Nuclear Legacies of the Atomic West:
Radioactive Brown Fields in Colorado

In the mid-1960s the Houston-based oil company, Austral, joined with the US Atomic Energy Commission (AEC) to pursue a so-called peaceful nuclear explosion to release gas trapped deep beneath the surface at the Rulison oil and gas fields, not far from the Colorado River. The gas turned out to be too radioactive to use. Building on the nuclear enthusiasm of that decade, Public Service of Colorado (PSC) ordered a high temperature gas cooled reactor at 300 MWe to be built at Fort St. Vrain. The station was shuttered at great cost within fifteen years, never operating close to design parameters. The state was also a major contributor to the Cold War in the production of plutonium pits for nuclear bombs at the Rocky Flats facility – and produced uranium for the Hiroshima and Nagasaki bombs.

Since the 1940s onward Colorado's ores, landscapes and peoples have contributed significantly to the peaceful and military atom, from mining and milling, to the production of electricity, and to the manufacture of plutonium pits for nuclear bombs. But as the Cold War came to an end its radioactive legacy came into clear focus for citizens, state officials, and for the nuclear industry. They recognized the complexity and high costs of cleanup, especially for the large number of uranium mines in the state, and for Colorado's bomb factory, Rocky Flats, just outside of Denver. They engaged the effort to transform them into stable sites, and some of them into nature refuges. The challenges faced by the nuclear enterprise included the vast quantities of low- and high-level radioactive waste (RW) whose quantities and disposition were frankly uncertain, and whose toxicities stretched centuries into the future.

At a time when leaders, industry spokespeople and environmentalists in a variety of nations have embraced nuclear power as a "green" technology, by which they mean low carbon energy production as one solution to the problem of global warming, it is good to ask how green is the atom from the point of view of its legacies of RW, high costs, and unique risks. Colorado's nuclear history provides one such answer. This essay advances the concept of radioactive brown fields to help evaluate the short- and long-term impact of nuclear technologies on the environment and the extent to which proper cleanup is possible. While remediation of chemical, iron and steel, mining and other industries has a relatively long history, the idea of "industrial brown fields" entered the literature only in the 1990s. A brown field site "is any land or premises which has previously been used or developed and is not currently fully in use…It may also be vacant, derelict or contaminated," and thus may require intervention.[1] In hopeful literatures, the idea is that brownfields may ultimately been converted to "sustainable reuse."[2] Yet beyond high costs of remediation for reuse, another problem with brown fields is that are nearly always associated with negative health outcomes.[3] This is certainly the case with what I call radioindustrial brown fields, with their millions of tons and cubic meters of solid and liquid RW; their volatility and long-term toxicity; and the failure to shepherd them properly up to the present day.[4] These brown fields appeared in Colorado at first from uranium mines and weapons fabrication facilities, next in "peaceful" nuclear explosions, and then power reactors, and they continue to pose dilemmas for landscapes and people.

Feeding the Nuclear Enterprise

Colorado's major contribution to the nuclear age and its residues was from uranium mines. From the perspective of settler history, Colorado was first of all a site of empty spaces, of rich mineral resources from gold (the Pike's Peak Gold Rush) to lead, zinc, copper, molybdenum, and tungsten, and to vanadium and uranium. Miners recognized a broad area that contained precious minerals, the so-called Colorado Mineral Belt. The Uravan Mineral Belt, a 120 km by 50 km geological zone of carnotite ore deposits in Colorado's San Miguel, Montrose, and Mesa counties and eastern Utah, added radioactive ores to the mix. From 1910 to 1922, the Uravan Belt produced half of the world's radium for such purposes as illuminated watch dials. In the late 1920s US Vanadium Company (USV) began producing vanadium, in the late 1930s uranium, and in the early-to-mid-1940s, yellowcake that was used in the Hiroshima and Nagasaki bombs. Uranium was mined in Colorado to supply nuclear power plants (NPPs) from the 1950s, although this market declined in the 1970s due to environmental and health concerns, and resulted in the transfer of radiation risk to African and Asian countries.[5]

For nuclear visionaries and military planners, Colorado had everything necessary to justify investment in the atom. To them, rough terrain that was relatively empty of human settlement seemed excellent sites for the nuclear enterprise, and the rocky landscape, on top of woodlands, grasslands, shrubland and steppe, convinced them that they had nearby places to dispose of waste. The Colorado River and its tributaries were available to lubricate and cool industrial processes. And there were mines. From 1944 to 1986, nearly 30 million tons of uranium ore were extracted from Navajo lands alone under leases with the Navajo Nation. Many Navajo people worked the mines, often living and raising families in close proximity to them, and even using radioactive rip rap in building their houses unaware of the risk. Readings in some mines were ten times higher than suggested levels. Winds continue blow radioactive dust from the wastes into populated areas. Potential health effects include lung cancer from inhalation of radioactive particles, as well as bone cancer and impaired kidney function from exposure to radionuclides in drinking water.[6] Today a legacy of uranium contamination remains, including over 500 abandoned uranium mines.[7]

Uranium production in support of the Cold War arms race reached peak in the US from approximately 1948 to the 1980s when thousands of mines were opened in the American west.[8] "Colorado Legacy Land" includes a large number of these mines, many of them in a sad state of remediation. The now-closed Schwartzwalder Mine, at one time the single largest uranium mine in Colorado, produced 10.5 million pounds of U_3O_8 by 1978. The Cotter Corporation acquired the mine it 1965, but its stewardship was totally inadequate for health, environment and safety. Its operations contaminated reservoirs; for example, Denver Water's Ralston Reservoir which contains uranium levels at 310 ppb (ten times the federal limit). Cotter agreed to remove tainted water from its mines, but has not, instead pumping and cleaning only surface ponds, and it has refused to pay state fines for its refusal to complete cleanup. Groundwater near the mine contains uranium levels that are 1,000 times higher than human health standards. In 2023, the state had to take over cleanup as Cotter Corporation had walked away.[9]

Cotter's irresponsibility is a constant feature of legacy waste. In 1959 the AEC cited Cotter for failing to maintain proper records and violating rules requiring airborne emissions; in the 1960s the AEC cited Cotter "inadequate" sampling of airborne radioactivity. Concentrations of molybdenum were found at levels injurious to cattle, and tailing ponds were leaking. In 1978 federal mine inspectors cited Cotter with 18 violations, including overexposing three workers to silica dust. In 1980 the Colorado Bureau of Investigation found that Cotter had falsified occupational health reports and repeatedly exposed workers to excessive radioactivity between 1968 and 1978.[10]

As with any brute force process, mining and milling violently crush rock, and if as valuable as uranium, extract even minute quantities, with huge piles of rock debris left over.[11]

Another Cotter mine is the Lincoln Park site, located south of Cañon City in Fremont County. The site includes a 1,050-hectare uranium mill and areas of mill-associated contamination. In addition to churning out yellowcake, the mill produced vanadium and molybdenum. Mill operations and disposal practices released radioactive and metal contamination into the environment. The alkaline leach mill (1958-1979) dumped liquid wastes containing radionuclides and heavy metals into 11 impoundments, eight of which were unlined (the "Old Ponds Area"). Floods carried dangerous wastes into towns and villages for decades where contaminants entered surface soils and groundwater. In 1971, the Soil Conservation Service erected a flood control dam on Sand Creek that holds surface runoff and spring flow. The ponds in the Old Ponds Area were replaced in 1979 with two lined impoundments. The mine operated intermittently from 1979 and was closed in 2018.[12]

Uranium mining in Colorado and elsewhere has never been carefully regulated, and is technically self-regulated by the state. In fact, AEC rules encouraged dangerous practices. An AEC decision to honor contracts to buy yellowcake if it was produced from ore mined before November 24, 1958, created immense challenges for Cotter how to continue to operate the Lincoln Park mill and take advantage of its existing licenses. Cotter found a money-making scheme by taking in "homeless" RW. In 1968 Cotter bought waste from residues of the Manhattan Project stored in St. Louis, Missouri, where the Mallinckrodt Chemical Works processed uranium. After World War II, the government stored the waste near the St. Louis airport; it was left in the open, exposed to the rain and wind, the drums rusted and deteriorated, and radioactive material entered nearby Coldwater Creek, threatening neighboring residents. The federal government moved the RW to another Missouri site where, once again, it was left in the open; it may take until 2038 to clean up all of the St. Louis RW.[13] Once it acquired the waste, Cotter dumped 8,700 tons of it illegally in the West Lake Landfill in Bridgeton, Missouri (now a Superfund site, and it shipped the remaining 112.000 tons by open rail cars across the United States to the Canon City Mill. At least one of the train cars lost its cargo on the way. A first alarm was raised in 1968 when cattle started dying from molybdenosis, and uranium contamination was detected in private water wells in Lincoln Park, leading to the site's designation as a Superfund site in 1984.[14])

Colorado's nuclear legacy has been scattered everywhere, in the open air, near bodies of water, without a complete sense of much there is, and without funding to manage all of it. Near the Sand Creek dam the EPA and state authorities have installed gates, fences and signage to discourage people from entering the radioactive brown field. Indeed, a geologic bowl occupies a spot near the mill in which an estimated 5.8 million tons of radioactive waste is buried. A Superfund site for over 40 years, there is still no plan for how to clean up Lincoln Park, although 6,000 people live within two miles of it. The Colorado Citizens Against Toxic Waste (CCAT) group has been struggling to force the government and private sector to complete Superfund remediation.[15] Spills and leakages continue to occur, with one recently characterized as an "inconsequential spill of water likely tainted with uranium" at 1,600- to 2,000-liters in June 2023, where it was contained and potentially contaminated soil was removed.[16]

Another Colorado mine, the Durita, a 78-hectare facility with a secondary extraction heap leach operation, was owned by Ranchers Exploration and Development Corporation (Ranchers), and operated briefly in the late 1970s. Hecla Mining Company (Hecla) merged with Ranchers in 1984 and gained responsibility for a reclamation plan for 700,000 tons of feedstock "ore" tailings. Crushed tailings were conveyed to one of the three clay-lined heap leach tanks which were flooded with a dilute 5% sulfuric acid solution; the percolating acidic solution leached uranium and vanadium from the tailings. This solution was collected by slotted pipes in the bottom of each leach tank and then transferred by gravity flow to the extraction plant. The waste liquid was stored in six onsite evaporation ponds. After operations ceased, a real radioactive brown field formed: the leach tanks were covered, the evaporation ponds were left uncovered to allow liquids to dry up, and the volatile chemicals and radionuclides awaited their final fate. Formal decommissioning and reclamation of Durita began in 1992. According to the NRC. "During reclamation, no evidence of leakage from the evaporation ponds was noted, and material beneath the ponds was dry. Final reclamation construction activities were completed in 1999."[17] Yet soon disagreements between the federal government, the state government and Hecla over the latter's effort to discontinue any further groundwater detection monitoring program. Based on investigations complete in the early 2020s, the NRC ultimately took Hecla's word that "with respect to groundwater, the Durita site would provide reasonable assurance of control of radiological hazards effective for 1,000 years."[18]

There are also radioactive blue fields. In 1949, USV built a small mill at the confluence of White Canyon and the Colorado River to process uranium ore from the nearby Happy Jack Mine. For the next four years, the mill crushed about 20 tons of ore per day, treated it with acids and other chemicals, and produced about 3 kg of uranium; almost 20 tons of tailings piled up on riverbank. The mill closed in 1953, the tailings remained in the open, and in the 1950s waters backing up behind the newly-built Glen Canyon Dam in Northern Arizona (Lake Powell) covered the 26,000 tons of tailings where it remains submerged.[19] According to the *Colorado Nuclear Atlas*, hundreds of mills await cleanup, and plumes of contaminants continue to pollute the San Miguel, Dolores and Colorado Rivers.[20]

A shocking demonstration of the dangers of attempting to store radioactive mine waste occurred in Church Rock, New Mexico, on July 16, 1979, when an earthen dam containing a large settling pond near Grants, New Mexico, failed. The spill released 360,000 m^3 of acidic, radioactive tailings solution into the Puerco River in Navajo lands, more radioactivity than the Three Mile Island Accident, contaminating groundwater and land. The spill killed crops and cattle. The New Mexico Environmental Improvement Division dismissed concerns about radiation impacts on humans or animals consuming water. It determined radiation risk for local livestock consumption small, but acknowledged that wells should be tested, and suggested the need to avoid the arroyo during wind.[21] Poor handling of mine and mill tailings and other wastes resulted in the release of elevated concentrations of metals and radionuclides, which pose imminent environmental and human health concerns especially in Wyoming, Arizona, New Mexico and Colorado (and more directly the Colorado Plateau of the Four Corners Region).[22]

Testing Bombs in the American West: Indigenes, Downwinders, and Coloradans

Colorado's nuclear history includes atomic bombs. On January 27, 1951, nuclear testing at the Nevada Test Site (NTS) commenced with the detonation of Shot Abel, a 1-kiloton blast. Of a total of 215 atmospheric and 815 underground nuclear bombs that the US detonated between 1945 and 1992, there were 1,021 nuclear tests at the NTS between 1951 and 1992, of which one hundred were atmospheric.[23] Over the years, the immediate victims of US atmospheric tests were 400,000 US soldiers who were used as guinea pig observers, in detachments or as cleanup detail. Nearby local people including Native Americans, ranchers and small town folk were exposed to fallout as downwinders. The most ambitious series of tests, "Plumbbob," between May 28 and October 7, 1957, involved 29 atomic bombs that exposed roughly 16,000 American troops to approximately 58,300 kilocuries of radioiodine (^{131}I), or about 32% of all exposure due to continental nuclear tests.[24] Much of the ^{131}I was taken up by dairy cattle across the US, and according to one estimate approximately 50,000 iodine milk deaths resulted.[25] Sheep and other livestock also were exposed and damaged by the fallout.[26] Along with Nevada, Utah, New Mexico and Arizona, Colorado residents were exposed to large amounts of fallout that contributed to significant increases in cancer deaths. Virtually everyone living in the United States during the tests was exposed, but 25 counties in Montana, Utah, Idaho, Colorado and South Dakota received enough to be considered hot spots (Image 1).[27] Most of this fallout has never be cleaned up because of the short half-lives of many of the isotopes, its wide and uncertain dispersion across the nation, and because it has never been considered RW.

In addition to ^{131}I, Colorado suffered other kinds of fallout from highly dangerous plutonium. Plutonium is manufactured in military production reactors and in breeder reactors. The primary mission of Colorado's Rocky Flats (1952-92) was the fabrication of plutonium pits, which were shipped to other facilities to be assembled into nuclear weapons. Because it emits alpha particles, Pu is most dangerous when inhaled. Pu can enter the blood stream from the lungs and travel to the kidneys, meaning that the blood and the kidneys will be exposed to alpha particles. Once plutonium circulates through the body, it concentrates in the bones, liver, and spleen, exposing these organs to alpha particles.[28] Fatefully, the 6,240-acre (25 km^2) Rocky Flats plant was located within the most densely populated area of the state, 28 km northwest of Denver and 16 km south of Boulder. Rocky Flats was known for frequent spills and fires including illegal waste burning. The site managers ordered that thousands of barrels of hazardous waste be haphazardly discarded. These and other practices led to the contamination of sediment, groundwater and surface water with hazardous chemicals and radioactive constituents.[29]

Even worse, two large fires, in 1957 and 1969, resulted in plutonium release, exposing downwind Denver. Two employees in building 771 were injured in an explosion and fire in June 1957 involving routine handling of Pu. Three months later, another fire broke out when filters over the glove boxes caught fire. Firefighters turned on the ventilation fans, which spread the flames; seven days later, monitors showed smokestack emissions of radioactive elements at 16,000 times greater than standards. Rocky Flats scientists mismeasured wind direction; plant officials did not inform the public about this fire. The 1969 fire turned out to be less serious, and the firefighters – and Denver – were lucky. It involved at least 60 glove boxes on the north foundry line in building 776. Heavy smoke conditions resulted from burning Plexiglas and Benelex. The facility had yet to install fire suppression sprinklers that had been mandated after the first fire. Fortunately, the relatively fireproof roof filters did not burn through.[30] Cleanup costs were $26 million ($197 million in 2021 dollars). If by contemporary decontamination standards, cleanup would cost much more. This second fire was mentioned only in passing in local newspapers.

The trace of the Pu radioactive contamination over Denver (Image 2a) reminds of the Ural Mountain Radioactive Trace (EURT, Image 2 b) that formed after a huge, secret accident in the USSR that led to serious radioactive exposures of the population of the villages along the Techa river. On September 29, 1957, 20 MCi (740 PBq) of radionuclides were released by a chemical explosion in a RW storage tank at a Pu facility. Waste spread over 20,000 km^2 where more than 270,000 people lived.[31]

Nuclear Fracking

Colorado has been a mining mecca of gold, coal, and other wealth, and it supplied fuel for the Hiroshima and Nagasaki bombs. Might nuclear bombs in Colorado help expand gas and oil exploration? Both the United States and the Soviet Union pursued extensive programs for peaceful nuclear explosions (PNEs). To make the atom less frightening to the public, and demonstrate to Cold War opponents that one's weapons research and development program was vital, the superpowers sought economic value in the bomb. PNEs were also the only opportunity to continue to test nuclear devices after the signing of the LTBT (Limited Test Ban Treaty, 1963) that banned nuclear tests in the atmosphere, in space, or underwater. The USSR's Leonid Brezhnev immediately ordered the acceleration of the Soviet PNE program at the time of increasing tension between the superpowers to demonstrate the technical skills of Soviet weapons designers. The Soviets conducted over 120 PNEs from 1965-1988, many at the 5-10 kiloton range, but also at 10-20 kilotons and even larger, some with significant radioactive venting.[32]

Advocates claimed that PNEs were a sound method of carrying out large engineering projects: building dams, creating lakes, putting out raging gas field fires, incinerating chemical weapons, building storage domes, and so on. US Cold War PNE enthusiasts advanced far-fetched ideas for applications: a new canal across the Panamanian isthmus (the "Panatomic Canal"); the Cape Thompson, Alaska, harbor (Project Chariot); and another project that originated in US-Israeli thinking to create a new Suez Canal with 520 nuclear bombs. The risks were great. The thermonuclear PNE "Sedan" in New Mexico in July 1962 ejected 12 million tons of debris, left a crater nearly 400 m across and 100 m deep, and shot a radioactive cloud into the sky.[33] Even so, 50 years after the end of the US PNE program, engineers discussed using nuclear explosives to put out the British Petroleum Deep Horizon oil platform and well fire in the Gulf of Mexico in 2010.

Colorado's contribution to PNEs was modest (Image 3). In September 1969 in Rulison scientists detonated the first of two PNEs. AEC scientists drilled down 2,600 meters into gas deposits trapped in shale with the goal of "reinvigorating local gas fields and bolstering the economy." Austral Oil joined the AEC, Lawrence Livermore National Laboratory, home of the US H-bomb, and the US Geological Survey in planning. Austral was interested in opening the Mesaverde formation with several hundred billion m^3 of natural gas. The company acquired 20,000 acres and built a road to the proposed site. Drilling was carried out in the first half of 1969, with the blast delayed by public concerns, including over the stability of the Harvey Gap Dam about 30 km away. Eventually, a 43 kt nuclear bomb was exploded in September 1969. There was no venting of radioactivity and ground tremors were essentially as predicted. After seven months to allow for radioactivity to reach acceptable levels for reentry, the operation undertook a controlled drillback into the chimney followed by flow testing of gas to determine the cavity size and potential rate and volume of production. Courts rejected plantiffs' suit for a permanent injunction to prohibit the flaring of potentially radioactive gas, a wasteful and highly polluting oil industry practice in any event. In October 1970 flaring commenced with a total of 340,000 m^{3}..[34] A second PNE in 1973 also involved nuclear fracking. Sadly for PNE enthusiasts, the natural gas turned out to be too radioactive for commercial sale, and the site was closed to any more drilling.[35]

The courts were not convinced that plaintiffs produced undisputed evidence of irreparable damages, and in fact sided with the AEC and other cooperating government agencies that they had exercised great caution and care. The courts acknowledged that the plaintiffs introduced impressive evidence of new developments in the field of radiation biology, but failed to prove those developments showed the necessity of lowering the standards, first by not establishing an adequate correlation for low dose level exposures, nor refuting new evidence of "repair" of biological damage from radiation at low does rates.[36] Nuclear authorities have long argued that the possible effects of low doses were insufficiently known to permit firm conclusions about their danger to any one individual, and also argued that only a very small proportion of individuals who were exposed to radiation would be affected; in fact, exposure to low levels of radiation increases cancer risk.[37]

NPPs and the American West

The atom in the American West was primarily the military atom at Hanford, Washington, Los Alamos, New Mexico, and Rocky Flats.[38] Yet from the dawn of the atomic age, industry has celebrated the peaceful atom with pastoral imagery of reactors situated on placid rivers and lakes for cooling water, and often in agricultural settings to create the sense of powerful serenity. Most NPPs in the US are in the east, along the Atlantic coast, near the Great Lakes, and in the southeast. NPPs have suffered billions of dollars in cost overruns, retrofitting and construction delays at all sites, and the bankruptcy of an entire utility, Washington Public Power Supply System (WPPSS, but often called WHOOPS). But in the nuclear enthusiasm of the 1960s and 1970s many utilities turned to NPPs as a hedge against higher energy prices and a gateway to the atomic age.

This pastoral atom had a brief and entirely unsuccessful turn in Colorado. The 330 MWe Fort St. Vrain, CO, NPP, sixty km northeast of Denver, offered promise as a prototype HTGR (high temperature gas-cooled reactor) when proposed in 1965. It required comprehensive testing since US experience was nearly entirely based on light water reactors (pressurized and boiling, PWRs and BWRs). The end result of the lack of experience with this kind of reactor was considerable added cost, delays, and growing confusion between the AEC and the utility, PSC, that essentially dimmed interest in the HTGR. Finally, in January 1974 the reactor reached initial criticality and was brought up to full power, with electricity produced almost two years later, and with full power achieved only in November 1981.[39]

The AEC environmental impact statement generally determined that the Fort St. Vrain would have innocuous impacts on the environment: 80 acres of agricultural land with potential earnings of $14,000/year would be converted to industrial use; about 3.7 million m^3 of water would be lost in evaporation from cooling towers which might mean that in dry years 600 ha of irrigated farming would be retired; a modest 1,000 curies of gaseous radioactive wastes would be released annually; but that there was a very low probability of the risk of a radiation accident. Finally, the station would add 2.3 million MW/h per year to the PSC network, and the local economy would gain a modest $0.6 million/year in taxes, with 65 persons directly employed. However, as with all NPPs, there would be thermal shock to the South Platte River and St. Vrain Creek from cooling effluent water.[40]

The FStV NPP had to be shut down after a short lifetime. In fact, the station generated electricity for only thirteen years (1976 to 1989), whereas design parameters were for 30-40 years. It was decommissioned 1989-1992 (at $230 million in 2018 costs), and in 1996 converted into a conventional natural gas station at 1,000 MWe.[41] The reactor experienced severe corrosion problems. Its legacy of 23 tons of highly radioactive spent nuclear fuel (SNF) required the construction of a heavily reinforced concrete building that is half a football field in size.[42] SNF is a major and growing problem worldwide. Presently, there are 400,000 tons worldwide of highly radioactive SNF, for the most part in storage pools at NPPs, and the amount is growing by at least 10,000 tons annually.

In addition to Colorado's problem with storage of SNF, FStV had to be decommissioned. Of the world's approximately 450 commercial power reactors, the US has operated 123 of them, with 93 reactors currently on line at 54 plants. Yet by 2017, only 10 of the shutdown reactors had been successfully decommissioned, with another 21 US nuclear reactors in the process. The costs, time frame and uncertainties surrounding this effort seem underappreciated by industry and government, with insufficient reserve funds to pay the costs. Further, no decommissioning effort is judged fully complete until decades later to decrease radioactivity, the so–called "SAFSTOR" phase,[43] The costs in the 2020s run into the hundreds of millions of dollars per reactor.

Might the peaceful atom return to the Rockies in the twenty-first century? Not fully appreciating the great cost of today's industry-touted SMRs (small modular reactors), their unproven nature (only a handful are being built or operated worldwide), and the persistent problem of waste, including SNF, some Coloradans are again pushing for nuclear power as "cutting edge, safe, clean (carbon free) and affordable."[44] For the editorial board of Colorado's *Gazette*, the worry is that Colorado, which generates 29% of electricity from natural gas, 32% from coal, 28% from wind (sixth in the country in capacity), will suffer significant energy shortfalls unless more capacity can be found, while they maintain that nuclear power is safe, green and not too costly.[45] An SMR proposed in 2015 for neighboring Utah at $3 billion was cancelled when the price tag reached $9 billion years in 2023.

Colorado and the Cold War Bomb

The history of the greening of the military atom is a catalog of nearly insurmountable challenges in recreating stable and radioactively safe landscapes. The entire bomb-making process was fraught with radioactive dust, toxic residues, industrial din, and dangerous discards. For example, at the Fernald, Ohio, plant, through a series of chemical and mechanical processes, workers extracted uranium from scrap metal or recycled materials. Uranium ingots in the shape derbies was shipped to the gaseous diffusion plant in Paducah, Kentucky, or converted on site to uranium tetrafluoride. Overall, Fernald produced 14 million kg of uranium product, 1.1 billion kg of waste, and 2.5 million m^3 of contaminated soil and debris. A 90 ha portion of the underlying Great Miami Aquifer that served as drinking and agricultural water for surrounding communities had uranium levels well above standards.[46]

When operations at Fernald ceased in 1989 the plant turned to environmental restoration and waste management activities that enabled the creation of the Fernald Nature Preserve.[47] The former uranium-processing facility now exists as a nature center with walking trails and an information center with a list of "key words": waste pits, silos, mixed waste, on-site disposal, derbies and ingots, soils and plumes.[48] Transforming the radioactive site into a brown field had great symbolic meaning for local residents. They gained a seven-mile "network of trails meandering through the wetland, prairie, and forest landscape. Several overlooks, and a boardwalk are open to visitors. The portable toilet in the visitors center parking lot is available for public use and continues to be cleaned daily." During the COVID epidemic the visitors center was closed, and guests were urged to "follow the social distancing guidance, provided by the Ohio Department of Health and Hamilton County Public Health."[49] The Cold War thus begat a nuclear park for walks and bird watching that was dangerous because of COVID, and not because of proximate buried RW. Such other sites as the Portsmouth, OH, gaseous diffusion plant (PORTS) situated on a 1,503 ha Ohio River site, belatedly addressed the need to clean up 70 years of its extensive radioindustrial pollution. [50] During its cleanup, PORTS has turned to a virtual (online) brown field museum with no onsite hiking or trails.

Colorado's efforts to address long-lived Cold War RW have face significant challenges in terms of the scale and pressing need for cleanup. Radioactive brown fields may result from the razing of entire towns, not factories alone. The 350-ha Uravan Site opened in the late 1800s and remained operational into the 1980s. Mine workers were regularly exposed to hazardous radiation levels and have experienced disproportionately high rates of cancer.[51] Radium production slowed with the discovery of rich deposits of pitchblende in the Belgian Congo. Between 1923 and 1936 mine operations focused on uranium and vanadium. USV eventually built a company town to house 250 workers that grew to over 400 workers and their families. With the Manhattan project, uranium production became central to operations. The mines produced three tons of uranium sludge per day. The town remained active until the 1970s when persistently high radiation levels mandated its closure.[52] The federal government declared Uravan unsafe, indeed, a Superfund site, and 800 people were forced to move.

At one point, the next owner of Uravan, Umetco, a subsidiary of Union Carbide, proposed offsetting cleanup costs by opening a for-profit RW dump on site; Coloradans rejected the dump. Twenty-two US states have passed laws that limit nuclear power in one way or another, including prohibitions against RW dumps.[53] In any event, the US government sued Union Carbide and Umetco to force the cleanup and ensure responsibility for long term monitoring. All of this mirrored the discovery of toxic chemicals in Love Canal, New York, that led to illness and death, required the evacuation of 900-some families and the designation of Love Canal as a Superfund site, and demonstrated how government can act quickly in the face of mortal risks.[54]

Uravan was removed from the face of the earth, or almost removed (see Images 4a and 4b). Special crews dealt with more than 13 million cubic yards of mill tailings, evaporation pond precipitates, water treatment sludge, contaminated soil, and debris from more than 50 major mill structures on the site. These wastes were collected and disposed of in four on-site "disposal cells" which also contained wastes from a nearby abandoned mill in Gateway, Colorado, and mill tailings from the Naturita mill site. Uravan now is just a patch of land whose dangers lurk under the surface. The trees, the houses, the post office, "the Coke glasses from the drug store" – everything was shredded and buried in a concrete-lined hole. The lasted 20 years and cost more than $120 million.[55] The Rimrocker Historical Society has tried to preserve some remnants and memories of Uravan. The society salvaged two structures and purchased a baseball park which hosts annual August gatherings for former residents. The former ballpark includes picnic and camping areas, an information kiosk, and the flag pole from the Uravan Post Office.[56]

With the US buying most of its uranium abroad, it seems to have lost interest in and the will for final cleanup, especially since many of the mines are on Native American land. The the EPA has identified 15,000 abandoned uranium mines in 14 western states with about 75% of those on federal and tribal lands.[57] All of that ore is loaded with radon gas or radon progeny that are highly carcinogenic. The risks and dangers to environs and people disproportionately affects colonial and post-colonial spaces: seventy percent of global uranium deposits are located on traditional lands of indigenous people in the US, Canada, Australia, Niger and elsewhere, and removed by Navaho, Inuit, Aboriginals, Hausa, Namibian and Kazakh hands.[58] Miners carried dust on their clothing, and in their lungs, where it spread into their homes and among their families and friends. Navaho families planted fruit orchards, corn and squash with water taken from nearby gulches that were fed with rain water that carried radionuclides into their gardens.[59]

The human costs of mining in the southwest have long been known. The US Public Health Service (PHS) carried out studies of uranium mines from the late 1940s and assembled evidence of high exposure rates – and soon would have evidence of high rates of cancer. Even as studies accumulated that indicated the risk health risks to miners, the adoption of protections was slow and incomplete, and the industry actively opposed them. NIOSH (National Institute for Occupational Safety and Health), created in 1970 as part of a groundswell of regulatory concern to raise levels of industrial hygiene and environmental safety in the US, confirmed the significant health impacts among the miners. Of 150 Navajo miners who worked at the Shiprock, New Mexico, mine, 38 had died of cancer by 1980s.[60] The EPA to this day publishes online tear sheets and handouts warning local residents near mines of the persistent surrounding dangers of radiation exposure.

A Radioactive Brown Field

Rocky Flats is a flagship of the effort to green radioactive brown fields. The original cleanup was estimated at decades to complete and $40 billion dollars, but took less than 10 years and cost $7 billion which were hopeful signs for the environment and nearby inhabitants. Like other facilities, Rocky Flats was operated by private contractors – Dow Chemical Company, Rockwell International and EG&G – which enabled the handing down of responsibility for proper management of the site and making the claim that RW was not entirely its responsibility. Cleanup workers were ordered to bury most of the buildings onsite under six feet of soil, paving over portions of it, but ultimately were unable to remove the vestiges of pit manufacture.

Persistent safety problems and criminal activity on the part of Rockwell contributed to the site's closure.[61] Unsealed barrels of radioactive waste leached poisons across the land; traces of plutonium and elevated levels of radioactive tritium were discovered in local reservoirs; employees were injured. After the US Congress purchased land for an additional buffer zone around the site to prevent public access, more plutonium was discovered in topsoil beyond the original buffer, and Congress expanded the buffer zone again. Polychlorinated biphenyls (PCBs), chromic acid, beryllium, and other radionuclides entered the environment. Auditing revealed more than 1,360 kg of missing plutonium (enough to make 250 small atomic bombs). Throughout it all, the authorities used secrecy to limit public access to information and punished on-site whistleblowers, all in the name of national security.[62]

Plant workers leaked documents to the EPA about the continued willful polluting that led to a joint FBI-EPA onsite investigation, "Operation Desert Glow." In June 1989, plain clothes FBI agents entered Rocky Flats, ostensibly to inform officials about a threat from an ecoterrorist organization. In fact, they kept Rockwell officials occupied while 30 vehicles with more than 70 armed agents arrived. They gathered documents that revealed the extent to which Rockwell violated of environmental regulations with workers being instructed to dump toxic chemicals and radionuclides willy-nilly. The raid resulted in charges and $17 million in fines against Rockwell International.[63]

Rocky Flats cleanup commenced in the 1990s after the end of the Cold War, and was intended to transform much of the site into a wildlife preserve. Cleanup involved decommissioning and demolishing the entire plant of more than 800 structures; the removal of over 21 tons of weapons-grade material and 1.3 million m^3 of waste; and treatment of more than 61,000 m^3 of water. Four groundwater treatment systems were also constructed. Federal legislation was signed into law in 2001 designating most of the Rocky Flats site a National Wildlife Refuge. The Refuge opened in July 2007 when the US Fish and Wildlife Service took over management of the site (Image 5). But the central area where the former plant was located was fenced off and will not be opened to the public. Thus, a nuclear waste Superfund sits at the center of a wildlife refuge.[64]

According to Friends of the Front Range Wildlife Refuges (FFRWR), the 5,000-acre Refuge "has striking vistas of the Front Range of the Rocky Mountains and rolling prairie grasslands, woodlands and wetlands. It is home to 239 migratory and resident wildlife species, including prairie falcons, deer, elk, coyotes, songbirds, and the federally threatened Preble's meadow jumping mouse." Because the military site was enclosed and off limits for decade, large areas of the Refuge remained relatively undisturbed "resulting in diverse habitat and wildlife. A portion of the Refuge contains rare xeric tallgrass prairie, providing habitat for a variety of wildlife…"[65] This is an oft-repeated argument: that military reservations are somehow good for nature by keeping people out. Ultimately, the DOE, EPA, and Colorado Department of Public Health and Environment (CDPHE) determined that the *off-site* area surrounding Rocky Flats was not contaminated at levels that required cleanup. The off-site area consists of about 20,480 acres of open space, residential developments and agricultural lands.[66] Miles of hiking trails, bicycling, horseback riding, cross country skiing, snowshoeing and in 2024 a new archery range are part of the refuge. But eating fish and game from the refuge is forbidden.

Along with the transformation of Rocky Flats into a nature refuge, lands abutting the area were redeveloped "into residential property by the Terra Causa Capital and GF Properties Group, a subsidiary of the Southern Ute Indian Tribe." Residents of the village of Candelas, 1,500-acre master-planned bedroom community of Denver, learn from the housing development website that they are a new breed of western settlers living along "a magnificent sweep of mountain pastureland" which is the "epitome of raw western beauty."[67] What they do not learn from the Candelas website is that their homes abut reclaimed radioactive lands with a Superfund site. Rocky Flats became a refuge. And Rocky Flats became Candelas. A "Greenway" project began in 2016 as an effort to connect three national wildlife refuges — Rocky Mountain Arsenal, Two Ponds and Rocky Flats — through an interconnected trail system involving the installation of an underpass and overpass to facilitate access to trails among them. But in spring 2024 filters set up in three locations to monitor construction debris and contaminated soil picked up plutonium particles during gale-force winds.[68]

Radioindustrial Brown Fields

Humans who toiled in radioindustrial ecosystems, or were used as human guinea pigs in horrific nuclear experiments, and their families, paid the health and safety consequences for exposures to radiation. The same is true everywhere – in Algeria and Australia, Tahiti and Pacific atolls, Russia, and China – which also have engaged in belated, halting, and poorly-funded and -administered efforts to clean up nuclear waste and to offer financial compensation to nuclear workers, soldiers and downwinders.[69] Navaho miners; workers in Rocky Flats; Denver downwinders; and other Coloradans cannot know precisely their health costs. In 1990 Congress passed the Radiation Exposure Compensation Act (RECA) to make payments to those affected by fallout from nuclear tests at the Nevada Test Site – while making it difficult for them to prove they had been affected. By 2021 $2 billion had been paid out to 37,000 claimants, an insignificant sum compared to the trillions of dollars spent on building the nuclear weapons establishment and the soon-to-be $1 trillion to clean up the radioactive wastes and residues from the peaceful and military atom.[70] As of 2020 thirty percent of all Navajo people still lacked access to uncontaminated drinking water, largely because of uranium.[71] So bad is uranium pollution that the state and industry have had to pay for a $600 million aqueduct – sixty years late and in 2024 still unfinished – to bring potable water to 50,000 people in southeastern Colorado whose wells and other sources of water are radioactive.[72] And the Superfund Trust, which taxed polluting industries to ensure the wherewithal for cleanup, was forced to lapse by Congressional Republicans so as to shift the burden of all cleanup to taxpayers.

Uranium is a boom and bust business – when bombs or new reactor come calling, the price goes up and miners stake claims. With the closure of US mines for sources abroad, hazardous mine shafts and radioactive tailings were left behind across the western states. In southwest Colorado, some of these mines are being reentered and developed again.[73] Elsewhere, local people have been forced to choose jobs over waste, for example, those in Nucla, Colorado, a mining and agricultural community, who see the profitability of accepting uranium tailings from outside into their town, where it might contaminate the soil and water, but "bring in some business," although perhaps only 10 temporary jobs.[74]

An examination of Colorado's uranium mines, mills, enrichment and bomb making plants, NPPs, and PNEs adds to a rich global literature on the environmental history of the nuclear age. It confirms the significant, and usually irreversible human, environmental and financial costs connected with the nuclear enterprise because of the long-lived nature of radionuclides, security considerations which prevented public knowledge of the risks associated with nuclear technologies, and a public-private industry interface which downplayed or ignored the dangers of both peaceful and military technologies, in the name of national security or job formation.

One of the ways in which industry and government have dealt with the extensive pollution of the nuclear age has been to re-cast reclaimed and cleaned-up facilities as green – as parks, preserves and refuges. Yet wherever a nuclear facility exists, a sign or a gate indicates a clear public warning about risks of radiation to health and safety, even in so-called fauna refuges. Along these lines, historian Adam Rome worries that a major reason for this situation is that it is cheaper to convert a heavily polluted weapons complex into a wildlife refuge than to make it truly safe for homes, schools and businesses.[75] The cost and incompleteness of the efforts raises the questions again whether military sites, let alone NPPs, can be "returned to nature"? Will habitat in any ways resemble the pre-nuclear landscapes? Will fauna return? Is it possible to hold toxic wastes within or adjacent to engineered natural areas? In a word, from mines and military facilities to NPPs, and from the East Coast to the West Coast and to Colorado, will nuclear brown fields ever be green – or even brown?

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