Meltdown in the USSR

The story of the Chernobyl nuclear disaster and its import

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A CHILD OF THE ATOMIC AGE

As a child of the Atomic Age, and a budding scientist, even as a boy I harbored a deep and abiding fascination with all things nuclear. The vast, hidden power lurking deep inside the atom, as unveiled by ingenious nineteenth and twentieth century physicists making one startling discovery after another, both intrigued and haunted me, filling me with wonder and yet foreboding. This was true of many of my generation, born in the aftermath or the afterglow of the atomic fireballs and mushroom clouds that incinerated Hiroshima and Nagasaki.

The tiny nuclei of certain elements seemed to possess an incomparable potential to unleash unprecedented good or evil upon man and nature, a technological utopia or a dystopian hell. Nuclear fission and fusion occur when larger, unstable atomic nuclei such as those of uranium and plutonium are split apart or fissioned, or in the opposite case, when nuclei are fused together, as in the case of hydrogen, the smallest, lightest element and the nuclear fuel that powers trillions of stars in the cosmos. Helium is the result, as it is in our sun and the stars.

Which is the appropriate metaphor from the myths of yesteryear to describe man's discoveries: letting the atomic genie out of the bottle, or opening Pandora's Box? As a young Baby Boomer, "duck and cover" exercises and discussions of bomb shelters and the doctrine of Mutually Assured Destruction (MAD) were part of the "new normal" of my upbringing in this Brave New World, one wrought by the pursuit of pure science juxtaposed with the exigencies of total war.

My fascination perhaps bordered on the morbid at times. Yet for anyone with a modicum of curiosity about the deepest secrets of nature, the conversion of infinitesimal amounts of invisible matter in an atomic nucleus into enormous amounts of energy via the most famous equation of the twentieth century, Einstein's $E=mc^2$ in the special theory of relativity, simply beggars belief. Above all else, I was a curious child and young man, both curious about the universe around me, and a bit of a curiosity (as in an oddity) myself. In college, I preferred to be off by myself at night, searching for mysterious barn owls and screech owls that flitted about the darkened campus, rather than chasing coeds or hanging out in the dorm room drinking beer or smoking pot with the "normal, well-adjusted" guys on the hall. In a word, I was a geek years before that term was even coined.

MIDNIGHT IN CHERNOBYL
The Untold Story of the World's Greatest Nuclear Disaster
By Adam Higginbotham
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In high school I wrote a term paper about the dropping of the atomic bombs on Hiroshima and Nagasaki to end World War II in the Pacific. My dad was a U.S. Army veteran of the Pacific theater of World War II, and as a combat engineer, might have been among the 500,000 to one million U.S. casualties estimated by military planners if President Truman had decided to invade the Japanese homeland itself to force its unconditional surrender. The Bomb was claimed to have averted that terrible invasion, perhaps saving my father's

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life and allowing for my own eventual existence. Yet at a cost of many innocent Japanese civilian lives —although, arguably, not as many as would have perished in a full-scale Allied invasion, though we can never know this for certain.

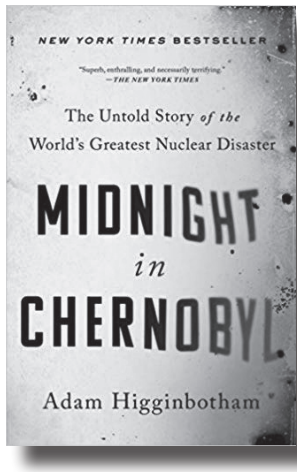
I read the powerful and moving, Pulitzer-Prize-winning 1946 book *Hiroshima* by John Hersey of *The New Yorker*, with its shocking firsthand accounts of eyeballs melting in eye sockets and other horrors. *Hiroshima* was based on Hersey's interviews with survivors of that annihilated city, destroyed by a single enriched-uranium fission bomb of 15 kilotons yield (equivalent to the energy release from exploding 15,000 tons of TNT). This weapon of staggering lethality was whimsically nicknamed Little Boy, which seemed in one sense an insensitive insult to the tens of thousands of men, women, and children it obliterated, and tens of thousands more to whom it brought years of cruel and chronic suffering.

I discussed and debated the ethics of the Hiroshima and Nagasaki bombings with doves and hawks alike, as well as with others who brought a unique perspective to the subject. My interlocutors over the years included a proud Japanese girlfriend of mine, Mineko, who, to my astonishment, thought Americans had little to apologize for, since Japan had started the brutal war of mass murder with their surprise attack on Pearl Harbor. They also included a senior member of America's nuclear weapons establishment, who, as a young electrical engineer in the U.S. Navy stationed on the island of Tinian in the Pacific, had worked on the electrical wiring for the B-29 Superfortress bomber, the *Enola Gay,* named after its pilot's mother. If a tossed coin had landed on the opposite side, my friend, then just in his mid-20s, would have been aboard that fateful flight early on August 6, 1945, piloted by brigadier general Paul Tibbets, which dropped the bomb over Hiroshima.

In the fifties, my dad, by then armed with a B.S. from Tufts University in chemistry, took coursework from Columbia University in nuclear physics and worked as an engineer for Westinghouse, helping to design and build nuclear reactors in U.S. Navy submarines. Later in life, I was married in Albuquerque, New Mexico, in the backyard of a director of the National Nuclear Security Administration's Sandia National Laboratory; during the Cold War, he used to negotiate nuclear arms control agreements with his Soviet counterparts.

While living in New Mexico, I also got to visit ground zero at the Trinity Site in person, where the first atom bomb in the 4.6-billion year history of the Earth was detonated on July 16, 1945. This test of an implosion-design plutonium device (similar to that dropped on Nagasaki) took place in the southern New Mexico desert, in a desolate valley near Alamogordo and the White Sands named *La Jornada del Muerto*, loosely translated from Spanish as the Journey of the Dead Man. Observing that epoch-shattering fireball and mushroom cloud from a safe distance, Robert Oppenheimer, head of the Manhattan Project's secret weapons laboratory at Los Alamos, New Mexico, famously remembered a verse from the Hindu holy book, the *Bhagavad Gita*: "Now I am become Death, the destroyer of worlds." Four decades on, I stood right at the very spot where the bomb had been detonated and temperatures briefly flared to many thousands of degrees; elevated radioactivity lingered still, but not enough to be harmful on a short visit.

Later still, I visited the Yucca Mountain site in Nevada with a busload of engineers. Yucca Mountain was intended as the final repository for high-level nuclear waste from America's civilian nuclear reactors, until opposition by U.S. Senator Harry Reid and other Nevadans torpedoed it. I also toured the otherworldly and remote Nevada Test Site, where the USA had exploded scores of aboveground and underground fission and fusion (atomic and thermonuclear) bombs. I stood at the rim of the enormous Sedan Crater on Yucca Flat, gazing into a gaping pit created several decades earlier as part of Operation Plowshare, idealistically but naively conceived to utilize nuclear weapons for peaceful civil engineering purposes. I remember thinking that in spite of the pockmarked, barren surface, this isolated desert location, surrounded by austere mountains, still possessed an ethereal, timeless natural beauty. It had endured the worst man could throw at it: blast waves, temperatures hotter than the sun, and intense alpha, beta, and gamma radiation bombardment that would have killed a human, or thousands of humans, in a blinding flash; yet it still retained an exotic, transcendent beauty.



I also worked as an environmental scientist and planner, managing an environmental impact statement (EIS) for the U.S. Forest Service, on a proposed underground uranium mine on national forestland in western New Mexico. This mine, if built, would provide uranium oxide (U_3O_8) ore for America's and the world's uranium supply, for use in civilian nuclear reactors. These reactors in turn could furnish relatively carbon-free electrical power in an era of growing concern about anthropogenic carbon dioxide emissions, CO_2 accumulation in the atmosphere, and global warming. The U.S. Department of Energy, for which I also consulted, deliberated over all of these considerations in its EISs, on projects ranging from actions at the nation's nuclear weapons complex to electrical transmission lines, wind and solar energy farms, and cutting-edge renewable energy and carbon sequestration projects.

On nuclear issues, there are always pros and cons, often very complicated or technical ones. And there are always scores of experts — to say nothing of hundreds of hotheads — prepared to passionately argue those pros and cons.

In *Midnight in Chernobyl: The Untold Story of the World's Greatest Nuclear Disaster*, veteran journalist Adam Higginbotham, who has written for *The New Yorker*, *New York Times Magazine*, *Wired*, *GQ*, and *Smithsonian*, recounts a riveting, disturbing tale of technological hubris, Soviet secrecy and folly, confusion, and heroic though foolhardy bravery. It is a vivid story told through the firsthand accounts of the men and women whose lives were changed forever — or brought to a premature and tragic end — by what happened in a matterof seconds in the control room of Unit 4 of the Chernobyl nuclear complex in the Ukraine — officially named the Vladimir Ilyich Lenin Nuclear Power Plant — late at night on April 25 and early in the morning of April 26, 1986. In those critical seconds, the nuclear genie escaped the bottle and slipped its bonds, to devastating effect. Higginbotham draws upon hundreds of hours of interviews with eyewitnesses, spanning more than a decade,as well as on unpublished journals, diaries, letters, and recently declassified documents.

Higginbotham starts his story by giving some needed background and context for the hard-charging Soviet civilian nuclear power program, although more focused than I do here.

In both the Soviet Union and the United States, the initial rationale for advancing nuclear technology was military: fear that a dreaded enemy might soon acquire (or had already acquired) a weapon of unimaginable destructive potency. In 1938, German chemists Otto Hahn and Fritz Strassmann discovered nuclear fission, and the theory behind it was soon elucidated by Lise Meitner and Otto Frisch, rendering an atomic bomb at least theoretically possible. On August 2, 1939, in the month before a resurgent Nazi Germany invaded Poland to officially start World War II in Europe, Albert Einstein signed and sent his famous letter to President Franklin D. Roosevelt. Written by immigrant Hungarian physicist Leo Szilárd, after conferring with fellow immigrants Hungarian physicists Edward Teller and Eugene Wigner, the letter Einstein signed warned that the recent discovery of nuclear chain reaction in a critical mass of uranium could be used to build "extremely powerful bombs."
The Szilárd/Einstein letter continued:

> A single bomb of this type, carried by boat and exploded in a port, might very well destroy the whole port together with some of the surrounding territory. However, such bombs might very well prove to be too heavy for transportation by air.

This latter speculation, of course, about such atomic bombs potentially being too heavy for an airplane to carry and deliver to a target, proved not to be the case, as the aerial bombings of Hiroshima and Nagasaki demonstrated decisively. But Einstein's warning that the Germans had stopped the sale of uranium from Czechoslovakian mines they had commandeered, with its implication that the mighty *Wehrmacht* and formidable German scientific establishment might be investigating nuclear fission as an über-weapon, certainly caught Roosevelt's attention. In 1942, he authorized the top-secret Manhattan Project, which resulted in the rapid development of atomic bombs and their deployment just three years later in Japan, after a shattered Germany had already surrendered. On August 29, 1949, thanks to Stalin's crash program and his network of spies and Communist sympathizers in the West, the Soviets exploded their own atomic bomb, just four years after the Americans had. And the nuclear arms race was on.

Within several years more, both countries had successfully tested hydrogen fusion or thermonuclear bombs, utilizing two isotopes of hydrogen — deuterium and tritium, with one and two neutrons, respectively — and unleashing an explosive force orders of magnitude greater than a mere fission bomb.

In a display of the USSR's strength and determination, on October 30, 1961, the Soviets detonated Tsar Bomba ("King of Bombs" in Russian), also nicknamed Big Ivan, over the island of Novaya Zemlya in the Arctic Ocean. In a glowing illustration of the "gigantomania" that often characterized the USSR in its single-minded determination to best or bury the Capitalist West, this was the largest thermonuclear bomb ever tested by either country. It resulted in the single most powerful manmade explosion ever documented.

Originally set for a yield of 100 megatons of TNT, it was reduced to 50 megatons because the radioactive fallout from the higher yield was deemed too dangerous. Yet even scaled down, Big Ivan was still 3,800 times more powerful than Little Boy, which had annihilated Hiroshima. And for the first time in history, the world began to seriously contemplate the prospect of Nuclear Armageddon as the arms race between the USA and the USSR heated up. Nuclear weapons and their "delivery systems" (intercontinental ballistic missiles or ICBMs, submarine-launched ballistic missiles or SLBMs, multiple independently targetable reentry vehicles or MIRVs, etc.) grew ever more sophisticated and accurate, while weapons stockpiles swelled. This was one particularly chilling facet of the so-called Cold War, the geopolitical struggle for global mastery between the two ideologically opposed superpowers and their acolytes, allies, and minions. Before long, the United Kingdom, France, and China had joined the "nuclear club," followed by Israel, India, Pakistan, and North Korea. Nuclear proliferation was both vertical (larger stockpiles) and horizontal (more countries with nuclear weapons).

In 1963, the Partial Test Ban Treaty was signed, prohibiting nuclear testing in the atmosphere, under water, and outer space. Yet in the previous decade and a half, more than 500 nuclear weapons had already been exploded above ground as testing and development proceeded. These open-air tests dispersed large quantities of radioactive particles and gases into the atmosphere, which could be transported long distances by atmospheric circulation before falling back to earth as so-called radioactive fallout. People and other living things could be exposed to the resulting radiation, once these by-products of nuclear activity return to the biosphere. The radioactive isotopes strontium-90 and iodine-131 were of particular concern, raising the risks for leukemia and thyroid cancer.

Looking back decades later from the vantage point of 2019, scientists at the Centers for Disease Control and Prevention and the National Cancer Institute have concluded that the public health risks from that early atmospheric nuclear testing actually turned out to be rather small for most people. Yet it was good that it was stopped when it was, in time to avert much more widespread radiological contamination. And certainly, by the late fifties and early sixties, the fear of exposure to spectral radioactivity lurking in and pervading the figurative ether was very real, widespread, and understandable, in the wake of the carnage at Hiroshima and Nagasaki.

Even as nuclear weapons complexes proliferated in the U.S., USSR, and other countries, the nuclear arms race spiraled upward toward a fearsome future. Scientists, policy-makers, and politicians in both primary Cold War adversaries were dreaming up more benign applications for what was dubbed, in one of the twentieth century's greatest initiatives at rebranding, the "peaceful atom." Now that the colossal potential energy locked inside the atomic nucleus had been discovered, the culmination of centuries of accelerating scientific breakthroughs, surely this hard-won knowledge could be harnessed for peaceful purposes, for the betterment of humankind rather than its destruction. Surely we could beat swords into plowshares, advancing medicine, agriculture, civil engineering, and electricity generation.

Walt Disney — entertainer extraordinaire, animator, film producer, and propagandist for the American Way — referred to "our friend, the atom." In 1953, former Supreme Allied Commander and U.S. President Dwight D. Eisenhower delivered a speech entitled "Atoms for Peace" to the U.N. General Assembly, and the U.S. Postal Service celebrated the occasion and the ideal with a new postage stamp. International concern over Egypt's nationalization of the Suez Canal in 1956 drove consideration of using nuclear explosives to excavate a second canal.

In the U.S., the Atomic Energy Commission (AEC — precursor agency to both the Department of Energy and the Nuclear Regulatory Commission) established Operation Plowshare in 1958, whose aim was to explore the technical and economic feasibility of applying nuclear explosions to civil engineering, industrial, and resource extraction projects. Investigators studied the use of nuclear explosives in large excavation schemes, underground fracturing of geologic formations for oil and gas production and mineral leaching, creation of artificial aquifers, and manufacture of chemical isotopes. Twenty-seven of these nuclear tests were conducted up to 1975, when Operation Plowshare was terminated for environmental, technical, and political reasons.

Likewise, in the USSR, geophysicists and engineers pioneered the use of peaceful nuclear explosions to stimulate lagging fossil fuel production in oil and gas fields, extinguish oil and gas well fires, mine mineral ores, incinerate nuclear and chemical waste, excavate underground storage reservoirs for chemical wastes and gas condensate, and implement large-scale geophysical engineering schemes. In their characteristic hubris, the Soviets referred to the application of nuclear detonations in the construction of canals, ports, and reservoirs as "correcting the mistakes of nature." A large number of these peaceful nuclear explosions were carried out, even in more populous realms of the European USSR, with scant regard for their potential health, safety, or environmental consequences, according to Professor Paul Josephson, author of *Red Atom: Russia's Nuclear Power Program from Stalin to Today* (1999).

NUCLEAR POWER: TOO CHEAP TO METER — OR AN ACCIDENT WAITING TO HAPPEN?

Applications for electricity and the aggregate electrical demand (a grid's "load") expanded exponentially after the Second World War. As the industrialized world became ever more electrified, it was in the generation of electrical energy — the circular flow of electrons (an electric current) in a conductor, generated by a rotating copper coil in a magnetic field — that nuclear science and engineering appeared to find its most beneficial application, providing the greatest good to the greatest number. In June 1954, the Soviet Union beat both the United States and the United Kingdom in becoming the first country to build an operational nuclear power reactor (at Obninsk) and connect it to an electric power grid. At just 5 megawatts (5 MW), it was quite small, elfin in size and output compared to the 1,000 MW reactors that would follow in the coming decades.

It didn't matter if dissident physicist and alternative energy guru Amory B. Lovins disparaged electricity generation in a thermal power station with steam turbines as overkill, an inelegant, inefficient use of nuclear fission, the equivalent of "using a chain saw to cut butter." Back in the fifties, the grand wizards of science and high priests of science policy deemed that nuclear power would become "too cheap to meter" (in the immortal words of AEC chairman Lewis Strauss). These arrogant attitudes were on full display both in the USA and the USSR. They were a specific manifestation of a widespread phenomenon: a smug technological hubris that had built up throughout the developed world after the centuries of stunning, spectacular scientific and technological progress. This progress had liberated men and women from drudgery and grinding poverty, from drab, dreary lives that were once denigrated as "nasty, brutish, and short."

This hubris was reflected in such slogans as "Better Living Through Chemistry." Throughout the twentieth century, but especially from the sixties onwards, as the unintended consequences and side-effects from the unbridled applications of ever more impressive scientific and technological achievements became ever more apparent, this simple-minded arrogance began to be confronted. Books such as *New Yorker* writer John McPhee's *The Control of Nature* (1989) appeared, which challenged the conventional wisdom that "progress" was all good, all the time. Sometimes nature was not amenable to our meddling, harnessing, exploitation, and control, and sometimes the adverse effects of such efforts at control might outweigh the beneficial effects. So-called cures could be worse than the diseases they purported to fix.

Powdered infant formula was not healthier for babies than mother's breast milk, even if it was more convenient and "modern." Brittle technologies could break. Aldous Huxley wrote a prescient novel about an imaginary dystopian future in *Brave New World*, while his British colleague C.S. Lewis discussed factors that might bring about *The Abolition of Man*. The Sierra Club, under its innovative, feisty executive director, David Brower, popularized the expression of its founder John Muir: "not blind opposition to progress, but opposition to blind progress."

Then there was the nagging issue of commercial nuclear power reactor safety. Back in 1976, as an undergraduate at Virginia Tech, I took and aced a 1 credit-hour elective in atomic energy for non-majors taught by a nuclear physicist in the College of Engineering. One of the major takeaways from that class was that concerns about nuclear reactor safety then being raised by the public and anti-nuclear power activists were blown far out of proportion. In their plant designs and operational procedures, engineers and physicists had built in multiple redundant safeguards and precautions that reduced the chance of accidental releases of radioactivity from nuclear power plants to levels that should satisfy any normal person who didn't freak out about the minuscule risk of getting struck by lightning or a meteorite.

Our professor introduced us to the Rasmussen Report (WASH-1400, or the Reactor Safety Study) on nuclear reactor safety, published in 1975 by a committee of specialists under the direction of MIT Physics Professor Norman Rasmussen. Using a fault tree/event tree analytical approach — called Probabilistic Risk Assessment (PRA) — WASH-1400 investigated the possibility of serious, radiation-releasing accidents in large modern light-water reactors, the nuclear reactor design most prevalent in the United States.

WASH-1400 determined that the risks to the public posed by commercial nuclear power plants were acceptably small, even minute, compared to other known acceptable or unavoidable risks. Specifically, it concluded that the probability of a complete core meltdown was about 1 in 20,000 per reactor-year. Looking at the representative year of 1969 in particular, WASH-1400's Table 6-3, "Individual Risk of Early Fatality by Various Causes," compared the risk of fatalities posed by nuclear accidents at 100 reactors (zero) to a number of other prevailing risks in American society at that time:

Accident Type	Total Fatalities in 1969	Approximate Individual Risk of Early Fatality (Probability/Year)
Motor Vehicle	55,791	3×10^{-4} or 0.0003
Drowning	6,181	3×10^{-5} or 0.00003
Poison	4,516	2×10^{-5} or 0.00002
Firearms	2,309	1×10^{-5} or 0.00001
Air Travel	1,778	9×10^{-6} or 0.000009
Falling Objects	1,271	6×10^{-6} or 0.000006
Electrocution	1,148	6×10^{-6} or 0.000006
Lightning	160	5×10^{-7} or 0.0000005
Tornadoes	118	4×10^{-7} or 0.0000004
Hurricanes	90	4×10^{-7} or 0.0000004
Nuclear accidents*	---	2×10^{-10} or 0.0000000002

Note: At 100 reactors modified from Table 6-3, WASH-1400

The Lewis Committee, chaired by University of California-Santa Barbara Physics Professor Harold

Lewis, peer-reviewed the Rasmussen Report in 1977, and the Lewis review largely vindicated the PRA methodology as the best then available. However, at the same time, the Lewis Committee and other critiques cautioned that WASH-1400's specific risk figures were of dubious validity because of questionable assumptions, methodology, calculations, peer review procedures, and objectivity. Subsequently, when the serious accident occurred, at Three Mile Island (TMI) in 1979 (which did not result in any immediate fatalities), it triggered even greater scrutiny of WASH-1400's methods and findings. These analyses often reached sharply divergent findings as to the safety and reliability of commercial nuclear power in the U.S.

Three Mile Island Nuclear Power Plant and the Susquehanna River in Pennsylvania; the largest structures, roughly conical in shape with water vapor venting to the air, are cooling towers.

A report issued by the American Physical Society (APS) "found much to criticize" in WASH-1400. It observed that WASH-1400's fatality estimates had included only those that occurred in the first 24 hours following an accident, ignoring other fatality pathways. One such pathway involved radioactive cesium-137, which could cause chronic environmental exposures to large numbers of people, albeit at small doses, well after the initial acute phase of an accident. Cancers might not appear for many years or even decades later. The APS report also criticized WASH-1400's methodology for predicting the performance of reactor core emergency cooling systems. Another report by Science Applications Inc. (SAI, the predecessor of massive federal contractor SAIC) found that WASH-1400 underestimated accident frequency, while a simultaneous study by the Institute of Nuclear Power Operators found SAI's own estimate 30 times too high. Still another report by the nuclear watchdogs at the activist nonprofit, The Union of Concerned Scientists, was highly critical of WASH-1400.

Higginbotham's *Midnight in Chernobyl* briefly discusses the TMI incident, the first major accident at a nuclear power plant, that humbled and humiliated a nation's nuclear establishment, leading to a substantial loss of prestige. This didn't happen in the Soviet Union, but began to unfold early on the morning of March 28, 1979, at the Three Mile Island (TMI) nuclear generating station on the Susquehanna River, near Harrisburg, Pennsylvania's state capital. Minor equipment malfunctions and human error led to a loss of coolant, and the reactor core began to melt down, partially filling the containment building with radioactive water. Staff were forced to vent radioactive gases to the atmosphere, but these consisted of isotopes with short half-lives that drifted out over the Atlantic Ocean and quickly dispersed and decayed. (Radioactive half-life is the time it takes for half the mass of a radioisotope to undergo radioactive decay into its daughter products, and depending on the element and isotope, can range across many orders of magnitude, from split-seconds to billions of years.)

While the TMI accident caused no deaths from radioactivity, it still provoked widespread panic in the surrounding population and major traffic jams on regional roads, when 135,000 residents tried to flee in their vehicles. Yet in spite of its lack of even a single fatality, TMI's failure triggered far-reaching and long-lasting effects on the growth of the nuclear power industry in the United States: in the following years, dozens of reactors were cancelled in various stages of construction. Even prior to TMI, the public had already been growing more anxious about nuclear power's risks, skeptical of nuclear waste disposal, and concerned about massive cost overruns at a number of plants under construction. After the TMI incident, nuclear power lost the trust of many politicians and much of the public.

According to Higginbotham, ominously and tellingly, news of the TMI accident was censored by authorities within the Soviet Union, even though it made their capitalist American adversary look bad, "for fear it could tarnish the ostensibly spotless record of the peaceful atom. Publicly, Soviet officials attributed the accident to the failings of capitalism." An official at the prestigious Kurchatov Institute, the USSR's leading nuclear energy research and development institution, wrote an article claiming that the Three Mile Island experience was irrelevant to the Soviet nuclear industry, "because its operators were far better trained and its safety standards higher than those in the United States."

Valery Legasov of the Kurchatov Institute boasted in January 1986 that: "In the thirty years since the first Soviet nuclear power plant opened, there has not been a single instance when plant personnel or nearby residents have been seriously threatened; not a single disruption in normal operation occurred that would have resulted in the contamination of the air, water, or soil." Famous last words. And false words. Higginbotham and others document numerous incidents that were covered up by Soviet authorities because they were regarded as sensitive state secrets.

Just three months later, complacent Soviet nuclear officials would go from gloating and crowing about the superiority of their program over that of the Americans, to eating crow, and lots of it.

PRIDE OF THE UKRAINE, BANE OF THE UKRAINE

In January 1986, the Soviet Union's embassy in the United States had published a new issue of its glossy, English-language magazine, *Soviet Life*, which featured a ten-page special section devoted to the marvelous new technology of nuclear energy that was transforming the USSR. It displayed color photos of the Chernobyl nuclear power plant and its smiling staff, as well as the proud residents of Pripyat, Ukraine, the model city "born of the atom" — an *atomgrad*. Pripyat had grown up alongside Chernobyl, and housed most of the plant's workers and their families.

The Chernobyl reactor was located in northern Ukraine, then a Soviet Republic, 75 miles from Kiev.

One of the strengths of *Midnight in Chernobyl* is its elaborate detail in describing the cast of characters and the surreal, frightening forces they were up against early on the morning (the middle of the night, actually) of April 26, 1986, and the following days and weeks. The reader identifies with these confused, hapless, and helpless human beings, struggling in the face of a grim catastrophe beyond their comprehension. Black and white photos give us glimpses of the warmth and humanity of these mere mortals: plant director Viktor Brukanhov, his wife Valentina, and their young son Oleg posing for the camera with wild mushrooms they had picked in Pripyat's nearby woods; handsome 24-year old senior mechanical engineer Alexander Yuvchenko, his wife Natalia, and their two-year-old son Kyrill; lead radiation reconnaissance scout Alexander Logachev, with his cute toddler daughter hoisted up on his shoulders. Brukanhov went to prison, and Yuvchenko died, because of their roles in the disaster.

So what went wrong at Chernobyl? In brief, a seriously flawed Soviet reactor design (the widely deployed RBMK) combined with operator error to unleash a localized Hell on Earth. The Chernobyl disaster was also a direct result of Cold War isolationism, the Soviet penchant for secrecy, especially on nuclear matters, and the concomitant absence of a culture of safety.

Soviet secrecy was strong even under reformist Communist Party General Secretary Mikhail Gorbachev, who had come to power just a year earlier, in March 1985 (when I happened to be aboard a large Soviet fishing ship operating in Alaskan waters of the Bering Sea, monitoring catches and compliance as a fisheries scientist for the U.S. National Marine Fisheries Service), and was just beginning to implement his policy of *glasnost* (openness). The only reason the Soviets confessed to the Chernobyl disaster at all is because radiation sensors at several nuclear installations outside of the USSR — hundreds of miles from the destroyed Chernobyl reactor — recorded irrefutable evidence of a nuclear incident with massive radiation release within the USSR that was all but impossible to deny without losing face, and even more credibility in the international community.

The accident occurred at 1:24 AM local time on April 26, some 40-60 seconds after beginning a test simulation of an electrical power outage. Ironically, the purpose of the test was to help develop a safety procedure for maintaining the circulation of reactor coolant (water) until back-up generators could provide electricity. An operational gap of about one minute had previously been identified as a potential safety hazard that could cause the nuclear reactor core to overheat dangerously and begin to melt down.

The supervisor of the simulation failed to follow procedure, creating unstable operating conditions. Combined with intrinsic RBMK reactor design flaws and the intentional disabling of several nuclear reactor safety systems as part of the test, this resulted in an uncontrolled nuclear chain reaction (nuclear fission). A large amount of thermal energy (heat) was then created very suddenly, vaporizing superheated coolant and rupturing the reactor core, in an extremely destructive steam explosion that blew the 2,000-ton lid (affectionately nicknamed "Elena") off the reactor and demolished the roof of the building.

Several seconds later there was a second explosion, this one with features of a nuclear detonation, with a yield of about 300 tons of TNT (0.3 kilotons, or one 1/50th the yield of the Hiroshima bomb). According to eyewitnesses, the first of the explosions was followed by a red blaze, and the second explosion produced a light-blue blaze, after which a mushroom cloud briefly appeared above what was left of the reactor core.

This was immediately followed by an open-air reactor core fire that continuously released large amounts of radioactivity-laden smoke into the atmosphere for nine days. These radioactive particles, in turn, were precipitated onto parts of the USSR and Eastern and Western Europe as radioactive fallout, before the open-air fire was at last contained on May 4.

It is estimated that the Chernobyl explosion and fire ejected some 400 times more radioactive material into the Earth's atmosphere than the atomic bomb exploded at Hiroshima. In contrast, in aggregate, all above-ground nuclear weapons tests in the 1950s and 1960s are estimated to have released between 100 to 1,000 times more radioactive materials into the atmosphere than the Chernobyl disaster. However, the radioactivity emitted at Chernobyl tended to be more persistent than that of a bomb detonation, and thus the two events cannot be directly compared. In addition, a radiation dose spread across many years (as is the case with Chernobyl) is less harmful than the same dose received in a short period.

The Aftermath and the Upshot

Some 24 hours after the explosion, bewildered, distraught officials in cover-up mode still had not informed Pripyat's 50,000 residents about the night-time explosion at the nuclear plant, or warned them about the threat of radioactive contamination. Nor had they provided the public with preventive iodine pills to counteract the effects of radioactive iodine-131. Meanwhile, radiation levels in Pripyat began to rise, varying widely and seemingly at random, spiking up to a thousand times above natural background levels in places.

Then, the next day, in an abrupt reversal, Pripyat's residents went from receiving no information or warnings at all to being ordered to evacuate immediately. This took place within 48 hours of the accident, on the afternoon of April 27, mostly by bus. Pripyat's inhabitants were permitted to bring only the most essential items; they were told they would be returning in three days, but in fact they never saw their homes again. Information was restricted to avoid panic and to prevent people from trying to take too much luggage and personal belongings with them. (The information blackout could backfire, because rumors ran wild.) Later, because of lingering and even increasing levels of radioactive contamination, Soviet authorities determined that the much ballyhooed model city and its environs would have to be abandoned permanently. Pripyat remains a ghost town to this day, 33 years after the disaster. Eventually, the so-called Chernobyl Exclusion Zone was enlarged to 1,004 square miles.

The purpose of the Exclusion Zone is to restrict public access to radiologically hazardous areas, to reduce the spread of radiological contamination, and to carry out radiological and ecological monitoring and studies. Even today, in 2019, the Chernobyl Exclusion Zone continues to be one of the most radioactively contaminated areas in the entire world. It attracts substantial interest from scientists interested in investigating the effects of high levels of radiation in the environment. The zone is also now receiving increasing interest from adventure tourists.

The accident and subsequent explosion killed one worker immediately and a second soon afterwards from injuries. Acute Radiation Syndrome (ARS) was originally diagnosed in 237 people onsite, helping extinguish the fire and assisting with clean-up; ARS was confirmed in 134 of these cases. Of these, 28 people died from ARS within a few weeks of the accident. Nineteen others died

UPPER LEFT: Chernobyl Nuclear Power Station in the Ukrainian Soviet Socialist Republic; UPPER RIGHT: Chernobyl Power Plant Unit 4 was destroyed by the explosion early on April 26, 1986, but the problems had just begun.

subsequently between 1987 and 2004, though these deaths could not be linked definitively to radiation exposure at Chernobyl.

ARS did not afflict anybody offsite, but radioactive fallout did contaminate large regions of Belarus, Ukraine, Russia, and beyond to varying extents. In the broader population, an excess of just 15 childhood thyroid cancer deaths had been documented as of 2011. However, incubation periods for radiation exposure to induce cancer are often long. Because of this, the UN Scientific Committee on the Effects of Atomic Radiation has reviewed all the published research, and estimated that fewer than 100 documented deaths, to date, are likely attributable to increased radiation exposure from the Chernobyl accident.

A group of Liquidators gathered at the Museum of Slavutych on the 32nd anniversary of the Chernobyl disaster, 2018. Note the clock on the wall behind (above the photo of the reactor), stopped at 1:24, the exact instant the crisis began in Unit 4. *Photo credit*: **Tom Skipp**

More than half a million emergency "liquidators," both civilian and military personnel, were ordered into action to confront the crisis, or "liquidate" the threat of another explosion, extinguish the fire, and reduce radioactivity. Liquidators included nuclear plant staff, firefighters, Civil Defense troops of the Soviet Armed Forces, military reserve units, internal troops and police, military and civil medical and sanitation personnel, and Soviet Air Force and civil aviation units, who made hundreds of gallant helicopter runs dumping a cocktail of lead, clay, and dolomite into the wreckage, in a futile effort to quench the raging graphite fire. In some places they had to work, radiation was so intense that individual liquidators were limited to mere minutes of total exposure. Any longer and they jeopardized their health and lives. This is why more than half a million liquidators were used. Liquidators are widely acknowledged with having limited both the short-term and long-term adverse consequences of the disaster. Humans were often sent in to do hazardous cleanup when the extreme radiation had scrambled even the circuitry of robots, which proved relatively ineffectual.

Calculating the total eventual number of radiation exposure-related deaths is technically fraught, and is based on a contested statistical methodology that has also been used in modeling the results of low-level radon gas and air pollution exposure. Model predictions of Chernobyl's eventual total death toll in the coming decades are quite variable. They range from 4,000 excess fatalities when counting only the three most contaminated former Soviet states (Ukraine, Belarus, Russia), to about 9,000 to 16,000 excess fatalities when taking into account the entire European continent.

To prevent further dispersion of radioactive materials from the remains of Unit 4 and to protect the accident site from further weathering, the Unit 4 wreckage needed to be enclosed or entombed. In a truly herculean effort, the Chernobyl Nuclear Power Plant "sarcophagus" was constructed hastily and finished in December 1986. The sarcophagus was also intended to protect personnel at the three undamaged reactors at the Chernobyl plant; Unit 3 continued to generate electricity right up until 2000. As noted, the sarcophagus was hastily constructed, and even before it was completed, it had begun to deteriorate. Due to its continuing corrosion and the hazard this posed, both the sarcophagus and the Unit 4 reactor were further encapsulated in 2017 by the internationally funded Chernobyl New Safe Confinement. This is a still larger enclosure that will contain the radioactive hazard while facilitating the disassembly and decommissioning of the reactor, and while preventing water intrusion. Not until 2065, nearly eight decades after the accident itself, is nuclear clean-up scheduled for completion.

The Chernobyl disaster is ranked as the worst nuclear accident in history to date. It is one of just two civilian nuclear energy disasters rated at seven — the highest severity — on the International Nuclear Event Scale. The other is the 2011 Fukushima Daiichi nuclear disaster in Japan, caused by an earthquake and tsunami.

While the Three Mile Island accident in the United States arrested the expansion of the commercial nuclear power industry in the U.S. for some decades, the impact of Chernobyl was far more widespread and global. Its

Investigating the Impossible

Saturday, April 26, 1986: 4:16p.m.
Chernobyl Atomic Energy Station, Ukraine

Senior Lieutenant Alexander Logachev loved radiation the way other men loved their wives. Tall and good-looking, twenty-six years old, with close-cropped dark hair and ice-blue eyes, Logachev had joined the Soviet army when he was still a boy. They had trained him well. The instructors from the military academy outside Moscow taught him with lethal poisons and unshielded radiation. He traveled to the testing grounds of Semipalatinsk in Kazakhstan, and to the desolate East Urals Trace, where the fallout from a clandestine radioactive accident still poisoned the landscape; eventually, Logachev's training took him even to the remote and forbidden islands of Novaya Zemlya, high in the Arctic Circle and ground zero for the detonation of the terrible *Tsar Bomba*, the largest thermonuclear device in history.

Now, as the lead radiation reconnaissance officer of the 427th Red Banner Mechanized Regiment of the Kiev District Civil Defense force, Logachev knew how to protect himself and his three-man crew from nerve agents, biological weapons, gamma rays, and hot particles: by doing their work just as the textbooks dictated; by trusting his dosimetry equipment; and, when necessary, reaching for the nuclear, bacterial, and chemical warfare medical kit stored in the cockpit of their armored car. But he also believed that the best protection was psychological. Those men who allowed themselves to fear radiation were most at risk. Bit those who came to love and appreciate its spectral presence, to understand its caprices, could endure even the most intense gamma bombardment and emerge as healthy as before.

As he sped through the suburbs of Kiev that morning at the head of a column of more than thirty vehicles summoned to an emergency at the Chernobyl nuclear power plant, Logachev had every reason to feel confident. The spring air blowing through the hatches of his armored scout car carried the smell of the trees and freshly cut grass. His men, gathered on the parade ground just the night before for their monthly inspection, were drilled and ready. At his feet, the battery of radiological detection instruments—including a newly installed electronic device twice as sensitive as the old model—murmured softly, revealing nothing unusual in the atmosphere around them.

But as they finally approached the plant later that morning, it became clear that something extraordinary had happened. The alarm on the radiation dosimeter first sounded as they passed the concrete signpost marking the perimeter of the power station grounds, and the lieutenant gave orders to stop the vehicle and log their findings: 51 roentgen per hour. If they waited there for just sixty minutes, they would all absorb the maximum dose of radiation permitted Soviet troops during wartime. They drove on, following the line of high-voltage transmission towers that marched toward the horizon in the direction of the power plant; their readings climbed still further, before falling again.

Then, as the armored car rumbled along the concrete bank of the station's coolant canal, the outline of the Fourth Unit of the Chernobyl nuclear power plant finally became visible, and Logachev and his crew gazed at it in silence. The roof of the twenty-story building had been torn open, its upper levels blackened and collapsed into heaps of rubble. They could see shattered panels of ferroconcrete, tumbled blocks of graphite, and, here and there, the glinting metal casings of fuel assemblies from the core of a nuclear reactor. A cloud of steam drifted from the wreckage into the sunlit sky.

Yet they had orders to conduct a full reconnaissance of the plant. Their armored car crawled counterclockwise around the complex at ten kilometers an hour. Sergeant Vlaskin called out the radiation readings from the new instruments, and Logachev scribbled them down on a map, hand-drawn on a sheet of parchment paper in ballpoint pen and colored marker: 1 roentgen an hour, then 2, then 3. They turned left, and the figures began to rise quickly: 10, 30, 50, 100.

"Two hundred fifty roentgen an hour!" the sergeant shouted. His eyes widened.

"Comrade Lieutenant—" he began, and pointed at the radiometer.

Logachev looked down at the digital readout and felt his scalp prickle with terror: 2,080 roentgen an hour. An impossible number.

Logachev struggled to remain calm and remember his textbook; to conquer his fear. But his training failed him, and the lieutenant heard himself screaming in panic at the driver, petrified that the vehicle would stall.

"Why are you going this way, you son of a bitch? Are you out of your [f%@&king] mind?" he yelled. "If this thing dies, we'll all be corpses in fifteen minutes!" ■

[Prologue, *Midnight in Chernobyl: The Untold Story of the World's Greatest Nuclear Disaster* by Adam Higginbotham, Simon and Schuster, 2019: pp. 1-3.]

overall cost to date, in multiple countries, has been pegged at $235 billion. The accident stimulated safety renovations on all remaining Soviet-designed RBMK reactors, ten of which are still in operation as of 2019. Chernobyl led many countries and even the Soviet Union itself to question the naive faith they'd placed in nuclear power to deliver affordable, reliable, and, above all, safe electrical energy to meet growing economies' ever-growing demands for additional energy. Many countries, especially in Europe, put their plans for expansion of nuclear energy on hold, or even considered phasing out existing facilities. Former Soviet leader Gorbachev has stated that the Chernobyl disaster was an even more important catalyst in precipitating the fall of the Soviet Union than *perestroika* and *glasnost*, his campaigns for liberal reform and openness.

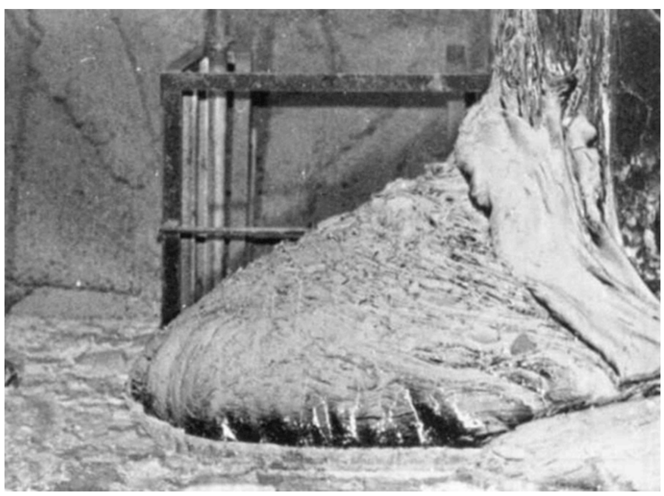
In spite of the proven risks nuclear power has posed to workers, safety, public health, and the environment, does it still have a role to play in meeting the world's surging demand for electrical energy in an ever more climate-and-carbon-constrained world? Many would argue yes. Some of them are even a growing number of scientists and environmentalists deeply concerned about anthropogenic climate change due to carbon emissions from fossil fuel combustion.

Many others would argue no, and not just on the basis of the risk of devastating accidents highlighted in this review of *Midnight in Chernobyl*. Nuclear power is inherently and prohibitively costly, and renewable, "green" alternatives are getting cheaper all the time. Radioactive waste disposal, fissile material proliferation, and nuclear theft and terrorism challenges have yet to be resolved. And perhaps most fundamentally, dwindling reserves of high-grade uranium ore are a limiting factor in how much nuclear power can grow and how long it can last. Nuclear power based on nuclear fission of enriched uranium is not a renewable energy source.

Not so fast, say nuclear's advocates, among them prominent climatologist James Hansen, formerly with NASA's Goddard Institute for Space Studies, and now with Columbia University's Earth Institute, and the UK environmentalist and writer George Monbiot. Newer reactor designs are inherently safe, and naturally occurring thorium (just two spots away from uranium on the Periodic Chart of the Elements) resources are much more abundant in the Earth's crust than uranium. As I said at the outset of this article,

> "On nuclear issues, there are always pros and cons, often very complicated or technical ones. And there are always scores of experts — to say nothing of hundreds of hotheads — prepared to passionately argue those pros and cons."

The role of the atom — and human use and abuse of the atom's nucleus — in shaping the course of human events in the twentieth century cannot be understated. The atom's role in the twenty-first century and beyond will undoubtedly be substantial as well. Adam Higginbotham's excellent new book, *Midnight in Chernobyl,* documents as never before, with thoroughness and compassion, what happened in one particularly tragic and costly case, in which humans were less in control of nature than they assumed. The case is an instance in which Icarus flew too close to the Sun and plunged back to Earth. Or to use a more topical, sports-friendly metaphor, an instance in which "Nature Batted Last." ■



ABOVE LEFT: Nature reclaims the abandoned ghost town of Pripyat, which had nearly 50,000 residents in April 1986 before the Chernobyl disaster three decades ago. ABOVE RIGHT: The lethally radioactive (10,000 roentgens per hour) "Elephant's Foot" of "corium" in the Chernobyl Unit 4 reactor core meltdown: in 1986, five minutes of exposure would provide a lethal dose to a human.