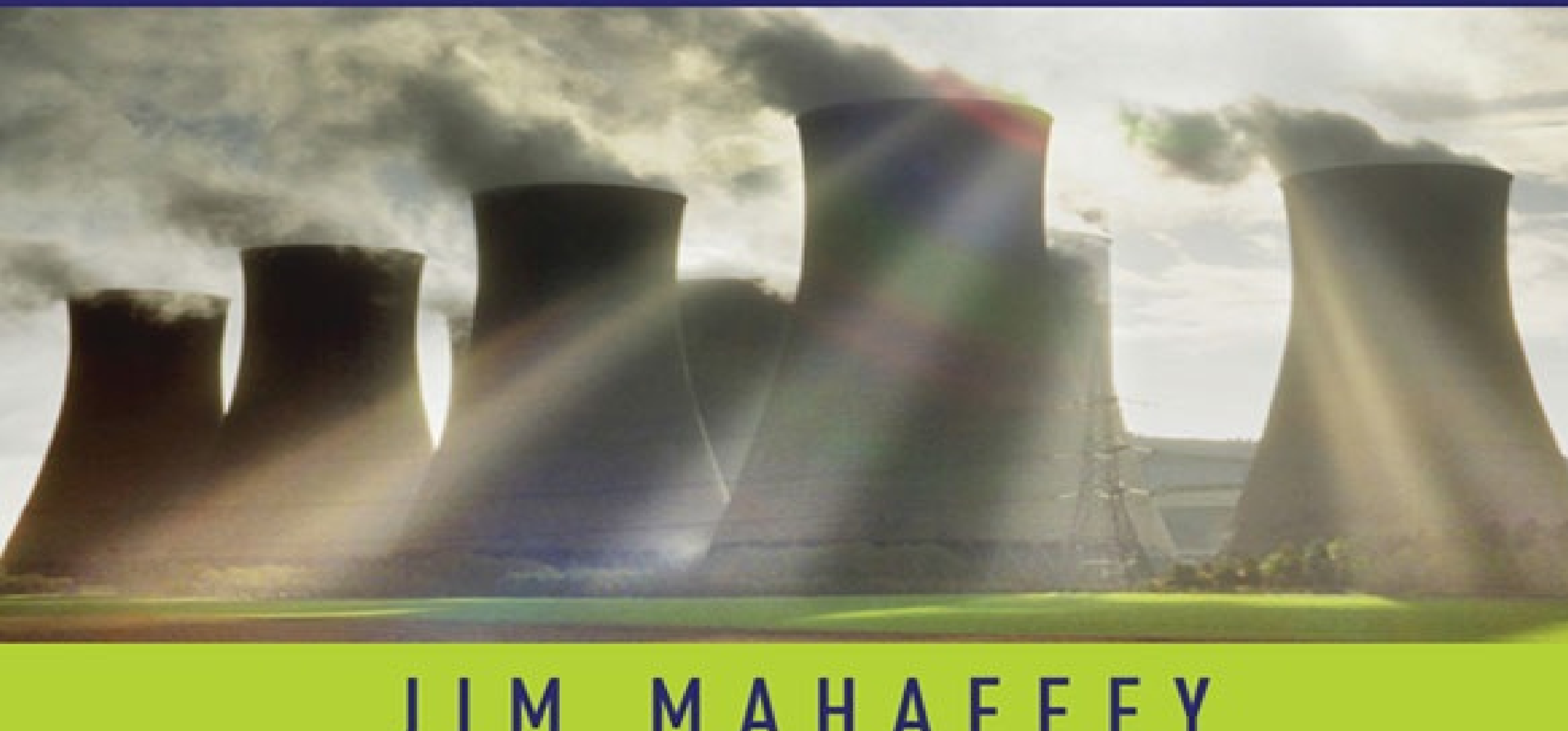
PEGASUS BOOKS

ATOMIC ACCIDENTS

A HISTORY OF NUCLEAR MELTDOWNS AND DISASTERS

FROM THE OZARK MOUNTAINS TO FUKUSHIMA



JIM MAHAFFEY

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JAMES MAHAFFEY

PEGASUS BOOKS
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For Mrs. King

My seventh-grade English teacher, who thought I should write

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A TRIUMPH OF SOVIET TECHNOLOGY

Nuclear engineers love and admire hydroelectric power. It's perfectly clean. It makes no smoke, n carbon monoxide, no radioactive waste, no toxic exhaust or lingering byproduct of any kind. Unli nuclear power, it's very simple. Dam up a river. Let the water from the top of the resulting lake fa through a pipe, gain energy, and spin a turbine. Connected directly to the turbine shaft, without an gears or transmission, is a multi-pole electrical generator. Three wires emerge from the side of th generator. Connect those to the transformer yard, and you're sending electricity to paying custome 24 hours a day, or as long as there is water in the lake.

It is shockingly quiet on the turbine deck. The spinning machinery, usually covered with ceram tiles made in subdued pastel colors or mounted flush with the floor, makes a high-pitched but subdue whine. The walls tremble, but only slightly, sometimes just beyond perception. The deck is spotless clean, and above, looking down on the machinery, is the glassed-in control room. Banks o instruments read out the status of the turbines, which is invariably good. Being a hydro-plant operat has got to be a boring job. You sit there as the generators go round and round, decade after decade, an the silt slowly builds up at the base of your dam. Excitement is when water starts to trickle dow where it isn't supposed to on the face of the dam, or a big snow-melt upstream has to be diverted ov the spillway, but aside from that it's fairly dull. If all the electrical power could be generated wi hydro dams, then the world would be a cleaner, calmer place.

There are many fine hydroelectric dams in the United States, each demonstrating the America ability to bend nature to our needs with well-thought-out engineering practice and the skill necessa to build large things. In 1961 the United States and the Soviet Union were engaged in an all-out war. was a cold war, in which the purpose was not to see how many of the other side we could kill but prove who had the superior experimental economic system. It was an American form of capitalis against a Russian form of communism, and the battles raged on many fronts. The Soviets had alread cleaned our plow in the race for manned space flight, putting Vostok 1 with Yuri Gagarin into orbit o April 14. We were falling way behind.

Thinking to show the U.S., which had built the magnificent Hoover Dam in Nevada, how to real build a hydroelectric plant, the Soviet Union decided to construct the world's largest reservoir produce an impressive 6.4 billion watts of power using a line of ten turbo-generators. Work began build an enormous dam, 3,497 feet wide and 807 feet high, across the Yenisei River near Sayanogors in Khakassia. The Sayano-Shushenskaya Hydro Power Plant took 17 years to build. This single da generated one tenth of the power used in Siberia, and 70 percent of it was used to smelt aluminum. 2006 production peaked, and the dam produced 26.8 trillion watt-hours of electricity. It was the six largest hydroelectric plant in the world, and it was built to withstand a Richter 8.0 earthquake. It w listed in the Guinness Book of World Records as the sturdiest dam in existence.

The water intake pipes on a dam are called penstocks, which is a carryover from the days of wood water wheels. The sieve at the intake that keeps floating stuff like canoes or swimming bears out the penstocks is the trash rack. The rotor, or the part of the turbine that spins, is called the runner, a it is hit with water from all sides. The force of the water and therefore the power that turns t generator is controlled precisely by hydraulically actuated wicket gates encircling the runner.

The turbine hall was magnificent, finished in white with gray and sky blue accents, with a curv picture window a couple of stories tall forming the front wall and looking out over the gently flowi Yenisei river, reformed from the turbine exhausts into an idyllic, park-like setting. An extremely lar traveling crane, capable of easily picking up a 156-ton turbine runner, ran the length of the hall rails in the ceiling.

On the morning of August 17, 2009, Unit 2 was the master turbine, setting the pace for the others follow and running at a precise 142.86 revolutions per minute. Each turbine had its own pensto down from the top of the dam and its wicket gates constantly followed the directions from Unit 2, b there were only nine turbines running that morning. Unit 6 was down for maintenance, and unusually large number of workers were down on the deck worrying over it.

At 8:13 local time something in the water, probably a loose log, made it through the trash rack at t top of the dam, fell 636 feet through the Unit 2 penstock, and lodged in the runner. Not good. In fraction of a second, the log had spun around and slapped shut all the wicket gates, and the turbi jerked to a low speed. The turbines were extremely smooth and stable in two conditions: running full speed and standing still. In any other condition while connected to the electrical grid, they wou vibrate. Unit 2, the master turbine, suddenly lost speed as its water was cut off. It was no long generating power, and was instead pulling power out of the other generators, acting as an electr motor. Unit 2 started hopping up and down, wrestling with its sudden change of identity and statu The bolts holding the top on Unit 2 blew off, and the 900-ton turbo-generator jumped out of the flo Suddenly having no speed control from Unit 2, Units 7 and 9 quickly reached runaway speed a started flinging parts through what was left of the picture window. The Unit 2 penstock collapsed a destroyed everything around it.[1]

Having no penstock to contain it, Lake Sayano-Shushenskoe started emptying into the powerhous Units 3, 4, and 5 were still generating power, but they could not do it correctly while under water. T main transformer exploded, sending 40 metric tons of cooling oil, mixed with highly tox polychlorinated biphenyls, down the Yenisei. The overhead crane wrenched loose from its rails a crashed through the floor, followed by the ceiling caving in on the only units left running. In a matt of seconds, a sweetly running hydroelectric plant was reduced to a twisted mass of water-soak wreckage. Pieces were scattered hundreds of feet away, and the once-beautiful powerhouse looked if it had been crushed under a giant’s foot and then ground up just to make a point. After weeks searching, the remains of 74 workers were found in the ruins. One was never found, making the to 75.

The potential power of a simple mass of water is amazing, particularly when it is leveraged by a 63 foot drop. In a few moments, a placid lake of life-giving water had killed 75 people, destroyed a lar power plant, and contaminated the drinking water for everyone downstream with a virulent carcinog called PCB. In 1986 it would take the Chernobyl-4 RBMK nuclear reactor several weeks to end t

lives of 54 men. Both power plants had been built about the same time, and both were the pride
Soviet technological advancement.

The problem of water inappropriately forced on a large power plant would come up again, this tin
in Japan in 2011. We now call this incident “Fukushima.”

1 This is one of three possible explanations for the Sayano-Shushenskaya Dam disaster, and it is my favorite. The official report on the accident, released on October 3, 20 concludes that six bolts holding the cover on the generator were missing (only 49 were found), and excessive vibration caused the cover to fly off. Maybe. You say y didn’t hear about this on the news? At the time, a popular singer named Michael Jackson had died from the improper use of an anesthetic, and the world was too spellbou to consider any other disasters.

BILL CRUSH AND THE HAZARDS O STEAM UNDER PRESSUR

My I can assign a date was in 1954. I was three months shy of my fourth birthday, and the event h stuck clearly in my mind for all these years.

Back then, there was a regional railroad in north Georgia named the Gainesville Midland. It was small operation, always strapped for cash, and it was probably the last railroad in Georgia to run stea locomotives. The flagship of the line was a decapod, a heavy freight engine having ten driver wheel number GM207, named “the Russian.” It was so named because it was built by the Baldw Locomotive Works in Eddystone, Pennsylvania, in 1916, under contract with Czar Nicolas II, Emper and Autocrat of All the Russias. It was ready to ship in 1917, but Nicolas was under severe stress the time, and payment was not forthcoming. Finding the Russian government completely collapse Baldwin sold its entire inventory of oddly specified 2-10-0 decapods at auction in an attempt recover manufacturing costs. The Gainesville Midland wound up with three of them, and Baldwin w happy to readjust the gauge for the light tracks in Georgia.

The Russian looked incomprehensibly huge to me. How could something so big, so massive, move all? It blotted out the sun when it passed, throwing black soot high into the crisp autumn air a causing the ground to move under my feet like a Japanese earthquake. The boiler sat so high, I cou see daylight through the spokes in the drive wheels as it thundered by at top speed, making 35 mil per hour pulling a mixed string of five cars. On the downhill, you could outrun it on a bicycle. It r back and forth, between Athens and Gainesville, roughly alongside the Winder Highway.

One Sunday afternoon we were at my grandparents’ house in Hoschton, Georgia. The town used to on the Gainesville Midland line, but the tracks had been torn up in 1947 when the route was cancelle The train station was still there, empty of purpose like other buildings in the hamlet that had se more prosperous times. It was a slow day.

It had been raining constantly for the past week, and everything in Georgia was soaking w including the fellow who came to the door with urgent news. “Colonel!” he cried. “The Midland do wrecked!”

Granddaddy dropped his *New York Times* and rose to his feet. “Wrecked?”

“Yes, sir! It’s the Russian. She’s off the rails, up yonder, nearly t’ Gainesville.” He pointed vague west.

This was no time to be sitting around listening to the house settle. We piled into the Studebaker a hot-wheeled it up the road to a wide spot that no longer exists, called Candler, just south

Gainesville. You could feel the spectacle growing as we approached. Cars were parked or abandone off the road. First a few, then clumps, then seemingly every car in the world. People were walkin jogging, and sprinting, all in one direction, pointing and shouting. We pulled off and started walking.

After trudging about a hundred miles we reached a sharp turn, where the tracks veered off to the le and there it was, lying on its side, wheels in the air, like a dead dinosaur. The heavy Russian had take the turn too fast, and the red clay under the tracks, saturated with water, just slid out from under it. could swear the thing was still breathing. Periodically you could hear steam burbling somewhere de inside its enormous body. People were just standing there in awe of the spectacle, uncountab hundreds, quietly staring and whispering to each other. Someone said that the engineer had to be c out of the wreckage with an acetylene torch. I stood on my tiptoes and tried to see the twisted wreck the cab. It was too far away, down a hill.[2]

I learned something that day, and it had nothing to do with going too fast around a curve: there's great deal of entertainment value in a train wreck. Even the aftermath of a crash, with the engi upside down and cars scattered all over the place, is surprisingly theatrical—a tragedy in hot stee plowed mud, and scattered coal. There was sport in just analyzing the disaster, thinking what cou have happened, back-tracing the last moments of the engine's life, and imagining it digging the lo trench as its energy dissipated into the ground. If it were roped off, you could sell tickets.

As is almost always the case, I was not the first to think of this. In 1896 a passenger agent for t Missouri, Kansas & Texas Railway (Katy), William "Bill" Crush, came up with a brilliant publici stunt that would drum up passenger business. Being a natural-born salesman, he was able to convin his boss that they should stage a head-on collision between two locomotives. With a little advertisin it would attract thousands of people! There would be no charge to see the crash, but they could se train tickets to bring people to the event. At two dollars per roundtrip ticket, they would not only ga publicity for their railroad, they would clear a profit as well.

In the 19th century, rail travel was the premier form of ground transportation, and just abo everybody spent time in a railcar, gazing out the window as the rural terrain sped by or sleeping in t sitting position. Steam trains were large, heavy, fearsome beasts, breathing fire and looki dangerous. Some people were excited by the technical advances that had made this ma transportation possible, and some were terrified of it. There were too many newspaper stories eve day about train wrecks. It seemed that engines were always blowing up for no obvious reaso crashing into each other, tilting off the rails, or plunging off a trestle into a gorge. There were citize who could not be forced onto a train at gunpoint. Engineers blamed impossible schedules and poor maintained tracks. Conductors blamed engineers. Railyard workers blamed brakemen, and railro owners blamed the newspapers for lurid prose.

In 1891, a particularly bad year, 7,029 Americans lost their lives in railroad accidents. There we only about 64.4 million Americans at the time, so that makes the fatality rate 1.4 times that automobile travel in 2011. The idea of staging a train wreck in 1896 was a superb piece of psycholog Instead of assuring passengers that all trains were safe and nobody could get hurt, show them t worst that could possibly happen. Let them feel the heat blast, the steam escape, and the groun trembling thud. Allow them to get as close as they dared, and, what was most essential, let them see coming. There would be no buried dread of the random, completely unexpected accident. The fear the unknown would be replaced by the excitement of expectation.

A bare patch of ground outside the city limits of Waco, Texas, was staked out, and a set of temporar tracks was laid. Two obsolete 4-4-0 American pattern locomotives, looking like Civil War relics, wer purchased and dolled up. One was painted green with red trim, and the other was painted red wi green trim. Boxcars were added, with advertising for the Oriental Hotel in Dallas and the Ringlin Brothers Circus painted on the sides. Tents were erected. A temporary restaurant was built, as well a a jail, and a 2,100-foot-long platform was banged together to give people a place to stand and watc the show. Eight tank cars filled with water were brought in to prevent spectator dehydration.

The event was scheduled for September 15, and by then the crowd had grown to over 40,000 soul As an afterthought, Bill Crush was asked, "Is this safe? Them old boilers ain't gonna explode, a they?"

Since the invention of high-pressure steam earlier that century, boiler explosions had become th number one fear of everyone participating in the steam-power revolution. Boiler explosions had bee killing anyone standing near an over-pressurized locomotive since 1831. Steam carried a lot of pen up energy. It wasn't just the immediate fire under the boiler that was the problem, it was the he energy built up and stored in the steel vessel that was so dangerous. A steam explosion could happe at any time, out of the blue, without a hint of warning. A boiler would disintegrate, sending hot, knife like pieces ripping mercilessly through a crowd. It was not the sort of publicity that a railroad ev needed.

"Naw," said Bill, patting the still-sticky paint. "These old engines are tough. It's just going to make big noise and crush it like a tomato can. No blow-up. I'm sure." Of all the employees in the Katy, Bi Crush probably knew the least about steam and mechanical stress.

The afternoon was getting hot, and the crowd was growing restless. Two hundred men were hired t control the mob, but it was beginning to get out of hand. The two engineers were ready at the throttle the boilers were redlined, and the steam relief valves had sprung open and were blowing mist. Crus rode out in front of the crowd on a borrowed white horse, raised his hat high, let it hang for a momen then dropped it. The crowd went wild, and the engineers jerked their throttles full open. C. E. Stanto in the green engine and Charles Cain in the red one coolly waited for 12 puffs from the cylinders an bailed out, with the lightly loaded engines gaining speed. People pushed and shoved for a unobstructed view.

On they came, blowing dark clouds of smoke and setting off emergency signal torpedoes placed a along the track. Bang. Bang. Bang bang bang. Faster and faster, reaching a combined collision spee of 100 miles per hour. The official event photographer, J. C. Deane, tripped his high-speed shutter ju as the two cowcatchers met. The two old engines, weighing about 35 tons each, suddenly occupied th same spot on the track. There was a terrific sound of crashing, bending metal as the two locomotiv melted together, lifted their front trucks off the track, and seemed to hang for an instant. The woode cars behind splintered and crushed as the two trains telescoped together.

Then, something bad happened. At least one of the boilers exploded with a heavy roar, sending a ra of jagged metal into the crowd. The first casualty was Deane, the photographer, stationed closest t the crash point. A piece of hot locomotive hit him in the face, cleaned out an eye-socket, and left bolt and washer embedded in his forehead. He spun around to face the audience and went limp. Lou Bergstrom, also on the photography team, was cold-cocked by a flying plank. Ernest Darnall, a bo with a rare viewing opportunity sitting high in a tree, caught a heavy iron hook trailing a length chain right between the eyes, splitting his skull down the middle. DeWitt Barnes, in a dignifie standing position between his wife and another woman, was killed instantly by an unidentifi

fragment. People in the front row were scalded, screaming, and dripping blood. In all, three peop
were killed on the spot and six were very seriously injured. A Civil War veteran was visibly shaken
saying that it reminded him of seeing a line of men dropped by a Yankee rifle volley.

Instant tragedy, however, did not dampen the crowd's enthusiasm. They rushed the scene by th thousands in an incoming wave, poring over the wreckage to pick up or wrench loose the large pieces they could carry. Many palms were singed as people pounced on bolts, rivets, bits of boil tubes, and all manner of unidentifiable relics. To appease grieving families, Bill Crush wa immediately and visibly fired from his job at the Katy. He was quietly re-hired the next day. From th day forward, the Katy Railroad flourished, and the many who had decided not to go to the eve regretted the decision for the rest of their lives, as the stories of "The Crash at Crush" were told ov and over in song, ragtime march, musical play, and *Sports Illustrated*.

Bill Crush wasn't even the first to think of this. Incredibly, there were four independently stage engine head-butts in September 1896. None was as spectacular as Crush's 100-mile-per-hour boil bust, but the clustering indicates an unfulfilled need in the human psyche, peaking in 1896. Ju outside Denver on September 30, two old narrow-gauge 2-6-0 Union Pacific and Denver & Gu engines were smushed together for a crowd as a fund-raiser for the Democratic Party.[3] The cras made a lot of smoke and noise, but the engines were so feeble, the railroad was able to rebuild the and put them back into service.

On September 18 at the county fair in Sioux City, Iowa, two ancient Mason Bogey engines we smashed together to a cheering mob. In Des Moines at the State Fair on September 9, just six day before Crush's spectacle, "Head-On Joe" Connolly arranged the collision of two really old 4-6- engines bought as junk from the Des Moines Northern & Western Railroad. The teeming masse numbered 70,000, and the gate receipts exceeded $10,000. That was a lot of money in 1896. Connol was more adept at staging a crash than was Crush, and he knew to avoid a steam explosion. He ha nothing to worry about. The elderly, arthritic engines were leaking steam at every joint. One was ab to make 10 miles per hour, and the other 20. They hit at almost the right spot in front of the stand there were the obligatory smoke and noise, and parts cartwheeled through the air, but the crowd wa slightly disappointed. Still, they swarmed over the heap of steaming wreckage and carried o everything that was loose. Connolly returned home with $3,538.

Head-On Joe went on to make a career of locomotive crashing, eventually boasting that he ha staged 73 wrecks, without killing a single spectator. He put together shows from Massachusetts California, mostly at state fairs but anywhere people would gather and pay to see two trains smas together. The city with the most staged crashes was San Antonio, Texas, with four. New York City Milwaukee, and Des Moines had three each. His biggest audience was at the Brighton Beac Racetrack, New York, on July 4, 1911, where 162,000 people paid at the gate to see two old 4-4- engines kill each other. There were imitators, of course, but Head-On Joe had it down to a science. H knew that he had to have at least 1,800 feet of track, or the engines could not make enough speed for proper spectacle. A track length of 4,000 feet was optimal, as the engines could accelerate to combined speed of 45 miles per hour. That was fast enough to tear up the machinery and make th tender ride up over the cab without a boiler explosion. It took a mile of track to make 65 miles p hour combined, but that was too fast. Boiler explosions were fine, but you had to have the onlooke so far away, they couldn't see anything. They wanted to be close enough to feel the collision, to he the iron screaming in agony, and smell the hot metal, without being maimed. The locomotives had be inexpensive and junky, without being undersized or wheezy. To wreck two nice-looking passenge engines seemed extravagant and in bad taste. To bury two old freight haulers in a moment of glor seemed merciful. Sometimes the engines looked hesitant as they tried to accelerate toward oblivio Sometimes they looked angry, like pit bulls, not really knowing why they had to kill the other engin but up to the task and really getting into it. It was art, in a machine-age sort of way.

At 73 years old, Head-On Joe's last staged train wreck was back in Des Moines, on August 27, 193 at the State Fair. A matched pair of 4-6-0s, just retired from the Chicago, Milwaukee, St. Paul & Pacific, faced off on the field. Both were freshly painted, and they were named "Roosevelt" an "Hoover." Roosevelt was aimed east, toward Washington, D.C. A respectable mob of 45,000 came t see them on their last trip. After a short but suspense-filled run, the engines met, with the dram intensified by a box of dynamite tied to the pilot on each participant and fire-starters in the trailin passenger coaches. Hoover's boiler exploded, rudely injuring two spectators with hurled shrapne There would be no lawsuits. They were, after all, standing near where they knew there was going to b a train wreck. What did they expect? Connolly collected his $4,000 and quietly faded away to h home town in Colo, Iowa. When he died in 1948, a brass locomotive bell was found on the fami estate, possibly the only souvenir he had kept from the destruction of 146 train engines.

The last staged train wreck in the United States was probably the one near Magnolia, Illinois, o June 30, 1935. Two 2-6-0s from the Mineral Point & Northern, the 50 and 51, were supposed to me on a bridge going a combined 50 miles per hour, but they missed the point, impacting instead in a open field at a fraction of the required speed. Coal flew vertically out of the 51's tender and a puff o smoke rose, but the damage was so slight and the spectacle was so pitiful, it didn't make the mornin paper. The age of the staged train wrecks ended with a whimper. A creative plan to replace them wit airplanes crashing into each other in mid-air did not materialize.

The need to see train engines crash together may have played out in the 1930s, but the specter exploding locomotives would affect engineering for generations. Even today, in the 21st century, mo of the safety design effort in a nuclear power plant is devoted to preventing a steam catastrophe. nuclear plant is, after all, just another steam engine, heating water to a temperature beyond the boilin point and using the resulting vapor to rotate a shaft. The main difference between a nuclear generatin station and its equivalent 100 years ago is that disintegrating uranium has replaced burning coal as th source of heat.

Numerous substitutes for steam as the prime mover in a power plant have been tried, but nothing h proven more reliable, efficient, or economical than boiling water. The task of converting heat in electrical current is not straightforward, but using steam as the transfer medium means that a larg output plant can be compact, and the working fluid is neither toxic nor flammable. Sitting on a sma plot of land next to a river, a four-boiler steam plant can light up everything for a hundred miles, an if it is nuclear-powered then there is not even a pile of coal cinders and a mile-long line of rail ca waiting to be unloaded. Still, there is the fear of a steam explosion, something that impressed itself o both the public and the technical acolytes long ago.

In the early years of nuclear power development, in the technology scramble after World War I early experiments and some small disasters pointed out the dangers of a runaway nuclear reaction. practice, it was possible to increase the power output of a nuclear reactor not as a gradual he transfer, like boiling water on the stove to make tea, but as a step function, or an abrupt increase in th blink of an eye. If you were standing near such an occurrence, you died, and it had the potential flashing water directly and promptly into steam. The possibility of a runaway reaction and a resulti steam explosion was seen as the most critical safety concern in nuclear power development. If on this worst possible accident could be designed out of nuclear reactor plants, then everything el would be taken care of. All we had to do was keep the steam from exploding, and nuclear power wou be stable enough to unleash on a safety-conscious public.

And so it was. With testing, accident simulations, well-thought-out engineering effort, and unusual robust building standards, the possibility of an explosive steam release was forcibly eliminated fro nuclear power plants. In 56 years of commercial nuclear power generation in the United States, the has never been a steam explosion, and not one life has been lost.[4]

No dreaded boilers coming apart, ripping holes in buildings and sending shrapnel into the crowd worry about, but everything else in the history of nuclear accidents has happened for what seem to the most insignificant, unpredictable reasons, much to the consternation of engineers everywher Entire reactor plants, billions of dollars of investment, have been wrecked because a valve stuck op or an operator turned a switch handle the wrong way. Some water gets into a diesel engine cooli pump, and six reactors are wiped out. Imagine the frustration of having built an industry having t thickest concrete, the best steel, meticulously inspected welds, with every conceivable problem failure having a written procedure to cover it, and then watch as three levels of backup fail one at time and the core melts. Obviously, the machinery was more sensitive to simple error than anyo could have thought, and thicker concrete is needed.

All the issues to be addressed concerning accident avoidance are not technical. Some are deep philosophical. It is painful to notice, but some of the worst nuclear accidents were caused by react operator errors in which an automatic safety system was overridden by a thinking human bein Should we turn over the operation of nuclear power plants to machines? Would this eliminate t strongest aspect of human control, which is the ability to synthesize solutions to problems that we never anticipated? The machine thinks in rigid, prescribed patterns, but in dealing with a cascade problems with alarms going off all over the place, has this proven to be the better mode of though Should operators be taught to think like machines, or should they be encouraged to be creative? Stu the history of nuclear disasters, and you will have this subject to ponder.

There is also the elephant in the room: ionizing radiation. Nuclear engineers are acutely aware of th elephant and have designed it out of the way. Concrete thickness helps a lot to keep radiation aw from all workers at the plant and certainly out of the public. The human fear of radiation is special a pervasive. As you will see, it originates in the initial shock of discovery, when we were introduced the unsettling concept of death by an invisible, undetectable phenomenon. We have never quite gott over it, and, in fact, all the fear of a steam explosion is not connected to the problem of hurtli chunks of metal or the burning sensation, but directly to the problem of radiation dispersal into t public. Steam, when it escapes in an unplanned incident at the reactor plant, takes with it pieces of t hot nuclear fuel. It floats in the air and blows with the wind, transporting with it the dissolved, high radioactive results of nuclear fission. This undesirable process is at the root of accident avoidance the nuclear power industry. Employee safety is, of course, very important, but public safety is eve more so. To keep the industry alive, thriving, and growing, it is imperative that the general populati not feel threatened by it.

Feeling threatened is not the same as being threatened, but the difference gets lost. The danger fro low levels of radiation is quite low, as expressed as morbidity statistics or probabilities, but there is unfortunate lack of connection to probability in the average person. Low probabilities are a particul problem of perception. If they were not, then nobody would play the lottery and the gambling indust would collapse. The impression of radiation, and even the science, can get lost in the numbers. reading these chronicles of nuclear incidents big and small, I hope that you can develop a sense for th origins and the realities of our collective dread of radioactivity. Will this universal feeling prevent th full acceptance of nuclear power? Will we develop a radioactivity vaccine, or will we gradually evolv into a race that can withstand it? Perhaps.

There is also the problem of the long-term radiation hazard. People do not mind a deadly threat s much if it leaves quickly, like an oil refinery going up in a fireball or a train-load of chlorine ga tankers crashed on the other side of town. For some reason, a cache of thousands of rusting, leakin poisonous nerve-gas cylinders in Aniston, Alabama, does not scare anyone, but the suggestion o fission products stored a mile underground at Yucca Mountain, Nevada, causes great concern.

In this book we will delve into the history of engineering failures, the problems of pushing into th unknown, and bad luck in nuclear research, weapons, and the power industry. When you see it all i one place, neatly arranged, patterns seem to appear. The hidden, underlying problems may come in focus. Have we been concentrating all effort in the wrong place? Can nuclear power be saved fro itself, or will there always be another problem to be solved? Will nuclear fission and its long-ter waste destroy civilization, or will it make civilization possible?

Some of these disasters you have heard about over and over. Some you have never heard of. In all o them, there are lessons to be learned, and sometimes the lessons require multiple examples before th reality sinks in. In my quest to examine these incidents, I was dismayed to find that what I thought knew, what I had learned in the classroom, read in textbooks, and heard from survivors could b inaccurate. A certain mythology had taken over in both the public and the professional perceptions o what really happened. To set the record straight, or at least straighter than it was, I had to find an study buried and forgotten original reports and first-hand accounts. With declassification at th federal level, ever-increasing digitization of old documents, and improvements in archiving an searching, it is now easier to see what really happened.[5]

So here, Gentle Reader, is your book of train wrecks, disguised as something in keeping with ou 21st century anxieties. In this age, in which we strive for better sources of electrical and motiv energy, there exists a deep fear of nuclear power, which makes accounts of its worst moments o destruction that much more important. The purpose of this book is not to convince you that nucle power is unsafe beyond reason, or that it will lead to the destruction of civilization. On the contrary, hope to demonstrate that nuclear power is even safer than transportation by steam and may be one the key things that will allow life on Earth to keep progressing; but please form your own conclusion The purpose is to make you aware of the myriad ways that mankind can screw up a fine idea whi trying to implement it. Don't be alarmed. This is the raw, sometimes disturbing side of engineerin about which much of humanity has been kept unaware. You cannot be harmed by just reading about i

That story of the latest nuclear catastrophe, the destruction of the Fukushima Daiichi plant in Japa will be held until near the end. We are going to start slowly, with the first known incident of radiatio poisoning. It happened before the discovery of radiation, before the term was coined, back when w were blissfully ignorant of the invisible forces of the atomic nucleus.

2 I'm not sure what happened to GM207. I've found GM206, GM208, and GM209, all resting comfortably in display settings. GM208 is in Winder, GM209 is in Gainesv and GM206 is somewhere in North Carolina at a railway museum. All are Russian-pattern 2-10-0 locomotives, but only GM206, built by Alco-Brooks, is said to have b

built for Russian export in 1918. I swear the wrecked engine was called “The Russian,” but the story is hazy, and I don’t even know why such a tiny railroad needed many engines.

3 For those who may wonder, “2-6-0” is the standard way of specifying a steam locomotive configuration. This particular engine has two wheels on the pilot truck, six stea driven wheels, and no trailing truck behind the drivers.

4 I have to be careful here not to fall into the usual pro-nuclear trap of overstating a concept. Several people have been killed in nuclear industry accidents, and many of th incidents will be discussed here. The worst nuclear accident in American history was a steam explosion, but it was a military reactor. So far, every death that can be positiv linked to nuclear activity has been of military personnel, government workers in the atomic bomb industry, or a civilian working in fuel reprocessing. Nobody has d because he or she was working in a commercial nuclear power plant in the United States. The Soviet Union is another matter.

5 A good example of this enhanced document availability is in my search for the original report, “The Accident to the NRX Reactor on December 12, 1952, DR-32,” by W. Lewis. This was a very important accident. It was the world’s first core meltdown, and it happened at the Chalk River facility in Canada. I had heard about it many times, I wanted the raw document. It seemed that every nuclear data repository I could think of, even in Canada, had an abstract of the paper, but not the paper itself. After a lo digging I found it. The Russians had it, possibly recovered from the old KGB archives. This turned out to be a gold mine of information, including such things as accou of the “Castor and Pollux” vertical assembly machines used in the development of the French atomic bombs.

CHAPTER

WE DISCOVER FIRE

“In Ozma’s boudoir hangs a picture in a radium frame. This picture appears to be of a pleasant countryside, but when anyone wishes for the picture to show a particular person or place, the scene will display what is wished for.”

—from a description of a plot device in L. Frank Baum’s *Land of Oz*, thought to be placed somewhere on the Ozark Plateau.

It was hunting season in the Ozark Mountains in November 1879. Sport hunters Bill Henry, Joh Dempsey, and Bill Boyceyer of Barry County, Missouri, were out to shoot a wildcat. They had le their hunting party behind, chasing a cat through the dense woods with their enthusiastic hunting do The dog, with his seemingly boundless dog-energy, ran full tilt down a gulley, then straight up the si of a steep hill, chasing the cat through previously untrampled territory. The cat looked desperat Leaping around on the side of the mountain, he disappeared into a black hole, and the hound did n hesitate to dive in after him.

The three men, somewhat winded from the pursuit, knew they had him now. They cocked the pieces, aimed high at the orifice, and waited for the cat to come blasting out. The wait becam uncomfortable. Fifteen minutes, and not only was there no cat, but the dog hadn’t come back. The half-cocked their firearms and started to climb, but just then they heard the dog barking, somewhe on top of the hill. They whistled him down. He had obviously gone clean through the mountain a come out the other side.

Henry, Dempsey, and Boyceyer immediately found this hole in the side of the mountain mo interesting than the wildcat. They had been around here before, but had never noticed the hole. It w oddly placed, and it would be easy to miss. It required investigation.

Cautiously, the three entered the opening. Shortly inside they saw along the wall what appeared to b a vein of pure, silvery metal, and dollar signs came up in their eyes. Could it be? Could they hav stumbled into an undisturbed silver mine? It was growing dark, and they decided to retire to th hunting camp and do some planning. Nobody was to say anything to anybody about the hole, and the would return tomorrow for a more thorough exploration. The next morning they returned to the sit dogless this time but with a boy to help carry things. They lit pitch-pine torches and crawled into th opening, single file, with Henry leading. The cavern opened up, and everything in it looked stran and unfamiliar. At about two hundred feet in, the tunnel was partially blocked by what looked like large tree trunk of solid silver. It was the strangest metal they had ever seen, with the bluish sheen of peacock’s tail. In the yellow glare of the torches it seemed faceted, like a cut diamond. In the tigh unfamiliar surroundings, imaginations ran wild. Henry selected a free rock on the floor and used it bang on the mineral column. A few unusually heavy pieces chipped off, and they put them in a sma tin box for transport.

Still feeling the tingle of adventure, they squeezed one at a time past the silvery obstruction ar pressed on. At an estimated five hundred feet from the entrance they entered an arched room, and the perceptions started to veer into hallucinogenic territory. The walls of the room shone like polishe silver, the floor was a light blue, and the ceiling was supported by three transparent crystal column Hearts raced as the oxygen level dropped. The men each knew that they had found their etern fortune, and in their minds, gently slipping away, they were already spending it. They pressed past th columns, and the torches started to sputter and die. The walls were starting to get very close, and blind panic gripped all three hunters simultaneously. They scrambled, crawled, and grabbed their way to the cave portal as quickly as possible, with Henry dragging the box of samples.

Boyceyer was first out into the fresh air and sunlight. He took a deep breath, and his legs stoppe working. He keeled over in a heap at the entrance, and shortly thereafter Henry tripped over him ar passed out cold. Dempsey emerged in a strangely talkative mood, babbling and making no sense at al The boy, left sitting out under a tree, had quickly seen and heard enough. He leaped to his feet and ra in the opposite direction, down the mountain in free fall, bursting into the campsite winded and tryir to explain what had happened up there, pointing. Eventually calming him down and extracting coherent message, the men quickly assembled a rescue team and hurried to the site.

It is now clear that the hunters were suffering the classic symptoms of oxygen deprivation. When th rescuers arrived, Boyceyer and Dempsey were coming around, but Henry was enfeebled, dazed, ar unable to hike out. The men decided to cut the hunting expedition short and take him home. On th way his condition deteriorated. Fearing the specter of a new form of plague, they took him to hospital in Carthage, Missouri. The doctors had no idea what was ailing him. His symptoms we puzzling. Sores resembling burns broke out all over his body, and his legs seemed paralyzed. Bi Henry remained hospitalized for several weeks, and he had time to plan for extracting his fortune fro the hole in the mountain.

When he had recovered enough to leave under his own power, he staggered back to the cave to stal out a claim and work his silver mine, but the person who actually owned the land on which th mountain stood did not share his optimism, and no mining agreement could be reached between th two men. The guy wouldn’t even come out and see the cave with its sparkling silver, just sitting the ready to be hauled away. Perhaps he knew more than he would admit about that mountain. He wante no part of a mining venture, and he advised Bill Henry to find something else to do.

Exasperated and angry beyond words, Henry returned to the site and avalanched as much material he could move into the portal, making a hole that had been hard to find impossible to see. He wou come back later, once he had figured out some further strategy.

There is no record of Henry having returned again, and he disappeared into the murk of history. Th cave location faded away, and the story became one of the colorful, spooky legends to be told aroun campfires after dark up in the Ozarks. That’s the story, but it was not written down until 34 years afte the incident, and facts could have drifted. There are questions. The initial problem was obvious oxygen deprivation, but what had taken the place of normal air in this cave? It could have bee methane, the scourge of coal mining, but the cave was not lined with coal and there was not a hint tool marks anywhere. And what had caused the burn-like lesions all over Bill Henry? Was he alon allergic to some mineral on the walls? What was the bright, iridescent stuff lining the cave? That not what silver, or even gold, looks like in its native state. Later explorations of the cave wou provide unexpected answers to these questions.

Meanwhile, in the formal physics lecture theaters and laboratories in Europe in 1879, the danger of being in a certain cave Missouri and what it had to do with anything were unknown. Scientists across the Continent and in the United Kingdom, working well-established universities, were busy studying the interesting properties of electricity in evacuated glass tubing. A thrilling dangerous piece of equipment called a Ruhmkorff coil produced high-voltage electricity for these experiments. They were essentia inventing and refining what would become the neon sign. Research was progressing at an appropriate pace, gradually unraveling t mysteries of atomic structure.

Working independent of any academic pretension in the United States was a highly intelligent, wel educated immigrant from Croatia, Nikola Tesla. He came ashore in June 1884 with a letter introduction to Thomas Edison, famous American inventor of the record player and the light bulb. H was given an engineering job at $18 a week improving Edison's awkward and ultimately unusable D electrical power system, but he quit a year later under intractable disagreements concernin engineering practice, salary, general company philosophy, and his boss's personal hygiene. H immediately started his own power company, lost control of it, and wound up as a day laborer for th Edison Company laying electrical conduit. Not seeing a need for sleep, he spent nights working high-voltage apparatus and an alternating-current induction motor.

In Europe they were working with induction coils that could produce a ripping 30,000 volts, stingin the eyes with ozone wafting out of the spark gap and with a little buzzer on the end making the spa semi-continuous. In New York, Tesla was lighting up the lab with 4,000,000 volts and artificia lightning bolts vibrating at radio frequencies. Naturally drawn to the same rut of innovation as his O World colleagues, he connected an evacuated glass tube to his high-voltage source in April 1887. had only one electrode. He connected it to his lightning machine and turned it on, just to see wh would happen. Electrons on the highly over-driven electrode slammed themselves against the gla face of the tube, trying desperately to get out and find ground somewhere. The glass could not help b fluoresce under the stress, making a weak but interesting light. Tesla had invented somethin important, but he would not know exactly what it was until years later. He applied for a patent for h single-electrode tube, calling it an "incandescent light bulb" as a finger-poke in Edison's eye.

In 1891 Tesla's fortunes improved considerably when George Westinghouse, Edison's competito for the electrical power market, became interested in his alternating current concepts. He moved into new laboratory on Fifth Avenue South, and he had room to spread out and really put his high-voltag equipment to use. One night, he connected up his single-electrode tube built back in 1887. He turne off all the lights so he could see arcs and electron leakage. To his surprise, something invisible wa coming out the end of his tube and causing the fresh white paint on the laboratory wall to glow Curious, he put his hand in the way. His hand did stop the emanations, but only partly. The bones i his hand were dense enough to stop it from hitting the wall, but not the softer parts, and he could se his skeletal structure projected on the paint. Tesla, fooling around in his lab after hours, had invente radiology. In the next days he substituted photographic plates for the wall, and made skeletal photos a bird, a rabbit, his knee, and a shoe with his foot in it, clearly showing the nails in the sole.

Unfortunately, Tesla was pulled toward greater projects, and he failed to pursue the obviou application of this discovery.

Four years later, on December 28, 1895, the discovery of the unusual radiation was formal announced, not by Tesla, but by Wilhelm Röntgen, working at the University of Munich. Röntgen wa also studying fluorescence, using his trusty Rhumkorff apparatus and a two-electrode tube custor built by his friend and colleague, Phillipp von Lénárd.[6] Like Tesla, he was startled to notice that son sort of invisible emanations from the tube pass through flesh, but are stopped by bones or den material objects. In his paper in the *Proceedings of the Physical Medical Society,* Röntgen gave th phenomenon a temporary name: x-rays. Amused at reading the paper, Tesla sent Röntgen copies of h old photo plates. "Interesting," replied Röntgen. "How did you make these?" Not trusting his ov setup to be kind, Röntgen covered his apparatus with sheets of lead, with a clear hole in the front direct the energy only forward.

Tesla, on the other hand, put his head in the beam from his invention and turned it up to full powe just to see what it would do. Röntgen had jumped him on the obvious medical usage, but there had be some other application that could be exploited for profit. After a short while directly under th tube, he felt a strange sensation of warmth in the top of his head, shooting pains, and a shock-effect his eyes. Seeing the value of publication shown by Röntgen's disclosure, he wrote three articles for th *Electrical Review* in 1896 describing what it felt like to stick your head in an x-ray beam.

The effects were odd. "For instance," he first wrote, "I find there is a tendency to sleep and I fi that time seems to pass quickly." He speculated that he had discovered an electrical sleep aid, muc safer than narcotics. In his next article for 1896, after having spent a lot of time being x-rayed, l observed "painful irritation of the skin, inflammation, and the appearance of blisters … , and in son spots there were open wounds." In his final article of 1896, published on December 1, he advis staying away from x-rays, "… so it may not happen to somebody else. There are real dangers Röntgen radiation."

These writings were the first mention in technical literature of the hazards of over-exposure to th mysterious, invisible rays. For the first time in history, something that human senses were not evolve to perceive was shown to cause tissue damage. The implication was a bit terrifying. It was somethi that could be pointed at you, and you would not know to get out of the way. Some of the effects we even delayed, and at a low rate of exposure, which was completely undetectable, one could l endangered and not even know it. The effect was cumulative. Tesla's equipment was powerful. He wa fortunate not to have set his hair on fire, but his health was never quite the same.

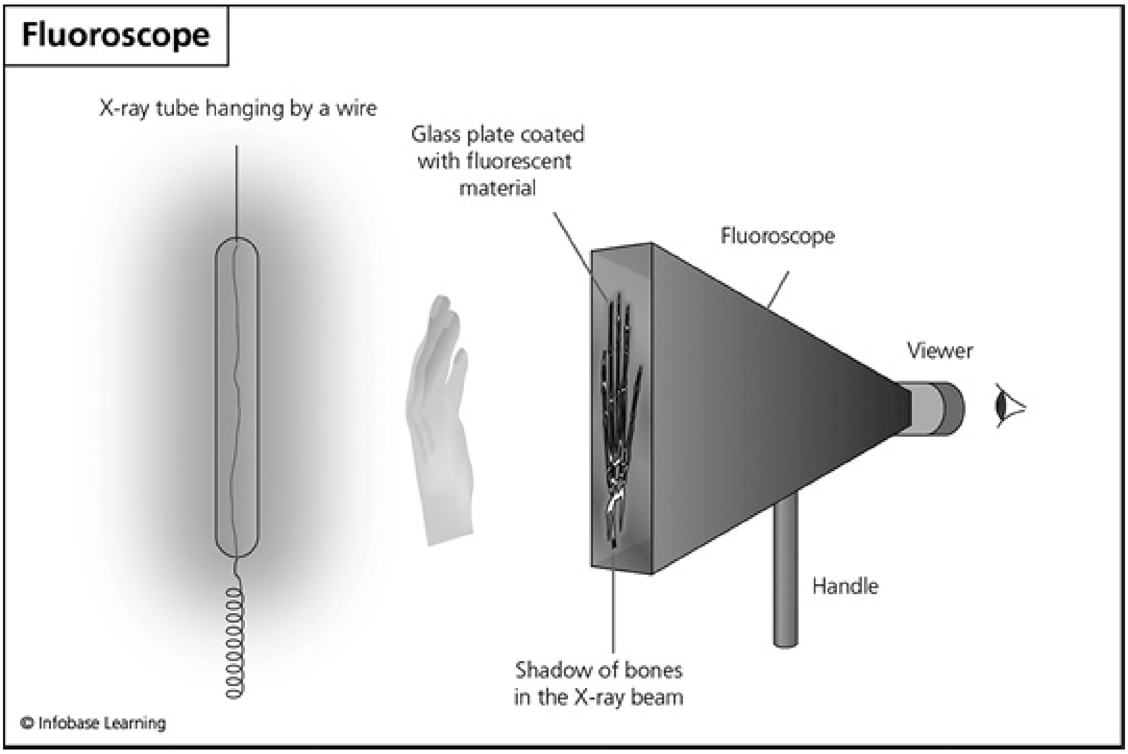
At the Sorbonne in Paris in 1898, Marie Curie, with some help from her husband, Pierre, discovere a new element, named "radium," in trace quantities mixed into uranium ore. It had invisible, energet influences on photographic plates, just as her thesis advisor, Henri Becquerel, had found in uraniu salt two years before. She named the effect "radiation." It was similar in character to Röntgen's rays, only these came streaming freely out of a certain mineral, without any necessary electricity. clue to the relation was its curious property of encouraging the formation of sores on flesh that w exposed to it.

The Curies were among the finest scientists the world had known, and their dedication to tas observational ability, and logic were second to none, but their carelessness with radioactive substanc was practically suicidal. Marie loved to carry a vial of a radium salt in a pocket of her lab smoc because it glowed such a pretty blue color, and she could take it out and show visitors. Pierre enjoye lighting up a party at night using glass tubes, coated inside with zinc sulfide and filled with a radiu solution, showing off their discovery to amazed guests. He got it all over his hands, and on swoll digits the skin peeled off. Surely, the cause and effect were obvious.[7]

In 1904 Thomas A. Edison, the "Wizard of Menlo Park," had been experimenting with x-rays f several years. Edison thought of using x-rays to make a fluorescent lamp, and he proceeded to test multitude of materials to find which one would glow the brightest under x-rays. His faithful assista was a young, eager fellow, Charles M. Dally, who had worked for him for the past 14 years.

~~Dally was born in Woodbridge, New Jersey, in 1865, and he had served in the United States Navy fo~~ six years as a gunner’s mate. After discharge from the Navy he signed on at the Edison Lamp Work in Harrison, New Jersey, as a glass blower, and in 1890 he moved to the Edison Laboratory in Wes Orange to work directly for Mr. Edison. He was put to work evaluating the new lamp technology. Da after day, he held up screens of fluorescent material in front of an operating x-ray tube, starin directly at it to determine the quality of the light it produced. Nobody gave thought to any danger, b after a while Edison noticed that he could no longer focus his eye that he used briefly to test a ne fluoroscope, and “the x-ray had affected poisonously my assistant, Mr. Dally.”

In the beginning Dally’s hair began to fall out and his face began to wrinkle. His eyelashes an eyebrows disappeared, and he developed a lesion on the back of his left hand. Dally usually held th fluorescent screen in his right hand in front of the x-ray tube, and tested it by waving his left hand the beam. There was no acute pain, only a soreness and numbness. Dally kept testing the fluoresce screens. His solution to the physical deterioration was to swap hands, using his right to wave in fro of the beam.



Thomas Edison’s radical idea for a new type of light bulb was to use x-rays hitting a fluorescent screen. Clarence Dally tested mar types of fluorescent paint for Edison by waving his left hand between an x-ray tube and a fluoroscope screen while viewing the effe through an eyepiece. The cumulative effect of hundreds of hours of x-ray exposure was fatal.

The lesion on his left hand would not heal, and conventional medical practice was at a loss to expla why. The pain became intolerable, and attempts to graft new skin onto the spreading sore we unsuccessful. The vascular system in the hand collapsed, and a cancer was detected at the base of th little finger. The physicians had no choice but to amputate the left hand at the wrist. Dally ke working on the x-ray project, holding the apparatus with his right and waving the stump in front of th screen.

In the meantime a deep ulceration developed on his right hand, and four fingers had to be remove Eventually, both arms had to be amputated, one at the shoulder and the other above the elbow. A efforts to stop the progression of the disease eventually failed and Dally, after eight years of sufferin died in October of 1904. Edison was shaken, and he dropped all work on the fluorescent lamp. “I a afraid of radium and polonium too,” he commented, “and I don’t want to monkey with them.”

At the time there were no rules, regulations, laws, procedures, or helpful suggestions for the handli and storage of radioactive materials. It was understood that radioactivity could be induced artificial with electrical equipment, or it could be found in nature. The new elements that the Curies ha extracted at great labor from uranium ore, radium and polonium, would turn out to be two of the mo dangerous substances in the natural world, and both are banned from all but the most critical industri uses. Both are alpha-ray emitters. An alpha ray is a particle, consisting of a clump of two protons ar two neutrons. It is literally the nucleus of a helium atom, and it breaks free of the radium nucleu flying outward into space.

In 1903 the physicist Ernest Rutherford calculated that the energy released from radium by a sing alpha particle is a million times larger than the energy produced by any chemical combination of tw molecules. The alpha particle has very limited range, and it is easily stopped by the uppermost lay of the skin, but the damage to healthy tissue to this shallow depth is significant. The greatest danger in ingesting or breathing radium dust, as the destructive energy of each alpha particle released is ful deposited in body tissues. Atop that danger, there is the continuing breakdown of the decay product the debris left after an alpha particle has jumped off the radium or polonium nucleus. These damag nuclei emit an entire range of different radiations from further decays. By the time of Rutherford calculation, Pierre Curie was suffering unbearable pain from burns all over his body. He would lie bed all night, unable to sleep, moaning. As a professor at the Sorbonne, the distinguished University Paris, he asked for a reduced teaching load, complaining of having only “a very feeble capacity f work” due to his work refining radium out of uranium ore.

On April 19, 1906, after a luncheon of the Association of Professors of the Science Faculties, h walked to his publisher’s office to go over some proofs of his latest scientific paper. It was rainin hard, and the street traffic was heavy. He found his publisher locked and closed down, due to a strik Curie then turned and stepped into the rue Dauphine to cross, slipped on a wet cobblestone, ar sprawled into the street. His head went under the wheel of a 6-ton, horse-drawn wagon loaded dov with military uniforms. Curie died instantly.

It took 11 years, but eventually news of the discovery of radium penetrated the Ozark Territory, and in 1909 James L. Leib, prospector and self-schooled geologist, saw a logical connection between the published properties of radium and the legend of t mysterious cave dating back to 1879. The spot price of radium at the time was, gram for gram, about one hundred times the value diamonds, or $70,000 per gram. It was the most valuable material in the world, as it had found use in cancer therapy. It was true th radium would kill living tissue, but its working range was very slight. A carefully placed radium needle would wipe out a canc tumor immediately adjacent to it without harming anything else. There was much demand.

With effort, Leib found the remaining member of the hunting party, Old Bill Boyceyer, still alive i Chance, Oklahoma. Old Bill was glad to tell the story yet again and give what he could remember directions to the hole, with a caution: Don’t go in!

Leib found the cave, right where Boyceyer remembered, and he entered with unusual caution. H went in only far enough to pick up some bits of weird-looking, bluish rocks. Leib corresponde directly with Madame Curie, obtaining instructions for exposing photographic plates to the ore ar confirming radioactivity. With the help of a photographer in Bentonville, Missouri, he succeeded. Th few rocks he had brought back from the hole burned dark images into the plates, right through th dark-slides and black paper wrapping. Steel nails and a key left atop the plates showed up clearly shadows, blocking the radiation. The radiographs were displayed at county fairs and apple shows a over the Ozarks, with Leib trying to drum up interest in opening up a radium mine. There we fortunes to be made, far greater than could be extracted from a mere gold mine.

In the spring of 1912 an enterprising man of vision from Chicago named John P. Nagel bought th land out from under Leib and commenced developing it as a mineral excavation site. Nagel proud owned a mining operation that employed several men, housed in a dormitory built from loc materials, and photos show him standing over a production table heaped with big chunks of or Within a few years the easy pickings in the mine played out, it was abandoned, and the mystery ho in the Ozarks once again slipped into obscurity.

It is clear that Leib and Nagel saw a connection between the inexplicable burns on Bill Henry aft his cave adventure and later tabloid descriptions of burns on lab technicians from handling radiu They reasoned that the hunting trio had stumbled upon a radium mine.

This account of the first documented radiation injury requires clarification.[8] For one thing, there no such thing as a radium mine. All the radium-266 that may have been in existence when the Ear was assembled from interstellar debris quickly disappeared, in astronomical terms, as its half-life only 1,600 years. However, there is always a very small supply of radium in the Earth's crust, becau it is a decay product of uranium, which has been on this planet from the beginning. The radium als undergoes radioactive decay into radon gas, and an equilibrium exists between production and los Radium is therefore available in uranium deposits in trace amounts. Many tons of uranium must b processed to extract a few milligrams of radium-266. Note that none of the many minerals known contain uranium are shiny, metallic, or particularly interesting looking. Uranium metal does not exi in nature, but if it did, it would quickly turn dark gray and soak up every oxygen molecule that pass its way.

Mining uranium in the confines of tunnels is, of course, dangerous without safety measures, but th danger is slow to affect the human body. Breathing the radioactive dust and gas in a mine for decad can cause lung cancer, but it can take 20 years for it to metastasize. Just standing in a uranium min leaning against the wall, or taking a nap in a dark corner will not cause anything. No person before since has developed radiation burns on skin from being in contact even with pure uranium. It certain gives off alpha, beta, and gamma radiation plus a chain of radioactive decay products, but the proce is so slow, it cannot immediately affect living tissue. How then is this incident explainable? In 187 there wasn't even enough knowledge to make up such a story.

Henry, Dempsey, and Boyceyer had ventured into an undisturbed series of caverns lined wi uranium ore of exceptional purity.[9] There was no cross-ventilation of the rooms, and radon-222 ga with a half-life of 3.842 days, had been free to collect, undisturbed, as it seeped out of the walls, floo and ceiling. It is a heavy, noble gas, not interacting chemically with anything, but emitting powerf alpha particles and associated gamma radiation. The back chambers of the cave may have collect radioactive gas for millions of years, as it displaced the cover gas of atmospheric nitrogen and som oxygen, again reaching an optimum equilibrium state between production and loss by radioacti decay. There was no mention of anything alive in the cave, and the apparently clean floors indicat that no bats had ever lived in there.

Radon-222 is the product of the decay of radium-226, and is, indirectly, a product of the slow deca of uranium-238, the predominant isotope in uranium ore. The rough walls of the cave gave tremendous surface area of radioactive ore, and the loss of radon by rapid decay was slightly less tha the production of radon by radium decaying at or near the inner surface of the cave. Radon productio occurring significantly below the surface of the ore would not contribute anything, as the gas wou decay into something else before it had a chance to diffuse to the surface. Without the abnormal high production rate due to the large surface area, the radon leaking into the cave would hav dissipated faster than it was made, and trivial amounts would have built up. When the hunte advanced deeper into the cavern, they were breathing it instead of normal air. The lack of oxyge made them hallucinate, pass out, and talk crazy.

Uranium or thorium, regardless of how pure or how close to the skin or the length of the exposur cannot produce the burns described on Henry. These natural materials are simply insufficient radioactive, and the radium traces must be laboriously extracted and concentrated to start doing harr The concentrated radon, however, in this highly unusual situation, could have done it. Why it seeme to affect Henry most severely is probably because he was the most aggressive explorer of the thre squeezing through every narrow passage, and perhaps the clothing he wore contributed to the effect. was probably heavier or had more layers than what the other two explorers wore. The radon gas, n reacting chemically with anything, was free to diffuse into his clothing, subjecting him to alpha ar gamma radiation as it decayed, but this would not explain his burns. It is also possible that Henry w the one of the three explorers who was unusually sensitive to radiation.

The decay products of radon-222 are a complex chain of 11 radioactive isotopes, from polonium-21 down to thallium-206, before it ends at stable, non-radioactive lead-206. Half-lives range from 0.146 milliseconds to 22.3 years. All the radon decay products in the 11-member chain are solids, even the atomic level, and they would definitely stick to his clothing and his skin, with each produ extremely radioactive. As Henry squeezed through the cave, scrubbing the wall and standing concentrated radon gas, his clothing was loaded up with radon decay products in the form of fine dus Over the next few days, being portaged to the hospital in Carthage, he could have been hit with eig beta rays coming from each radon atom. His lungs started to clear as soon as he got into fresh air, b his clothing was heavily contaminated.

Alpha radiation consists of a large clump of nuclear particles, or nucleons, and it represents sudden, radical crumbling of an atomic nucleus, just happening out of the blue. The resulting alph particle is a helium-4 nucleus, complete, and when hurled at anything solid it can cause damage on sub-atomic level.

The beta “ray” or “particle” (either term is correct) is actually an electron or its evil twin, th positron, banished from a nucleus and hurtling outward at high speed. It is the result of the sudde unpredictable change of a neutron into a proton or a proton into a neutron down inside an atom nucleus. This decay event also completely changes the atom’s identity, its chemical properties, and i place in the hallowed Periodic Table of the Elements. Meanwhile, the traveling beta particle, whi much lighter than the alpha particle, is still an “ionizing” radiation. If it is a particularly energetic be example (they come in all strengths), it can hit an atom that’s looking the other way with enough forc to blow its upper electrons out of orbit, break up molecular bonds, and bounce things around, causin the matter in its way to heat up. On skin this effect turns up as a burn, or a reddening of the surfac just like you get from an aggressive tanning booth.

The gamma ray, yet another form of nuclear radiation, is an electromagnetic wave similar ultraviolet light or x-rays, only it is far more energetic. A gamma ray of sufficient energy ca penetrate your car door, go clean through your body, and out the other side, leaving an ionized trail c molecular corruption in its path. It is the product of a rearrangement or settling of the structure of a atomic nucleus, and it naturally occurs often when a nucleus is traumatized by having just emitted a alpha or a beta particle. Gamma rays can be deadly to living cells, but, unlike the clumsy alph particle, they can enter and leave without losing all their energy in your flesh. It's the differen between being hit with a full-metal-jacketed .223 or a 12-gauge dumdum. Both hurt.

Improbable as it seems, Bill Henry apparently suffered beta burns from exposure to concentrate radon-222 and radon decay products on the cave floor. He recovered from this acute dose and suffere no lasting effects, as is typical of brief radiation encounters. His exposure was only on the surface an not ingested. With current knowledge and understanding of radiation exposure symptoms, his sock would have been hazmat, held with tongs.[10]

Learning can be a slow process. In the first quarter of the 20th century, we at least developed a inkling of the danger of radiation, that unique peril that bedevils all things nuclear, particularly a medical applications were developed. Eventually the practice of testing an x-ray machine by puttin an arm in the beam and watching it turn red became taboo, as technicians began failing to show up f work. As radiologists began to suffer from leukemia, bone cancer, and cataracts, the procedure fo taking an x-ray picture evolved into assuring the patient in no uncertain terms that this procedure w absolutely harmless, then slipping behind a lead-lined shield before pressing the START button. Sti at the time there were no government-level safety standards in place, and radiation intensity or dosag measurements had not been established.

Radium therapy was widely hailed for definite curative effects in treating cancer, the dreaded disea that killed so many people, and this was the public's introduction to radiation by nuclear deca Further applications of this miracle metal by enthusiastic entrepreneurs would soon lead to trag consequences, and the two most publicized disasters would change everything. The public, scientifi legislative, and industrial perceptions of radioactivity were about to be forever carved into stone in distinctively negative way, and it would affect our basic sense of fear to this day.

William John Aloysius Bailey, one of nine children raised by a widow in a bad section of Bosto was born on May 25, 1884. He grew up poor but bright and ambitious, beginning school at Quin Grammar and graduating near the top of his class from Boston Public Latin, famous as a launchin point for ragamuffins into the Ivy League. He did poorly on his Harvard entrance exam, but h appeared sharp of mind and had a certain intense determination, and he was accepted as a freshman the fall of 1903. Unfortunately, the cost of being a Harvard man was more than he could bear, and h had to drop out after two years. Not to be held back on a technicality, he would always boast of Harvard degree and to have earned a fictitious doctorate from the University of Vienna, which if aske would claim to have never heard of him.

Out of school, Bailey hit the street running. He set up an import-export business in New York City with the master plan to be appointed as the unofficial U.S. trade ambassador to China. This didn happen. He bounced around a while in Europe, acquiring a worldly patina, and he wound up in Russ drilling for oil at the beginning of World War I in 1914. This proved unprofitable and life-threatenin so he made it back home, where he worked on several mechanical inventions in his workshop. Bare half a year later, on May 8, 1915, he was arrested in New York on charges of running a mail-order co out of his apartment. He had been accepting mail deposits of $600 each for automobiles to be picke up somewhere in Pittsburgh. No cars showed up, and Bailey had to spend 30 days in jail. His mistal