original article

esboços
histórias em contextos globais

TOWARD A GLOBAL HISTORY OF THE NUCLEAR AGE

Para uma história global da era nuclear

Paul Robert Josephson [a]
E-mail: prjoseph@colby.edu

Tatiana Kasperski [b]
https://orcid.org/0000-0003-3392-3066
E-mail: tatiana.kasperski@sh.se

[a] Colby College,Waterville, Maine, USA.

[b] Södertörn University, School of Historical and Contemporary, Stockholm, Sweden.

UFSC
Esboços, Florianópolis, v. 31, n. 57, p.330-346, may/aug., 2024.
ISSN 2175-7976 DOI http://doi.org/10.5007/2175-7976.2024.e102709

ABSTRACT
The environmental history of the nuclear enterprise has grown increasingly important, not the least because of the strong conviction that an ongoing, and self-proclaimed "renaissance" in nuclear energy must be a major part of world energy scenarios in the battle against global warming and the need to abandon carbon-based energy production. This article suggests a number of ways to take advantage of the recently available primary sources by using a global approach to make sense of nuclear environmental history. It calls for looking at environmental impacts across a variety of ecosystems: desert, Arctic, tropical, limnological and oceanic. It insists on considering the entire nuclear enterprise from mining to enrichment to fission. It suggests focusing on interactions between the atom, nature, and the lives of mammals, fish and birds in the nuclear world. In the end, this analysis shows that the atom is not green, and that the argument that nuclear power is a solution to global warming ignores the troubled relationship between the natural environment and peaceful and military technologies.

KEYWORDS
Nuclear age. Global history. Environment.

RESUMO
A história ambiental do desenvolvimento nuclear é cada vez mais importante, sobretudo devido à forte convicção de que um "renascimento" contínuo e autoproclamado da energia nuclear deve ser uma parte importante dos cenários energéticos mundiais na batalha contra o aquecimento global e a necessidade de abandonar a produção de energia baseada no carbono. Este artigo sugere uma série de maneiras de aproveitar fontes primárias disponíveis recentemente, usando uma abordagem global para dar sentido à história ambiental nuclear. Ele também aponta para que se observem os impactos ambientais numa variedade de ecossistemas: desérticos, árticos, tropicais, limnológicos e oceânicos e considera todo o empreendimento nuclear, desde a mineração até o enriquecimento e a fissão. Sugere focar nas interações entre o átomo, a natureza e a vida de mamíferos, peixes e pássaros no mundo nuclear. Por fim, esta análise mostra que o átomo não é verde e que o argumento de que a energia nuclear é uma solução para o aquecimento global ignora a relação conturbada entre o ambiente e as tecnologias pacíficas e militares.

PALAVRAS-CHAVES
Era nuclear. História global. Ambiente.

Nuclear histories have generally focused on one nation, on the peaceful or military atom, or on such major accidents as Three Mile Island (1979), Chernobyl (1986) and Fukushima (2011). They have considered bombs or reactors, rarely both in the same works. They have considered protest or regulation, but again usually within one country. This brief article suggests the importance of pursuing a global environmental history of the nuclear age. Such an approach would overcome borders in geophysical, empirical and methodological senses. It would permit deeper comparisons of the environmental soundness of the nuclear enterprise, and it would contribute to fuller understandings of the real risks and benefits of pursuing nuclear power in the twenty-first century as a "green," meaning as a low-carbon technology.

Since its founding in 1994, the journal *Environmental History* has published 50 book reviews and 33 articles on nuclear topics, covering such issues as anti-nuclear protest, authoritarianism; downwinders; the nuclear fuel cycle; and regulation. *Global Environment* has published only a handful of nuclear articles in its nine years. Similarly, the recently articulated concept of envirotechnical systems that reflects an explicit conceptualization of the relationship between the environment and technology, and that adds to the well-studied social, political and cultural factors that shape technological change, has not integrated the nuclear enterprise, military or civilian, fully into environmental history. The end of the Cold War led to the declassification of documents, reports and studies that enable a more complete analysis of the human, financial, political and environmental aspects of the military and civilian atom.

The environmental history of the nuclear enterprise has grown increasingly important, not the least because of the strong conviction that an ongoing, and self-proclaimed "renaissance" in nuclear energy must be a major part of world energy scenarios in the battle against global warming and the need to abandon carbon-based energy production. Similarly, to indicate the environmental soundness of nuclear technologies, managers of military facilities claim that the closure of plutonium production plants, army bases, and testing facilities since the end of the Cold War has led to the rejuvenation of ecosystems and the fauna in them (Maag, 2020).

This article suggests a number of ways to take advantage of the recently available primary sources by using a global approach to make sense of nuclear environmental history. It calls for looking at environmental impacts across a variety of ecosystems: desert, Arctic, tropical, limnological and oceanic. It insists on considering the entire nuclear enterprise from mining to enrichment to fission. It suggests focusing on interactions between the atom, nature, and the lives of mammals, fish and birds in the nuclear world. In the end, this analysis shows that the atom is not green, and that the argument that nuclear power is a solution to global warming ignores the troubled relationship between the natural environment and peaceful and military technologies (Pritchard, 2012).

NUCLEAR SYSTEMS AND THE ENVIRONMENT

Four theoretical concerns help to frame the importance of understanding nature's agency in the nuclear enterprise: the social, political and environmental essence of large scale technological systems; "nuclearity" or nuclear characteristics of these systems and their components; the essential overlap of military and civilian nuclear technologies; and the colonial and post-colonial nature of the nuclear enterprise. Regarding the first, the meaning and function of technological systems, we cannot look at objects in isolation, but must consider the messy interaction of engineering, scientific, financial, governmental, and social institutions in giving impetus – or creating obstacles – to the dissemination of technology

(Hughes, 1989; 1998). It is almost technologically determinist to insist on the rigor of examining nuclear history through the lens of large scale systems since they develop, expand, and are augmented by other technological systems as if having a will of their own. Yet precisely they grow extensively in space and time. They involve geological engineering, deployment and construction across vast regions, nuclear tests in laboratories and in various terrains, in the atmosphere and under water, and massive numbers of individuals working on land and at sea, in offices and research sites, also underground or in the air, employed in a variety of public and private organizations, and carrying out a variety of tasks. In a word, the machinery of nuclear production employed – and often housed – hundreds of thousands of scientists, laborers and soldiers engaged across a series of landscapes with complex technological systems concerned with nuclear fuel manufacture and use, pushing the environment and its inhabitants because of national security concerns, economic pursuits, and other reasons.

Political desiderata contributed to the spread of interlinked nuclear systems. They were central to the wartime and postwar military and foreign policy efforts of powerful states and conceived in a military race in the search for unheard of explosive power to decimate the enemy. Adopting industrial approaches, the nuclear nations mass produced tens of thousands of nuclear warheads (weapons of mass destruction, WMD). They carried out dangerous atmosphere tests that employed thousands of soldiers operating in rapidly assembled testing grounds. They expanded further because of connections with Atoms for Peace programs in the 1950s and beyond. By the late twentieth century they were crucial to the export industries of major nuclear states. From laboratories and experimental reactors, they jumped to the construction of almost 450 commercial NPPs worldwide with another 100 or so forecast, planned or under construction. Nuclear technologies massively occupy riverine, lake and ocean ecosystems, taking control of them with extravagant human, capital, legal and other resources as manifested in prospecting, mining, fuel fabrication, weapons and nuclear power facilities (Krige, 2008). By examining the scale and diffusion across nations and ecosystems we can construct more complete understanding of their global environmental impacts independent of borders, fences and other geopolitical and physical barriers.

The geophysical scale of several nuclear sites instructive: by 2015 the US military-scientific enterprise consisted of eight national laboratories, tests sites, weapons facilities, affiliated production units. The facilities spread across hills, forest, and deserts that pulled lakes and rivers into systems that planners believed could be made hermetic. The Oak Ridge, TN, “reservation” for uranium production is 150 km^2, while the Hanford, WA, reservation at 1,290 km^2 used nine reactors and five plutonium processing complexes to generate more than 60,000 nuclear warheads. Military and public officials selected the huge, open sites precisely for their seeming distance from inhabited areas where they could locate hazardous manufacturing areas and store dangerous wastes, while ignoring local people and undervaluing flora and fauna. In fact, a good question for study is to what extent military and government officials and planners considered sites to be “empty” of people, flora and fauna. That is, by studying the thinking behind the organization of nuclear systems we can better understand the sources of and justifications for the great environmental impacts of the nuclear age.

Large scale nuclear systems have been reproduced in similar environments across the globe for both civilian and military projects. French, Soviet and British military planners similarly sought vast land holdings, to them devoid of human habitation, preferably far from borders, or in colonial possessions, to exploit ore, erect enrichment plants, test weapons and open nuclear power stations. They believed they could keep intruders of all sorts out (terrorists, spies, protestors, fish and other fauna that clog intake pipes or carry away pollutants on their fur). The extent of takings hardly prevented the movement of radioisotopes throughout the world's ecosystems, not the least from atmospheric nuclear tests that spread fallout especially in the northern hemisphere.

Not only technological systems, reservations, test sites and reactors have become nuclear. Many of the objects and features of this world – humans, fish, birds, uranium and concrete, power lines, construction machinery, rebuilt waterways and so on – are nuclear. How and when do such things as fish raised in NPP effluent become nuclear things? Hecht names this phenomenon "nuclearity" (Hecht, 2011). One way to examine nuclearity in greater depth is to consider how environmental aspects of nuclear applications share features with other industrial activities, and in what ways the nuclear world may be unique. Profligate water use, erosion, ground water pollution, discarded materials considered unimportant or worthless – all of these things occur in other spheres of industry. Similarly, nuclear projects involve terracing, excavating, mining, clearing of forest, draining of wetlands, modification of lakes and rivers, digging, construction, the use of explosives, and shipments of vast quantities of ore and other materials. Yet analysts have tended to keep these elements of production in the nuclear sphere at least hypothetically separate: mining, tailings and high level radioactive waste; reactor cooling water and the lakes and rivers fed by reactor cooling effluent and seeded with fish; isotopes used for medical purposes and consequential exposures to isotopes that may lead to blood poisoning, serious illness and death.

For decades analysts asserted that military nuclear programs significantly differed from civilian ones by virtue of their vast scale in terms of (potential) explosive power, kinds of toxic wastes, and the employment of tens of thousands of employees in research institutes, production plants and bomb making facilities. Mines and enrichment facilities exist equally for civilian and military purposes. Removal of local people and restrictions on entry to various landscapes must occur in civilian and military facilities. Thus, the dissimulation of military and civilian nuclear applications is intended to disarm critics of the dangers and hidden environmental costs of the enterprise (Stirling; Johnstone, 208). Keep in mind, for example, that enrichment "accounts for almost half of the cost of nuclear fuel and about 5% of the total cost of the electricity generated," and that historically enrichment was often based on coal-produced electricity (World Nuclear Association, 2022). Many nations embraced the peaceful atom with its promise of immediate modernity and clean electrical energy. But in so doing they ignored the coercive environmental impacts of the atom. A promising approach to a comprehensive global environmental history thus is to recognize that highly complex military and civilian nuclear systems are of the same piece with overlapping institutions, technologies, fuel systems, components, personnel, ionizing radiation and impacts on society and environment.

A last feature of the nuclear enterprise is its colonialist nature with attendant environmental and social costs. The nuclear powers took advantage of their superior military and geopolitical position at the end of World War II and into the 1950s to employ colonial holdings as test sites. The French, Americans, Soviets, British and Chinese tested weapons in such landscapes as deserts and Arctic regions, perceiving them as empty or perhaps occupied by less worthy people. The Algerian Sahara; the homeland of many Aborigines, the Maralinga Desert of Australia; the Mohave desert in Nevada; the Kazakh Steppe; the Nenets Arctic homelands; and the Polynesian and Marshall Islands atolls all were transformed into nuclear military-industrial facilities. The environmental and socio-political impacts on Aborginals, Bikinians, Nenets, Kazakhs and other people remain understudied because of the secrecy that surrounded weapons R and D.

Even before testing, colonialism was crucial to the nuclear age in uranium mines. Mining is heavy, dirty labor, and the uranium industry pushed the miners at each stage, from drilling and pulverizing rock to breathing in the dust. Miners harvest ore for milling to produce uranium oxide for enrichment into fuel. Miners used their hands, wheelbarrows and burrows as they worked underground. Drillers broke the rock and dug out ore with shovels and back hoes, they dynamited deposits and dumped riprap nearby. Muckers and trammers moved the broken rock; carted the ore with animals and small gauge trains, or bulldozed, loaded and trucked it about; pushed rock and other debris and uranium tailings to the side, in valleys and into streams from which radiation spread in water and air. All of them carried the dust on their clothing – and in their lungs, where it spread into their homes and among their families and friends. This damage to environs and people disproportionately affects colonial and post-colonial spaces: seventy percent of global uranium deposits are located on traditional lands of indigenous peoples. Burke notes that "some of the most advanced scientific industrial and military projects have come into direct confrontation with the world's oldest human cultures" – in testing of weapons especially in the Pacific Ocean and in mines in the US, Canada, Australia, and Niger – the Navaho, Inuit, Aboriginals, Hausa, Namibians and Kazakhs (Burke, 2017, p. 76).

In the US, uranium production in support of the Cold War arms race reached peak production from approximately 1948 to the 1980s when thousands of mines were opened in the American west. Native Americans in the Colorado Plateau area including Navajo, Southern Ute, Ute Mountain, Hopi, Zuni, Laguna, Acoma, and several other Pueblo nations, with their intimate knowledge of the land, often led miners to uranium resources during this exploration boom. It was mined and milled in four centers of nearby Navajo land near Shiprock, New Mexico; Monument Valley, Utah; Church Rock, New Mexico; and Kayenta, Arizona. Native American land was recast for military purposes across the southwest. Many people who reside near areas of mining or milling have had compromised health. The staggering human costs of mining worldwide can be estimated from the US case. Between 1945 and 1966, in growing numbers year by years, 98 miners died from lung disease, and thousands more were exposed to those levels sufficiently that likely led to many more cancers. But inexpensive ore was more important that worker safety that might be accomplished through ventilation, sealing mine walls, filtering mine air to reduce radon, enforcement and monitoring actually would improve the situation for miners (Eichstaedt, 1994, p. 82-87).

Nuclear colonialism and postcolonialism are also significant from a variety of environmental perspectives concerning Eastern Europe, Kazakhstan, Belarus and Ukraine which relied on the USSR for technology (reactors), the nuclear fuel system of fresh fuel supply and spent fuel removal, and in many cases for radioactive waste and detritus left behind after the collapse of the USSR. In a word, complex material, environmental and institutional entanglements, from uranium ore to fuel, from production to pollution, and from research to widespread applications went forward in colonial and postcolonial circumstances that call for investigation (Bauer, 2018; Biswas, 2014; Churchill and LaDuke, 1992; Dudar, 2019; Endres, 2009; Hecht, 2011; Hill, 2019; Schmid, 2019, 2011; Stawkowski, 2016; Wendland, 2019).

THE NUCLEAR MACHINE IN THE GARDEN[1]

One possibility for pursuing an environmental history of the nuclear age is through a kind of literary-cultural analysis. In his *Machine in the Garden* (1964) Leo Marx examined a

[1] For a pictorial essay on this subject, see Paul Josephson, "Global Nuclear Environmental History: A Photographic Essay," at https://globalnuclearenvironment.files.wordpress.com/2022/01/global-nuclear-environment.technology.atom_.nature.final_.pdf

ISSN 2175-7976 DOI http://doi.org/10.5007/2175-7976.2024.e102709

literary trope through which social, literary and artistic figures of the nineteenth century revealed awe, bewilderment and fear of the industrial age. They advanced the image of a mechanical intrusion into pastoral settings as a characteristic expression of a deeply troubled society. This expression of discomfort with rapid industrialization was the "machine in the garden." The nuclear enterprise has turned this trope on its head, as it were, using enthusiastic accounts of sponsored research, prospectuses, corporate brochures, annual reports, trade group publications, PR pamphlets, calendars and magazine articles to demonstrate the seamless compatibility of the atom with nature, and at the same time to argue that the environmental impacts of their facilities are reasonable given the purpose to produce clean and cheap electricity as demanded by the public. Yet how accurate are these depictions?

Two at once overlapping, yet divergent views of the nuclear world compete for our attention and approbation. One involves a pastoral vision of nuclear power as fitting neatly into the natural world, with its physical intrusions limited to acceptable land takings, manageable thermal pollution and minimal impacts on flora and fauna. A corollary to this view is that unexpectedly high capital costs of nuclear power plants (NPPs) are being reined in by standardized approaches, that catastrophic accidents will be eliminated through inherently safe technologies and new operational culture, and that the problem of radioactive waste is imminently solvable. More important, the atom is "green" in producing energy without contributing to global warming, its fuel volumes of uranium and plutonium are orders of magnitude smaller than those for fossil fuels, and it has a strong public health and safety record when compared with oil, gas and especially coal. As for nuclear weapons: they secured national security and prevented world war, and thus perhaps the environmental costs of the military atom can be overlooked. Or at least, the environmental impacts of nuclear weapons production were hidden from public examination until after the end of the Cold War.

Yet a second, darker vision confronts this nuclear landscape. It draws attention to extensive military nuclear programs that are hardly separable from civilian ones. Both the peaceful and military atom had tremendous and growing environmental impacts that will cost hundreds of billions of dollars to remediate. The darker view acknowledges the spread of radioactivity in every phase of the nuclear enterprise from mining to milling and fuel enrichment, and especially in nuclear weapons tests and accidents, and it points to significant impacts on ocean, river, desert, arctic and other biomes. The darker vision reminds us of the extensive and haphazardly handled radioactive waste that permeates the enterprise – and the 250,000 tons of spent nuclear fuel throughout the world that awaits proper storage.

Since the dawn of the atomic age, industry has framed nuclear power as environmentally sound, especially in comparison with dirty coal with its particulate, air pollution, and fuel volumes much greater than those of uranium. It has celebrated, as it were, the nuclear machine in the garden. Its publications offer vivid images of such cutting-edge technologies as nuclear powered locomotives, spaceships and reactors that are intended to indicate modernity, scientific achievement, energy independence and, at once, control of nature through the atom, yet a pastoral "oneness" with nature. Reactors must be sited on large bodies of water, and they may require extensive reworking of rivers, lakes and ocean coasts. Reactors are built in concert with other large scale technological systems – construction, concrete, transport, mining, iron and steel – but in nuclear publicity they are presented as sleek, simple and safe. A global environmental history of reactors would compare industry publications to explore their similarities. For example, the official photos of Bohunice, Slovakia, NPP; Dresden, IL, NPP; Borssele, Netherlands, NPP; Metsamor, Armenia, NPP; and Forsmark, Sweden, NPP; and many others are taken in fields of sunflowers and agricultural meadows in the foreground, or vineyards in the background, in lush green agricultural settings near rural towns, and if fauna are involved, then fishermen nearby cast lines over placid water, or a goose sits maternally on her nest outside a station. A happy fox in front of the Paks NPP (with four Soviet-designed pressurized water reactors, PWRs) adorns the cover of *Atomerőmű Magazin* (Hungary). In Taiwan, blue magpies and coral fish coexist with NPPs in official publications.[2] Électricité de France (EDF) publishes its annual environmental reports with hints of blue and green…and rainbows.[3]

From the 1950s, scientists and US Atomic Energy Commission (AEC) officials, working with and encouraging industrialists and utility representatives to pursue nuclear power, embarked on a publicity program to introduce the world to the first generation of nuclear power plants. Significantly smaller than today's standard 1,000 MWe units, often with rudimentary safety systems, they shared the promise of inexpensive energy before peak oil and without coal's filthy emissions. Across the world the standard presentation in visuals or words was green: many nuclear advertisements open in a bucolic setting, a meadow with a winding path, waving flowers, leafy trees, all illuminated by brilliant sunshine to indicate freedom from darkness. In some scenes, wispy clouds move through blue skies overhead. Another common message in nuclear brochures involved demystifying the unlimited possibilities of safe energy production through easy-to-follow discussions of nuclear physics, the chain reaction, and how to build a reactor. In still other publications, operator-priests in white uniforms occupy high tech control rooms with banks of computers and displays to demonstrate that modern science and safety go hand in hand with awe for the atom.

Promotional industry and government agency films presented a narrative of plentiful jobs, clean environment, inevitable progress and manifest public rewards. A film about the first US NPP, Shippingport, Pennsylvania, launched at 60 MW, and that operated from December 1957 until October 1972, stressed that the benefits of the peaceful atom extended far beyond the generation of electricity in "the matching of daring plans and centuries of learning," jobs and a higher standard of living.[4] Another early film about nuclear power professorially intoned, "For centuries the hills and valleys of New England have bred and raised pioneers" in inventions and economic developments – and Yankee Rowe NPP at 180 MWe, was the nuclear example of "Yankee ingenuity." The Yankee Atomic Electric Company, a consortium of ten New England utilities was formed in 1954 to build Yankee Row, New England's first NPP, on the Deerfield River in western Massachusetts. Yankee Rowe was built for a series of reasons, "all of them were sound": to generate electricity in the face of growing demand; demonstrate the power of US private sector, at the same time reflecting the old Yankee spirit; and realize the real potential of nuclear power. Yankee Rowe, unfortunately, was shut down prematurely due to reactor pressure vessel integrity concerns, and then cost $508 million to decommission between 1992 and 2004, 60% greater than original estimates.[5]

Entire green communities – with engineers and their families living in well-appointed houses separate from the mass of workers -- have been built around nuclear reservations.

---

[2] The covers of the major journal of the Rosatom, *Vestnik Atomproma* (*The Herald of Nuclear Industry*), show powerful, yet majestic NPPs that occupy picturesque green and blue nature scenes.

[3] Graveline, EDF*, La centrale nucléaire de Gravelines, Produire de manière sûre une électricité bas carbone à un coût compétitif en region*. Hauts-de-France (2022).

[4] US AEC, Power and Promise: The Story of Shippingport" (1958?) at https://www.youtube.com/watch?v=6hs_S7fUnoY&feature=youtu.be. See also W. Beaver, *Nuclear Power Goes On-Line: A History of Shippingport* (Praeger, 1990).

[5] Yankee Atomic Electric Company, "Yankee Rowe: Pioneering With Power," (1960?) https://www.youtube.com/watch?v=H--FbZlED98. See also Mullin, John R. and Kotval, Zenia, "The Closing of the Yankee Rowe Nuclear Power Plant: The Impact on a New England Community" (1997). *Journal of the American Planning Association*. 25. On decommissioning https://www.yankeerowe.com/decommissioning.html

Prominent among them are sites dedicated to plutonium production reactors to manufacture WMD fuel, national laboratories and NPPs, especially in the former Soviet Union, where centrally-planned urban greenness softens the scale, radioactive risks and industrial essence of the peaceful atom. To this day Russia touts its park-like nuclear weapons and reactor cities that are closed to outsiders, in all some twenty nuclear towns in Russia with a total population of 1.3 million people in 2023, or almost one percent of the country's population. Russian PR focuses on the high quality of life in orderly cities of broad thoroughfares, walkways and parks, playgrounds, movie theaters that moderate the risks of fission.

A Ukrainian film about Pripiat, the city of 50,000 people established to support the Chernobyl NPP, plays up precisely the consonance of reactor and nature. The 1982 film, edited four years before the world's greatest nuclear disaster, provides panoramas of manicured walkways and forests rich with berries and mushrooms available for the picking. Filmed in the summer, the film focuses on children walking to school and at play, as cameras peek out from under branches of trees through rustling leaves to reveal verdant knolls. Like many of atomic cities built to support reactors, Pripiat attracted first of all young families who moved there to get in the front of the line for new apartments and good jobs. (The average age in Pripyat was about 26 years old at the time of the accident; there were 15 kindergartens and elementary schools for 5,000 children, and 5 secondary schools for 6,800 students, and therefore children in place vulnerable to thyroid cancer in case of an accident.)[6] What has been left behind of the once vibrant, blooming community is wasteland of hastily abandoned concrete apartment buildings, rusted playgrounds, a Ferris wheel with paint peeling – and four reactors, the destroyed unit number 4 having been hastily entombed in concrete in summer 1986 ("the Sarcophagus"), and entombed again in 2017 at an international cost of $2 billion to protect the world from a second radioactive catastrophe when the Sarcophagus eventually collapses.

Many NPPs border nature preserves because of the advantage of being in underbuilt areas close to water sources. The Koeberg, South Africa, NPP is surrounded by a 3,000 hectare (ha) nature reserve it owns that contains more than 150 different species of birds and half a dozen small mammal species. The Davis-Besse NPP in Oak Harbor, Ohio, the most poorly operated station in the US as measured by down time, accidents, incidents and fines, is located adjacent to protective wetlands of the Navarre Marsh of the Ottawa National Wildlife Refuge which is home of several American bald eagle nesting sites and is a major migratory pathway for North American birds. Flamanville, France, NPP, coexists with the peninsula's main economic resource, agriculture, especially dairy and vegetable farming, and oyster and mussel aquaculture. Not far from Flamanville is France's La Hague nuclear reprocessing plant that stores all of the nation's high level waste. All this suggests that suggests agriculture, aquaculture, nuclear power and waste management can fit into the same proximate environments. Global approaches to their analysis will heighten our understandings of how green is the nuclear machine in the garden.

INDUSTRIAL WASTES

The public pitch to claim environmental stability has raised the objection of skeptics worldwide. These skeptics – homemakers, scientists, plant workers, insurance evaluators, and many others – worry about fallout, waste, accidents, and terrorist acts. The nuclear enterprise, like all industrial endeavors, presents challenges to ensure safe and

[6] Ukrainskaia Studiia Televizionnykh Fil'mov, "О городе Припять, возникшем при строительстве Чернобыльской АЭС," (1982), at https://www.youtube.com/watch?v=87wD5t8O8sY

environmentally sound operations. These include vast quantities of dangerous wastes produced in both the military and the civilian sectors; an immense burden on water that is used for cleaning, diluting, lubricating and cooling industrial processes; and the fact that nuclear power is hardly carbon neutral. First of all, there's a lot of radioactive waste, huge quantities of it, millions of cubic meters of solid and millions of cubic meters of liquid waste, it's very dangerous, it migrates if not properly handled and much of it is poorly stored. Radioactive wastes consist of very low, low, intermediate and high level wastes (RW, VVL, LLW, ILW and HLW). There are about 250,000 tons of SNF in temporary storage with more being produced all the time and that presently would require 25,000 to 30,000 dry casks to store properly – after the fuel has been cooled in basins of water. There is also the waste associated with mining, milling, enrichment and fuel manufacture; clothing, gloves, masks and other work materials; machinery and equipment; decommissioning materials. Only a few dozen NPPs have been decommissioned; decommissioning creates significantly more waste as reactor vessels, containments and auxiliary building are dismantled, chopped up and packaged for onsite storage or removal, and decommissioning costs $500 million to $2 billion per reactor. Inventories of military waste which are treated in a special category of "legacy" waste are incomplete (Kasperski, 2019). The IAEA (International Atomic Energy Agency) acknowledges great uncertainty about just how much of the stuff there is worldwide – which surely is not green (IAEA, 2008).

As for water, plant operators maintain that nuclear power is environmentally-sound, in part because cooling towers enable effluent to be returned to its sources when sufficiently cooled. They add the claim that NPPs become a special kind of nuclear animal sanctuary for birds, fish and small mammals. Indeed, the massively-built structures become a kind of nuclear sanctuary when completed; barbed wire fences around NPP exclusion zones certainly contribute to a sense of isolation and security of nature-atom interactions after the extensive construction has completed. Yet the plants are labor, capital and petrochemical intensive to operate. During peak construction up to 7,000 workers are engaged at a typical site in excavation, making and pouring concrete, laying and welding pipe and conduit, stringing wiring, bringing in truckloads of steel and other supplies. When stations enter operation they still require 500 to 800 employees who enter and depart a secured perimeter every day and whose commutes certainly unsettle the landscape and flora and fauna within.

Of course, power stations of all sorts require water to operate. The biologists of Duke Power in the US comment that "the production of electricity at nuclear power plants which are designed to use as little water as possible." They emphasize that "nuclear plant cooling systems have regulatory requirements established by the US Environmental Protection Agency (EPA), under authority provided by the federal Clean Water Act … Plants work closely with local wildlife agencies to establish wildlife protection and good environmental stewardship."[7] Yet – as our discussion of fission and fish shows (chapter 5) – vast quantities of water are heated in the production of electricity whose return to the environment as effluent has significant impacts on animal and plant life including outright fish kills and eutrophication. And what does "using as little water as possible" mean in the final analysis? According to the Union of Concerned Scientists (UCS), the typical 1,000 MWe nuclear power reactor "with a 30ºF ΔT needs approximately 476,500 gallons (1,800 m^3) per minute. If the temperature rise is limited to 20ºF, the cooling water need rises to 714,750 gallons (2,700 m^3) per minute" – the amount of water in an Olympic-sized pool, every second (UCS, 2007). Thus: Duke's eleven units heat something like 22,000 m^3 of water – approaching nearly 6 million gallons – every second.

[7] Duke Energy, Nuclear Education, "Importance of Water at Nuclear Plants," January 22, 2014, at https://nuclear.duke-energy.com/2014/01/22/importance-of-water-at-nuclear-plants

THE CONCRETE ATOM

As for carbon neutrality, how green are NPPs? One of the central claims of the nuclear industry has always been that nuclear electricity is competitive with fossil fuel, certainly much cleaner, and until recently cheaper than solar and wind power. The dreadful anthropogenic impacts of global warming have provided the industry with the opportunity to emphasize this claim of green energy. Nuclear power is significantly better from worker safety, public health and pollution points of view than coal energy at every step – from mining to processing to power generation. Électricité de France (EDF) religiously advances the green atom as the key solution for a low-carbon society. An EDF webpage opens with a chic woman, cooking at an electric stove in a clean, modern kitchen – all made possible with nuclear power.[8] (EDF is behind the times; the very same suggestions of cleanliness, modernity, and women in the kitchen were set forth in a Connecticut Yankee Power film "The Atom and Eve," [1962] to show how nuclear power would meet the housewife's desire consumer goods, appliances, and luxury.[9]) Spain's Endesa repeats the message that nuclear power is the key to clean energy. "We are the first nuclear operator in Spain, so we fully understand the advantages of having this type of energy to guarantee reliable, emission-free supply in the transition to the 'decarbonisation' of energy," reads the Endesa website. The Spanish Nuclear Forum President Ignacio Araluce emphasizes, "Nuclear energy is an extremely important component of the energy mix in Spain, most notably for its stability in the grid, which provides excellent security of supply, and for the absence of CO_2 emissions in accordance with the Paris Agreements" (Endesa, 2017) (Spain, in fact produces almost a quarter of its electricity from wind.)

Yet nuclear construction practices and costs challenge the "green" claims of nuclear energy. The Flamanville NPP with two PWRs has pursued a third, 1,570 MWe reactor since 2004. Everything, it would seem, was in place for the new reactor: a rural setting, content local fishers and dairy farmers, and long term nuclear knowhow and experience. Yet even with 4,000 people from 55 different countries engaged in construction, the cost of Flamanville 3 has ballooned from €3.3 billion to €9 billion and then €12 billion, and with an original forecast to be completed in 2015, the current target date of 2023 looks like a dream. Meanwhile Hinkley Point Hinkley Point C, a 3,200 MWe reactor, one of eight NPPs announced by the British government in 2010, a plant with a forecast sixty-year lifetime, was said to cost £20.3 billion, but final costs are now estimated at £50 billion. This outrageously costly machine is located near an idyllic seaside town in the rolling hills of Somerset county. And the US, whose nuclear boom had been buffeted by the growing costs for all ongoing projects and ended with Three Mile Island (1986), has been struggling to re-enter world industry's nuclear renaissance of cheaper, safer reactors as the answer to fossil fuels. The first US project completed since the twentieth century, the Vogtle Plant, Georgia NPP, was eleven years late, $17 billion over budget, and the utility has forced Georgia electric customers to pay billions of dollars before receiving any electricity. Total cost is around $35 billion (Amy, May 25, 2023).

Even with these costs, the European Nuclear Energy Agency (NEA) claimed in 2020 that "high costs and project schedule overruns are not an inherent characteristic of nuclear technology, but are a reflection of weak supply chains and a lack of recent nuclear construction experience in western OECD countries." NEA Director-General William D.

[8] EDF, "Nuclear energy, a key solution for a low-carbon society," at https://www.edf.fr/en/the-edf-group/producing-a-climate-friendly-energy/nuclear-energy/our-visions. EDF notes that "each kWh produced by EDF's nuclear fleet in France emits the equivalent of 4g of CO_2 where the global worldwide average is 12g of CO_2 per kWh. See also EDF "Analyse du cycle de vie du kWh nucléaire d'EDF" (2022) at https://www.edf.fr/groupe-edf/produire-une-energie-respectueuse-du-climat/lenergie-nucleaire/notre-vision/analyse-cycle-de-vie-du-kwh-nucleaire-dedf.

[9] Connecticut Yankee Power, "Atom and Eve," 1962 at https://www.youtube.com/watch?v=Fs_P7ggt03E

Magwood, IV, claimed “compelling evidence for highly achievable pathways to dramatic cost reduction in nuclear new build," and that “higher levels of industrial and regulatory harmonisation could bring additional long-term benefits. Industry still has much to do, but the leadership and timely action by governments is essential” (NEA, 2020).

NPPs are always over cost, and this reality must be weighed against any green claims. After all, any construction project that goes years over budget will require more labor and capital inputs, fuels, building materials and so on, all of which will have global environmental impacts. Already by the 1970s the growing costs and timelines of NPPs construction required the narrative of the green atom to be recalibrated. Costs for NPPs in the US had doubled and even more by the late 1970s over original estimates. At first the promoters of nuclear energy blamed increased costs on interveners for needless legal and regulatory interventions and superfluous or unnecessary safety changes and upgrades on reactors. A 1978 Rand study put to rest the argument that legal wrangling and excessive regulation were at the root of the problem. Rather it was overoptimistic estimates, poor management, and other factors contributed to excessive cost overruns. The standardization of PWR designs have not in the least slowed these trends (Mooz, 1978. Nor are decommissioning costs regularly placed in front of consumers to judge costs. Finally, another cost – a huge cost – has been a series of accidents at NPPs, as the cases of Chernobyl and Fukushima indicate, with evacuation, remediation, job loss, fishery and farm closure, and clean-up bills that could total $800 billion to $1 trillion dollars. Even the Three Mile Island reactor meltdown (1979), if relatively limited in radiation releases, cost roughly $1 billion.

On top of this, the nuclear industry is hardly carbon neutral from its ground up. Not only do NPPs emit carbon dioxide emissions through water vapor and heats. Concrete is essential to reactors and a major contributor to global warming. An environmental foray into nuclear concrete – a large scale technological system consisting of aggregate production, cement manufacture, mixing and pumping equipment, the building of forms and pouring of concrete – indicates significant carbon production in mining, milling, enrichment, fabrication and transport of fuel, and especially in construction. Widely available photos of the Bohunice, Slovakia, NPP, with two operational Soviet-designed PWRs and total capacity of 942 MWe, show an expansive field of sunflowers as the foreground of a magnificent engineered landscape eight concrete cooling towers, each of which is 120 meters (m) tall and 84.4 m at the base. Four of the cooling towers for the decommissioned reactors at the site were demolished in 2018 (Nuclear Engineering International Magazine, October 5, 208).

Worldwide, 30 billion tons of concrete is used each year, on a per capita basis three times as much as 40 years ago. The cement and concrete industry is responsible for about 8% of global carbon dioxide emissions, more than double those from flying or shipping. Roughly 600 kilograms of carbon dioxide is released for every ton of cement produced (Nature, 2021, p. 593-594). A typical PWR in the 1970s required approximately 75,000 m^3 of concrete. Larger contemporary units require from up to 200,000 m^3 of concrete, with the third-generation Framatome EPR being built at Flamanville NPP at 204,000 m^3 or 500,000 tons of concrete (Peterson; Zhao; Petroski, 2005. On British joy over concrete pouring at Hinkley C, see Bingley, 2020). If roughly 600 kilograms of carbon dioxide are released for every ton of cement, and if reactors require 150,000 tons of concrete per reactor on average, that’s 180 million tons of CO_2 per reactor, and over 80 billion tons of CO_2 to build the world’s 450 reactors – and many more to be built.

The concrete legacy of Chernobyl includes the original Sacrophagus that took 280 days and 400,000 m^3 of concrete to build and two unfinished cooling towers in the radiation exclusion zone that were intended to cool reactor units 5 and 6 had they been built. Local water supplies from the canals were no longer sufficient to handle the load of cooling two more units. One was 80% complete, and the other had just begun construction. They are now gravestones of the former Pripiat just 50 meters away from an ad hoc garbage dump the refrigerators abandoned by local inhabitants when they were evacuated where the gamma eradiation exceeds the norm tenfold (Abandoned Chernobyl cooling tower, April 18, 2018).

IS ATOMIC RECOVERY POSSIBLE?

We have examined the "green" atom from a variety of perspectives, each of which suggests a need for further research and analysis. To arrive tentatively at a proper evaluation, it is important to acknowledge the major insults upon the environment from nuclear enterprise. Consider the fallout spread around the globe from atmospheric tests in the 1950s that contributed hundreds of thousands of excess deaths from cancer. Consider the scores of spills and accidents, major and minor: Kyshtym, Russia (1957), Lake Karachai, Russia (1957), and Castle Rock, New Mexico (1979, which released significantly more radioactivity than Three Mile Island; major accidents (TMI, 1979, Chernobyl, 1986, and Fukushima, 2011). On top of nuclear waste, the costs of cleanup of these accidents likely approaches $1 trillion. Yet nuclear proponents insist that the environment recovers quickly from such intrusions as military reservations, fallout, NPPs, and accidents. Managers of military facilities have claimed the closure of production plants, army bases, and testing facilities demonstrates the "greenness" of the atom as the closed reservations witness the rejuvenation of flora and fauna in the absence of human intervention. Should we therefore lower our estimation of the environmental impacts of the fuel system, weapons tests, and other processes and events? Fernald, Ohio, which for decades produced a variety of uranium metal bomb products, was shut down in 1989, and after a $5 billion remediation effort was opened for nature walks and bird watching as the green zone Fernald Preserve, a seven-mile network of trails meandering through the wetland, prairie, and forest landscape, although built atop a massive burial mound of hazardous waste that will be dangerous for 1,000 years to come. After the closure of the Pease Air Force Base (New Hampshire) and its fifteen massive nuclear missile bunkers in 1991 that supported B-52 bombers aloft twenty-four hours a day to be prepared to devastate the USSR, the US government turned part of the base into the 430-hectare Great Bay National Wildlife Refuge, and transformed the bunkers into "caves" to encourage bats to roost and naturally to consume the seacoast's massive mosquito population.

Similarly, the Kazakh steppe, near the Soviet Semipalatinsk test site of 456 nuclear explosions, is now is dotted with abandoned rural settlements where sheep, cattle and horses ingest grasses and plants laden with strontium and plutonium, and where their meat is sold openly in market. Strangely, "game" animals have returned to the now-abandoned test site, and local Kazakh officials hope that the numbers of wild boars, roe deer and gazelles will increase, perhaps Bukhara deer will return, and some wildlife managers hope to restore the riparian forest and to reintroduce tigers, as a perverse measure of the recovery of fauna from nuclear destruction (Mikhtaeva, 2017).

The rejuvenation of some wildlife within the post-accident Chernobyl exclusion border zone has contributed to an argument about rapid environmental recovery from the nearly 3 billion Ci of radiation released in the explosion. This narrative gave impetus to a cottage industry of nuclear animal studies trying to confirm – or to dispute – this framing. Pro-industry groups report that bird, bison, wolf and other species recovered quickly after Chernobyl, while other researchers note that chronic radiation syndrome affects small mammals, birds and the now infamous Chernobyl dogs. The latter specialists argue that presence of such "recovered" wildlife is the result of immigration and not from locally sustained populations

(Møller; Mousseau, 2007). Several researchers who have spent 30 years studying the Chernobyl Exclusion Zone and now Fukushima have no doubt about the need to be circumspect about the viewpoint that nature recoveries rapidly from nuclear insults: "Long-term observations of both wild and experimental animal populations in the heavily contaminated areas show significant increases in morbidity and mortality that bear a striking resemblance to changes in the health of humans—increased occurrence of tumor and immune-deficiencies, decreased life expectancy, early aging, changes in blood and the circulatory system, malformations, and other factors that compromise health" (Yablokov; Nesterenko; Nesterenko, 2009).

How green is the atom? This is a call for more research.

REFERENCES

ABANDONED Chernobyl cooling tower. *Chornobyl.com.* April 18, 2018. https://www.chornobyl.com.ua/gradirnya-chernobylskoj-aes/

AMY, Jeff. Georgia nuclear rebirth arrives 7 years late, $17B over cost. *AP*. May 25, 2023. https://apnews.com/article/georgia-nuclear-power-plant-vogtle-rates-costs-75c7a413cda3935dd551be9115e88a64

BAUER, Susan. Radiation Science After the Cold War: The Politics of Measurement, Risk, and Compensation in Kazakhstan. In: ZVONAERVA, Olga; POPOVA, Evgeniya; HORSTMAN, Klasien (eds.) *Health, Technologies and Politics in Post-Soviet Settings:* Navigating Uncertainties. New York: Palgrave Macmillan, 2018. p. 225-249.

BINGLEY, Lem. In pictures: Hinkley sets new concrete record despite coronavirus crisis. *Construction News*, June 1, 2020. https://www.constructionnews.co.uk/contractors/in-pictures-hinkley-sets-new-concrete-record-despite-coronavirus-crisis-01-06-2020/

BISWAS, Shampa. *Nuclear Desire:* Power and the Postcolonial Nuclear Order. Minneapolis: University of Minnesota Press, 2014.

BURKE, Anthony. *Uranium.* Cambridge: Polity, 2017.

CHURCHILL, Ward; LADUKE, Winona. Native North America: The Political Economy of Radioactive Colonization. In: JAIMES, M. Annette (ed.) *The State of Native America:* Genocide, Colonization and Resistance. Boston: South End Press, 1992. p. 241–266.

DUDAR, Tamara. Uranium Mining and Milling Legacy Sites: The Ukrainian Case. *Environmental Problems*, v. 4, n. 4, p. 212-218, 2019.

ENDESA. *Nuclear energy, the clean generation.* 2017. https://www.endesa.com/en/projects/all-projects/energy-sector/nuclear-energy-the-clean-generation

ENDRES, D. The rhetoric of nuclear colonialism: rhetorical exclusion of American Indian arguments in the Yucca Mountain nuclear waste siting decision. *Communication and Critical Cultural Studies*, v. 6, n. 1, p. 39-60, 2009.

EICHSTAEDT, Peter. *If You Poison Us: Uranium and Native Americans.* Santa Fe: Red Crane Books, 1994.

HECHT, Gabrielle. *Being Nuclear:* Africans and the Global Nuclear Trade. Cambridge: MIT, 2011.

HECHT, Grabrielle. On the Fallacies of Cold War Nostalgia: Capitalism, Colonialism, and South African Nuclear Geographies. In: HECHT, Gabrielle (ed.) *Entangled Geographies:* Empire and Technopolitics in the Global Cold War. Cambridge: MIT Press, 2011. p. 75-100.

HILL, C. Britain, West Africa and 'The New Nuclear Imperialism': Decolonisation and Development during French tests. *Contemporary British History*, v. 33, n. 1, p. 274-289, 2019.

HUGHES, Thomas. The Evolution of Large Technological Systems. In: BIJKER, W. E.; HUGHES, T. E.; PINCH, T. J. (eds.) *The Social Construction of Technological Systems:* New Directions in the Sociology and History of Technology. Cambridge: MIT Press, 1989. p. 51-82.

HUGHES, Thomas. *Rescuing Prometheus.* New York: Pantheon, 1998.

IAEA. *Estimation of Global Inventories of Radioactive Waste and Other Radioactive Materials*, IAEA-TECDOC-1591.Vienna: IAEA, 2008.

KASPERSKI, Tatiana. From Legacy to Heritage: The Changing Political and Symbolic Status of Military Nuclear Waste in Russia. *Cahiers du Monde Russe*, v. 60, n. 2-3, p. 517-538, 2019.

KRIGE, John. The Peaceful Atom as Political Weapon: Euratom and American Foreign Policy in the Late 1950s. *Historical Studies in the Natural Sciences*, n. 38, p. 5-44, 2008.

MAAG, Christopher. Nuclear Site Nears End of Its Conversion to a Park. *New York Times*, September 20, 2006. https://www.nytimes.com/2006/09/20/us/20park.html.

MIKHTAEVA, Marina. Сколько стоит возрождение туранского тигра в казахстане? *EkoIs Bishkek*, August 7, 2017. http://ekois.net/skolko-stoit-vozrozhdenie-turanskogo-tigra-v-kazahstane/

MOOZ, William. *Cost Analysis of Light Water Reactor Power Plants. R-2304-DOE.* Santa Monica: Rand Corporation, June 1978.

MOLLER, A. P.; MOUSSEAU, T. A. Species richness and abundance of forest birds in relation to radiation at Chernobyl. *Biology Letters*, v. 3, n. 5, p. 483-486, 2007.

NATURE. Editorial - Concrete needs to lose its colossal carbon footprint. *Nature*, v. 597, p. 593-594, 2021.

NEA. *Reducing the costs of nuclear power on the path towards a clean energy future.* July, 2020. https://www.oecd-nea.org/jcms/pl_37787/reducing-the-costs-of-nuclear-power-on-the-path-towards-a-clean-energy-future.

NUCLEAR ENGINEERING INTERNATIONAL MAGAZINE. Cooling towers demolished at Slovakia's Bohunice V1. *NEI Magazine*, October 5, 2018. https://www.neimagazine.com/news/newscooling-towers-demolished-at-slovakias-bohunice-v1-6786719

PETERSON, Per F.; ZHAO, Haihua; PETROSKI, Robert. Metal and Concrete Inputs for Several Nuclear Power Plants: Report UCBTH-05-001. Berkeley: University of California, 2005.

PRITCHARD, Sara. An Envirotechnical Disaster: Nature, Technology, and Politics at Fukushima. *Environmental History*, v. 17, p. 219-243, 2012.

SCHMID, S. D. A new 'nuclear normalcy'?. Journal of International Political Theory, v. 15, n. 3, p. 297-311, 2019.

SCHMID, S.D. Nuclear Colonization?: Soviet Technopolitics in the Second World. In: HECHT, Gabrielle (ed.) *Entangled Geographies:* Empire and Technopolitics in the Global Cold War. Cambridge: MIT Press, 2011. p. 125-154.

STAWKOWSKI, M. 'I Am a Radioactive Mutant': Emergent Biological Subjectivities at Kazakhstan's Semipalatinsk Nuclear Test Site. *American Ethnologist*, v. 43, n. 1, p. 144-157, 2016.

STIRLING, Andy; JOHNSTONE, Phil. *A Global Picture of Industrial Interdependencies Between Civil and Military, Nuclear Infrastructures, SWPS 2018-13*. Sussex: University of Sussex, August 2018.

UCS. *Got Water?* Washington Office: UCS, October 2007. https://www.ucsusa.org/sites/default/files/2019-10/20071204-ucs-brief-got-water.pdf.

WENDLAND, A. V. Nuclearizing Ukraine – Ukrainizing the Atom. Soviet nuclear technopolitics, crisis, and resilience on the imperial periphery. *Cahiers du Monde Russe*, v. 60, n. 2-3, p. 335-368, 2019.

WORLD NUCLEAR ASSOCIATION. Uranium Enrichment. October 2022. https://world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/uranium-enrichment.aspx#:~:text=Enrichment%20costs%20are%20substantially%20related,(180%20MJ)%20per%20SWU.

YABLOKOV, Alexey; NESTERENKO, Vassily; NESTERENKO, Alexey. *Chernobyl:* Consequences of the Catastrophe for People and the Environment. New York: New York Academy of Sciences, 2009. p. 255-280.

AUTHOR'S NOTES

AUTHORSHIP
Paul Robert Josephson: History of Technology; Environmental History. Colby College, Department of History. Waterville, Maine, USA
Tatiana Kasperski: History of Technology; Environmental History.
Södertörn University, School of Historical and Contemporary, Stockholm, Sweden

CORRESPONDING ADDRESS
prjoseph@colby.edu

SOURCE OF THE ARTICLE
Not applicable.

FUNDING
US National Science Foundation, Grant 2020024; The Foundation for Baltic and East European Studies, grant number 23-PR2-0030.

ACKNOWLEDGMENTS
Not applicable.

IMAGE CONSENT
Not applicable.

ETHICS COMMITTEE APROVAL
Not applicable.

CONFLICT OF INTEREST
There is no conflict of interest.

PREPRINT
This pape is not a preprint.

PUBLISHER
Universidade Federal de Santa Catarina. Graduate Program in History. UFSC Journal Portal. The ideas expressed in this article are the sole responsibility of its authors, and do not represent, necessarily, the opinion of the editors or the University.

EDITOR
Jo Klanovicz.

HISTORY
Received on: July 9, 2024
Aproved on: Augut 18, 2024

How to cite: JOSEPHSON, Paul R.; KASPERSKI, Tatiana. Toward a global history of the nuclear age. *Esboços*, Florianópolis, v. 31, n. 57, p. 330-346, 2024.