothes and it would do the same thing to your skin." Sickness has stalked former employees, survivors claim. By the time the plant closed in 1952, an estimated 400 to 600 workers had been employed at the Area C plant. Cancer and heart ailments have been especially frequent among former workers, John L. Smith claims. "The people who worked there are dead. Those that ain't dead, there's five of them in the nursing home." The remaining veterans smolder with anger. Mostly, they wish they had been given the dignity of choosing their wartime fate. "At least we should have been properly informed," said Smith. "What few is left is as pissed off as they can be."[72]

"Hazards to the local population could occur"

WHEN HE WAS shown several declassified documents describing how fluoride and uranium were regularly vented from the Harshaw smokestacks, union organizer John Fedor was suddenly concerned. "I wonder about the immediate area," he remarked, "whether there were illnesses caused by that, or whether it just dissipated when it got in the air?"

Fedor is right to be concerned about the effects of fluoride on the area around Harshaw. It was not, of course, just the atomic workers who were secretly at risk from fluoride. From the beginning of the nation's nuclear program, officials worried about families living near bomb factories. "Hazards to the local population could occur if large amounts of fluorine or if fluorides were to be discharged in effluents," wrote the medical director Colonel Stafford Warren.[73]

Again, the fears proved accurate. Fluoride was secretly vented, and it spilled across communities in New Jersey, Pennsylvania, Kentucky, Tennessee, and Ohio.[74] Those releases increased as the United States expanded its cold war atomic arsenal and built two mammoth new gaseous diffusion plants, at Paducah, Kentucky, and Portsmouth, Ohio.[75]

Environmentalists often cite Cleveland's Cuyahoga River—which burst into flames in June 1969—as the lurid spectacle that helped bring about the Clean Water Act. The shocking sight of a waterway ablaze precipitated a moment of national clarity, focusing attention on the dumping of chemical wastes into the environment. Less well remembered, however, is a $9 million lawsuit brought in 1971 by the local Sierra Club against the Harshaw Chemical Company for fluoride pollution, which, the organization charged, had eaten and corroded the main Harvard Dennison Bridge over the same Cuyahoga river.[76] That bridge had to be rebuilt.

The government had watched the situation in Cleveland nervously. Following "complaints" in 1947, a team from the University of Rochester's Atomic Energy Project was quietly dispatched to measure fluoride pollution. The scientist Frank Smith secretly reported levels of 143 parts per million of HF venting from the Harshaw smoke stacks. (By contrast, 3 parts per million is the standard considered safe today for workplace exposure.) "The results are on the low side," Smith wrote, "since the efficiency of the sampling procedure we used is not too good for [elemental] fluorine and oxygen fluoride; if considerable quantities of these two gases were present in the air, we probably missed a part of them."[77] The AEC was worried about lawsuits. Dr. Smith pointed to several lower fluoride readings in his data. Those measurements, he said, might prove "the most valuable . . . [as they] in no case exceed the level declared legally permissible in Massachusetts, California and Connecticut."

Storm clouds continued to gather over Cleveland. A July 1949 AEC report warned that "although the complaints from civic organizations have been concerned with general atmospheric pollution, and neither fluoride nor uranium have been mentioned specifically, it is likely that as time progresses, the extent of air pollution by fluorides will receive attention."[78] The AEC ran more secret tests after a consultant, Philip Sadtler, was hired in 1949 by the local community to investigate Cleveland air pollution. While uranium releases were within permissible levels, they concluded that "the fluoride data, however, satisfied none of the criteria."[79]

Several of the former Area C workers confirmed that pollution was rampant. Allen Hurt parked his car downwind from the plant whenever he worked the night shift. "Overnight, fallout would come, and my black car was full of gray dust, and I washed if off and I could see little fine pits where it had ate into the paint. If it does that in metal, what would it do to us?" he wondered. Hurt recalled that local residents complained: "They had a problem with the people up on the hill, because it was coming up there and bothering their homes."

Environmental damage around atomic bomb plants was often widespread. At Oak Ridge, officials planned, in 1945, to dump 500 pounds of fluorides each day into the nearby Poplar Creek; a decade later, airborne fluoride emissions had scarred a fifty-square-mile area of wounded and dying trees, officials stated, and posed a clear threat to grazing animals. And in 1955, some 615,000 pounds of fluorine was "lost in the vent gases" from a single in-house plant making uranium hexafluoride at Oak Ridge.[80]

Lawsuits alleging fluoride human injury and destruction of crops and farm animals were sparked against DuPont's Chamber Works in New Jersey and the Pennsylvania Salt Company's plants in the Pennsylvania towns of Easton and Natrona.[81] At a second gaseous diffusion plant in Portsmouth, Ohio, which began operations in 1954, fluoride exposure was immediately declared a "significant liability" for "both employees and the general public," a document noted.[82] At the AEC's giant Feed Materials Production Center in Fernald, Ohio, waste fluorides were "the biggest single problem," where some 15,000 pounds of fluorides were being disposed of each month in the nearby Miami River, according to a pollution expert, Arthur Stern.[83]

And as late as the mid-1980s, thirty years after it began operation, the gaseous diffusion plant at Portsmouth, Ohio, was still dumping 15.6 tons of fluorides each year into the atmosphere.[84]

Darkness hid fluoride releases at the K-25 plant in Tennessee, according to former supervisor Sam Vest. "I could pull into the parking lot at night and smell it. I could tell they were releasing fluorine from the fluorine plant. They waited until after dark to release it, because it was just a horrendous cloud." Some workers found a strange beauty in the nighttime releases at Oak Ridge, Vest added. "Operators described it as being just beautiful, to just stand there and watch crystals on a clear cold night go up [into the air]."

5

General Groves's Solution

Dr. Harold Hodge and the University of Rochester

The Manhattan Project had seen the danger from fluoride early. Before the war private industry had contained the legal dangers from factory pollution by forming the Air Hygiene Foundation at the Mellon Institute. Also fearing lawsuits, in 1943 General Groves established the Manhattan Project's Medical Section at the University of Rochester to "strengthen the government's interests," placing Dr. Harold C. Hodge in charge of a secret unit studying fluoride and the other chemicals being used to make the atomic bomb.

FROM HIS CORNER office window in the medical school at Strong Memorial Hospital that summer of 1943, Dr. Harold Hodge could see construction workers placing the finishing touches on a half million-dollar building at the University of Rochester known as the Manhattan Annex.[1] The heavily guarded structure, funded by the U.S. Army, would be home to the Manhattan Project's Medical Section. Orders had been placed for hundreds of experimental animals: Puerto Rican monkeys, dogs, mice, rabbits, and guinea pigs.[2] And an umbilical cord–like tunnel linking the military annex with the university hospital was urgently being readied.

As the new Annex foundations were put down, so too was the keystone laid for the postwar practice of toxicology in the United States—and for the future career of the thirty-nine-year-old biochemist, Dr. Harold Hodge. The Annex would soon house the largest