INTRODUCTION

Nuclear Risk, Radiation Protection, and International Regulation

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In March 2022, invading Russian forces took control of the decommis-sioned Chernobyl Nuclear Power Plant and assaulted the Zaporizhzhia one in Ukraine, jeopardizing its safety and raising fears that it could become a dangerous pawn in the ongoing war.[1] Acknowledging the new risks, the World Health Organization updated its advice on radiation emergency stockpiles, as "potential scenarios" included "intentional uses of radioactive materials with malicious intent."[2] As the military threats became more clear, International Atomic Energy Agency (IAEA) Director General Rafael Grossi brought a team to the Russian-controlled nuclear plant and when he left "forgot" his inspection team there without formal permissions. "We did not ask [Russia or Ukraine]. Instead, we created the political space for the mission. The misinformation stopped when we got there."[3] Changed perceptions about nuclear safety reach beyond the theatre of war.[4] A recent US federal report argues that climate change and the rise of sea levels is expected to disturb nuclear waste dumped in the Marshall Islands, Palomares in Spain, and Greenland during the Cold War.[5]

As these actions and statements by international experts suggest, we live in an era of heightened global nuclear risk, one which subverts the traditional (but always problematic) distinction between military and civilian applications.[6] The work on this volume began before these events, but its chapters excavate the relevant history of the legislative, scientific, diplomatic, and personal challenges that current radiation protection poses. In historical episodes ranging from Japan to Canada, the United Kingdom to North Africa, Spain to Greece, this book details how the procedures for evaluating radiation's risk have been shaped by geopolitical and industrial agendas, usually with limited or no input from those exposed.[7] The authors track the roles of scientific institutions that assumed the task of regulating radiation, assessing risk fairly, and enforcing acceptable standards. The scientific knowledge on which radiation protection standards were based has long been contested,[8] yet nuclear powers have often classified critical information, limiting the scope for legal challenges.[9]

Collectively, the chapters document how the establishment of standards and protocols for radiation protection is not only a technical process but also the product of extensive and ongoing negotiations between historical actors, including states, international bodies, labor unions, trade associations, veterans, lawyers, scientists, economists, workers, and exposed individuals.[10] Some of those involved had the authority to classify risks or influence bodies that did; others were generally left out of the decision-making process. Several contributors are interested in how those exposed to radiation in the past navigated their own experiences, even as some were characterized as "irrational" in their perceptions of harm.[11] Questions of risk and uncertainty—a key theme in nuclear history—were made into bureaucratic and technical matters in dealing with radiation exposure, even when the underlying scientific rationale remained insecure. This book examines how and why particular aspects of natural knowledge became selectively institutionalized and subject to international control and consensus.[12]

In 2006 Hans Blix, former director general of the IAEA, praised the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) for operating in the domain of neutral facts during its fifty-year history: "On questions that are often highly emotional and political, UNSCEAR's reports are impartial, dispassionate and scientific, and have prompted significant worldwide reductions in radiation exposure."[13] This hyperbolic claim captures the tension between impartial expertise and embodied experience throughout the enterprises we study. In most of them, the IAEA stands at the center of our work, being the key global regulator of the nuclear infrastructure.[14] As it operates in a geopolitical realm, its credibility rests on the premise that it provides an "impartial, dispassionate and scientific" understanding of radiation exposure. This book shows that this has hardly been the case and surveys the Cold War history of using scientific expertise to navigate international disputes and technological risk.[15]

As Toshihiro Higuchi reminds us, the Cold War accelerated the radiological hazards of atomic energy development, most dramatically through radioactive contamination from the massive nuclear weapons tests by the United States, the Soviet Union, the United Kingdom, France, and China.[16] The initial Anglo-American hegemony over radiation protection standards from fallout was challenged by scientists, diplomats, and citizens in other countries who contested the view that radioactivity from nuclear weapons testing was "permissible" and acceptable. By 1963, the political fallout from these debates led to the signing by the United States, the United Kingdom, and Soviet Union of the Partial Test Ban Treaty, which did not end nuclear weapons proliferation or testing, but drove it (mostly) underground.[17] Our volume extends this analysis by examining the many other domains, both military and civilian, in which exposed individuals, scientific experts, and international diplomats struggled over the permissibility—and compensability—of exposure to artificial radiation. Due to scientific uncertainty, military secrecy, and technological unpredictability, the arena of radiation protection was, to use Higuchi's terms, "unstable, contingent, and prone to conflicts."[18]

In the face of these instabilities, governments and international bodies turned to experts for guidance in protecting people from the consequences of nuclear technologies. These experts ranged from physicists and physicians to ecologists, engineers, political scientists, insurers, and not least lawyers.[19] Reflecting their diverse specializations as well as different nationalities, experts competed and cooperated to exert their authority through international organizations, scientific field studies, the exploitation of accidentally irradiated groups, and regulatory recommendations. Experts were not the only actors implicated in scientific standard-setting and formal regulatory practice, however. Activists, labor union leaders, engineers in training, mine workers, veterans, and bomb victims provided (sometimes unwittingly) key human exposure data or insights as they sought to play a role in negotiating protection. Official recommendations commonly reflected, overtly or quietly, the intersections of technical detail, political contestation, and emotional reality threaded through the uncertainty and ambiguity of radiation risk.

This volume considers how radioactive exposure and contamination have vexed the perceived borders between science, diplomacy, and politics, and between neutrality and emotion. Contributors explore how individuals experienced their own radiation risk over time, and how radiation animated new international alliances and tensions that reflect broader issues in the postwar order. A key point we make here is that radiation risk has never been fully settled; new legal conflicts, new bodies of knowledge, and new historical actors have continuously reopened negotiations around risk, exposure, and responsibility. Our work is a contribution to an ongoing debate with a fractious history that continues to matter very much to policy and to those affected by it.

The Elusive Safety of Ionizing Radiation

Historians generally identify three major periods relating to radiation safety and protection. The first involved the effort to make sense of the biological effects of X-rays, discovered in 1895; of radium and polonium, discovered by Marie and Pierre Curie in 1898; and after 1900, of the increasing use of X-rays and radium in medicine and industry.[20] The second, after 1925, involved the rise of new disciplines, including radiation genetics and health physics, specifically oriented around understanding what radiation could do to living organisms, particularly in light of H. J. Muller's 1927 study showing that X-irradiation caused genetic mutations.[21] The development of nuclear weapons by the United States during World War II dramatically increased the number of people exposed to artificial radioactivity and raised new questions and stakes about informing and protecting them. Finally, the third arc of radiation protection unfolded after the uses of atomic bombs at Hiroshima and Nagasaki, Japan, in August 1945, and the rapid rise of atmospheric weapons testing and global fallout.[22] Our work focuses primarily on this post-1945 experience of radiation risk. Earlier developments, however, set the stage for postwar understandings of safety and risk from ionizing radiation.

In the first half of the twentieth century, medical, scientific, commercial, and then military applications of radioactivity and atomic energy ran ahead of regulatory action to protect users and patients—and even of sound knowledge about the harms from exposure. Scientists who worked with radioactive elements often suffered from radiation burns, cancer, or other symptoms—for example, damage to Marie Curie's bone marrow, which led to her death in 1934 at age sixty-six.[23] But ordinary people were also being exposed to new sources of radiation. The early entry of both X-rays and radium into clinical settings and the development of industrial products using radium meant that not only patients but also workers and consumers were systematically exposed to ionizing radiation.[24]

In part because of the accelerating uses of X-rays and radium, numerous medical reports about the dangers of exposure were published in the first two decades of the twentieth century.[25] Initial concerns about safety focused on protecting radiologists and others who worked with radiation sources in clinical settings. Regulatory bodies emerged at both national and international levels to set occupational exposure limits for X-rays, radium, and (after the 1930s) artificial sources of radioactivity, including artificial radioisotopes. In 1928 the International X-Ray and Radium Protection Committee (ICRP) held its first meeting.[26] The ICRP, like its national counterparts, was a voluntary body composed of scientists and physicians, not state regulatory authorities. Initially, protection was conceived as a matter of exposure time, distance, and shielding from the source.[27]

Faced with the new hazards of radiation and new sources, experts initially adopted the classic model of industrial hygiene (developed by toxicologists for chemicals) based on the idea that below a certain threshold, exposures did not cause harm.[28] As Soraya Boudia notes, the setting of exposure limits was the cornerstone of managing radiation risks.[29] Experts sought to determine that threshold dose for ionizing radiation from exposure to external X-rays, then also radium. Initially, the standard was pegged to reddening inflammation of white skin from radiation exposure, which physicists sought to correlate to a quantity of emitted radiation, called the "roentgen."[30] The limitations of early dose standards for radiation, based solely on external exposure, became apparent in the tragic plight of the "radium girls"—women workers who used their lips to tip their brushes while painting the dials of watches and instruments with radioactive paint.[31] Many of these women suffered from jaw necrosis and, over time, deadly bone cancer. Their horrific suffering showed that exposures from ingestion or inhalation were distinct from external irradiation, and potentially more dangerous. The US National Bureau of Standards, in its *Handbook 20* in 1936, published the first government statement of a tolerance dose of radiation in occupational exposure. The figure recommended was 0.1 roentgen per day; this standard held for twelve years and was used during World War II.[32]

The outbreak of World War II and the mobilization of nuclear scientists in the United States and elsewhere to develop nuclear fission-based weapons introduced into production plants—and into the environment—an ever wider array of radioisotopes whose effects on human health were unknown.[33] These included heavy and fissionable elements, such as plutonium, that were not found in the natural world. The Manhattan Project adapted ICRP standards to set occupational health policies in its atomic energy plants. Manhattan Project "health physicists" monitored and studied the effects of radiation for bomb workers' safety, drawing heavily on data collected in the "radium girls" case.[34] The Manhattan Project also commissioned research into the health effects of exposure to uranium, plutonium, and the many fission products they generated.[35] This research included unwitting human subjects who were injected with plutonium or uranium so that their fate in the body could be determined.[36]

In 1946, the National Committee on Radiation Protection (NCRP), the US-based professional standard-setting body, began using the term *permissible dose* rather than *tolerance dose* in work to update their standards.[37] This change in terminology subtly acknowledged that there was no certifiably safe level of exposure, even as the new presence of nuclear weapons and waste, and expanding medical use of radioisotopes, meant that exposure to ionizing radiation would become a continuing feature of postwar life.[38] The NCRP also embarked on several studies to inform the ongoing revisions of radiation standards. The organization's 1949 conference at Chalk River in Canada, which brought together experts from the United States, the United Kingdom, and Canada, disseminated the NCRP'sview of radiation safety. As scientists there concluded, there may be some degree of risk in any level of radiation exposure.[39] Ongoing research confirmed a linear model in the dose-response relationship of high and intermediate doses of radiation. Nonetheless, the model remained unconfirmed for low-dose exposures and prompted an array of controversies among federal agencies and scientists.[40]

The new world of atomic weapons also made harms from radioactivity into matters of national security and international diplomacy. Those survivors exposed to the atomic bombs at Hiroshima and Nagasaki, called *hibakusha*, were the subject of an epidemiological study funded by the US Atomic Energy Commission (AEC) and managed by the prestigious National Academy of Sciences to assess the long-term effects of those exposed to significant levels of radiation.[41] The hibakusha were regarded as experimental stand-ins for populations that would be exposed to radiation in future atomic warfare.[42] As a program controlled and funded by the United States, involving the biomedical study of victims in Japan of a new bomb built by the United States, this scientific project was subject to significant critique both in Japan and elsewhere. Its data, however, came to be seen as uniquely valuable, guiding responses to problems ranging from contamination due to atmospheric weapons testing, and the occupational exposures of miners and nuclear plant workers, to the management of medical uses of radiation technologies.

During the same period, the continuing development and detonation of nuclear weapons after World War II, in conjunction with the pushing of new "peacetime" applications, resulted in the exposure of many more human bodies to new sources of radiation. Regulation became an instrument of social management and a matter of political dispute among United Nations (UN) agencies, established international disciplinary organizations, state and nonstate actors, groups of prominent scientists, and uneasy diplomats.[43] Throughout the 1950s and 1960s, UN organizations such as the World Health Organization (WHO), the International Labour Organization (ILO), the IAEA, and even the United Nations Educational, Scientific and Cultural Organization (UNESCO) all strove, often in fierce competition, to create their own niche in the field of radiation protection. The IAEA, as the only UN-related organization with statutory responsibilities for radiation protection and nuclear safety, managed to assume disproportional regulatory power on nuclear issues after its establishment in 1957.[44] By the 1970s it had become the key actor in coordinating the work among other international scientific organizations with a long tradition in radiation protection such as the ICRP and UN organizations and, eventually, setting radiation protection standards.[45] In all these standard-setting efforts, the major study group has been the atomic bomb survivors. Yet, as early as the 1960s, and increasing through the 1990s, epidemiological data about nuclear workers, accident victims, medical irradiation, and the long-term consequences of fallout was incorporated into the calculations of the ICRP.[46]

The elaboration of radiation standards and protection practices has often involved both technical disagreement and political controversy. National governments and international organizations insisted that authority on matters of radiation safety was the purview of official experts, as is well-documented in the case of the United States. After 1946 the new US Atomic Energy Commission's campaign of reassurance regarding radiation reflected the idea that public fear of nuclear weapons—so called hysteria—was politically dangerous, likely to undermine national security.[47] All US citizens needed to have a down-to-earth, calm reaction to radiation exposure, in the logic of civil defense promotions and AEC policies, so that they would be prepared when nuclear war broke out. This meant that some findings about radiation risk were obscured, kept secret, or denied, while others were publicly scrutinized to suggest that more data were needed, no matter how strong the data already were.[48] The best-known example was the statement by AEC chairman Lewis Strauss in 1954, declaring that radioactive fallout from the massive Bravo shot was "far below the levels which could be harmful in any way to human beings, animals or crops."[49] Such exaggerations of radiation safety prompted scientists, even those who had worked closely with the AEC, to begin to challenge the agency's hegemony over expertise.[50] The AEC discounted this scientific dissent as "emotionalism within segments of the scientific community."[51]

In scientific and industrial contexts, new technologies were introduced to manage the hazards of hands-on work with nuclear materials. Emblematic was the glove box—a windowed, sealed container equipped with two flexible gloves that allow the user to manipulate radioactive materials from the outside in a shielded and presumably safe environment.[52] Use of the glove box as well as other specialized equipment, in conjunction with safety regulations and "good housekeeping," were supposed to insure safety for nuclear workers, though accidents invariably happened.[53] In the United States, the AEC sponsored studies designed to prove that it was relatively harmless for humans to work at facilities such as Hanford and Oak Ridge, major national nuclear facilities for the US atomic weapons program.[54] For genetic effects, for instance, a common goal in published guidelines was to keep exposure below the "doubling dose"; that is, the dose of ionizing radiation required to double the number of spontaneous genetic mutations.[55] The notion (contested by many geneticists) was that a population could withstand twice the spontaneous mutation rate without significant harmful effects. During the Cold War, the United States put a premium on building a large nuclear arsenal as necessary to preserve American hegemony and prevent world war. This did not prevent the Soviet Union from acquiring its own atomic weapons, starting with the detonation of Joe-1 in 1949.[56] The US government responded by escalating its nuclear weapons program, which by 1952 included the much more powerful hydrogen bomb.[57] In a political context of virulent anti-Communism, as represented by McCarthyism and the slogan "Better Dead then Red," American authorities sought to counteract fear of Soviet nuclear capacity with reassurance that the United States' weapons program offered protection—even as the AEC also touted the promise of energy "too cheap to meter" from civilian reactors.[58]

With the 1950s nuclear arms race, radioactive fallout from atmospheric weapons tests increased massively and generated concerns worldwide. Generally low dose but indiscriminate, fallout threatened the entire human population.[59] AEC officials routinely pointed to the presence of natural sources of ionizing radiation as a way to justify and normalize the new presence of radioactivity from atomic weapons and nuclear waste.[60] Yet new research confirmed that there was no dose below which exposure was certifiably safe, especially when it came to genetic damage.[61] Continuing studies showed damage from ionizing radiation to be cumulative, meaning that long-term low-dose exposure could add up to an equivalent exposure burden as a single high-dose exposure.[62] Thus an individual's radiation risk was a matter of lifetime exposure, including environmental contamination, occupational hazards, medical diagnostics and treatment, as well as natural background radiation. Just as confounding was the fact that, especially for chronic or low-dose exposure, one could not predict for any one individual what the effects would be, even if such determinations could be made at a populational level. There was an unavoidable element of chance in whether an individual would, for instance, develop cancer due to their exposure to radioactivity. And when an individual did develop cancer, there was generally not a way to determine whether it was caused by their exposure to radiation. Uncertainty was a pervasive feature of the science.[63]

In response, the postwar governance of radioactivity, as well as of chemical toxicants, shifted during the 1950s through the 1980s from a regime of safety through thresholds to one of risk management that deliberately included political and economic considerations.[64] Ulrich Beck has described this era in terms of the emergence of a "risk society."[65] In the late 1960s, the engineer Chauncey Starr developed a new approach to establishing safety standards in the face of uncertainty, based on the notion of *risk*. Following the publication of his 1969 article, "Social Benefit Versus Technological Risk," new journals, professional societies, and regulatory procedures were developed as risk became a bureaucratic way to quantify the uncertain effects of new technology.[66] The goal was to make a technology safe enough to meet the social, economic, or (in the case of radiation) geopolitical aims of a government.[67] At the same time, psychologists began to document how the perception of danger did not necessarily correlate with the risk calculated by scientists.[68] What had previously been seen as the "irrationality" of ordinary citizens around nuclear technologies now became the subject of a new field of study: risk psychology. This field of applied psychology offered scientists, companies, and government officials strategies for effective public communication around new products and technologies, running alongside the regulatory development of "risk assessment" methods to permit their production or use.[69]

The weaknesses of the risk management approach to nuclear technologies became visible. A series of disastrous errors and accidents with cobalt 60 medical irradiation, in which patients died from treatment in improperly calibrated machines, raised international alarms.[70] Nuclear accidents, including hydrogen bombs falling from compromised US Strategic Air Command B-52s (at Palomares, Spain; Thule Air Base, Greenland; Goldsboro, North Carolina; and other sites) added to general public concern.[71] The relatively minor 1979 accident at Three Mile Island Nuclear Generating Station, near Harrisburg, Pennsylvania, generated a surprisingly broad antinuclear response almost everywhere, appearing as a sign that nuclear power development should be slowed down, even though radiation exposure in the area was reported to be minimal.[72] However, the widespread radioactive contamination due to the Chernobyl accident in 1986 showed how catastrophic nuclear reactor malfunctions could be. Experts continue to debate the full human health toll from that accident; estimates of the number of exposed individuals who will develop thyroid cancer by 2056 range from 3,400 to 72,000.[73]

Meanwhile long-term radioactive waste became a recognized environmental problem, and in 1988 the plutonium processing plant in Hanford, Washington, run by the US Department of Energy, was named a "superfund" site under the Environmental Protection Agency's program to clean up abandoned hazardous waste.[74] Since the 1970s, legal and political activism around toxic substances buoyed similar efforts by citizens and scientists to address harms from involuntary exposure to radioactive contamination from a variety of sources: airborne fallout, nuclear weapons production, accidents with bombs, medical irradiation, and nuclear power.[75] Needless to say, cases in which companies or governments have admitted responsibility for harmful environmental exposures are exceptional. As mentioned earlier, for radiation—and also for many toxic substances—establishing disease causality after exposure is difficult. Scholars have begun to consider environmental contamination and harm to exposed populations in terms of wastelands and "sacrifice zones."[76] For example, from 1945 to 1963, the United States, the United Kingdom, and France subjected the peoples and island ecosystems in the Pacific Ocean and Oceania to dozens of nuclear blasts, whose harms are ongoing and are the subjects of numerous lawsuits.[77] As studies of these devastating events make clear, radiation exposure and risk are not merely personal but deeply, often invisibly, political and diplomatic.

Contesting Exposures and Calculating Risk

Historians have long recognized the significance of radiation protection for human health, bringing front and center case studies from the use and