Co-production of Science and Regulation
Radiation Health and the Linear No-Threshold Model

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ABSTRACT

The model used as the basis for regulation of human radiation exposures in the United States has been a source of controversy for decades because human health consequences have not been determined with statistically meaningful certainty for the dose levels allowed for radiation workers and the general public. This dissertation evaluates the evolution of the science and regulation of radiation health effects in the United States since the early 1900s using actor-network theory and the concept of co-production of science and social order. This approach elucidated the ordering instruments that operated at the nexus of the social and the natural in making institutions, identities, discourses, and representations, and the sociotechnical imaginaries animating the use of those instruments, that culminated in a regulatory system centered on the linear no-threshold dose-response model and the As Low As Reasonably Achievable philosophy.

The science of radiation health effects evolved in parallel with the development of radiation-related technologies and the associated regulatory system. History shows the principle of using the least amount of radiation exposure needed to achieve the desired effect became established as a social convention to help avoid inadvertent harm long before there was a linear no-threshold dose-response model. Because of the practical need to accept some level of occupational radiation exposure, exposures from medical applications of radiation, and some *de minimis* exposure to the general public, the ALARA principle emerged as an important ordering instrument even before the linear no-threshold model had gained wide support. Even before ALARA became the law, it had taken hold in a manner that allowed the nuclear industry to rationalize its operations as representing acceptable levels of risk, even though it could not be proven that the established exposure limits truly precluded harm to the exposed individuals.

Laboratory experiments and epidemiology indicated that a linear dose-response model appeared suitable as a "cautious assumption" by the 1950s. The linear no-threshold model proved useful to both the nuclear establishment and its detractors. In the hands of proponents of nuclear technologies, the model predicted that occupational exposures and exposures to the public represented small risks compared to naturally occurring levels of radiation and other risks that society deemed acceptable. Conversely, opponents of nuclear technologies used the model to advance their causes by predicting health impacts for undesirable numbers of people if large populations received small radiation exposures from sources such as fallout from nuclear weapon testing or effluents from nuclear reactor operations. In terms of sociotechnical imaginaries, the linear no-threshold model was compatible with both of the dominant imaginaries involved in the actor-network. In the technocratic imaginary of institutions such as the Atomic Energy

Commission, the model served as a tool for qualified experts to make risk-informed decisions about applications of nuclear technologies. In the socially progressive imaginary of the citizen activist groups, the model empowered citizens to formulate arguments informed by science and rooted in the precautionary principle to challenge decisions and actions by the technocratic institutions. This enduring dynamic tension has led to the model retaining the status of "unproven but useful" even as the underlying science has remained contested.

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GENERAL AUDIENCE ABSTRACT

This dissertation provides a social science perspective on an enduring paradox of the nuclear industry: why is regulation of radiation exposure based on a model that everyone involved agrees is wrong? To answer that question, it was necessary to delve into the history of radiation science to establish how safety regulation began and evolved along with the understanding of radiation's health effects. History shows the philosophy of keeping radiation exposures as small as possible for any given application developed long ago when the health effects of radiation were very uncertain. This practice turned out to be essential as science started to indicate that there may not be a safe threshold dose below which radiation exposure had no potential for health consequences. By the 1950s, a combination of theory, experiments, health studies of the survivors of the World War II atomic bombings, and other evidence suggested that the risk of cancer was proportional to the amount of radiation a person received (i.e., linear). Although this "linear no-threshold" model was far from proven, both sides used it in debates over nuclear weapon testing and safety standards for nuclear reactors in the 1950s through the early 1970s. Since the model predicted small health risks for the levels of radiation experienced by radiation workers and the public, nuclear advocates used it to argue that the risks were smaller than many other risks that people accept every day. At the same time, opposing activists used the model to argue that small cancer likelihoods added up to a lot of cancers when large populations were exposed. This decades-long discourse effectively institutionalized the model. The model's "unproven but useful" status was strengthened in the early 1970s when the Atomic Energy Commission supplemented its numeric exposure limits by turning the longtime practice of dose minimization into a requirement. This "As Low As Reasonably Achievable" requirement plays a vital role in rationalizing why a non-zero exposure limit is safe enough despite the fact that the linear no-threshold model treats any amount of radiation as harmful.

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1 Introduction

1.1 Motivation for This Research

I was motivated to pursue this research, in this particular manner, for two primary reasons. First, having spent 32 years working in the nuclear field, I am regularly confronted with the contradictory facts that (1) the linear no-threshold dose-effect model is the basis for regulation of radiation safety and (2) virtually no one in the field believes the model reflects reality. Available sources argue at length in terms of laboratory studies with various forms of life, interpretations and reinterpretations of the limited number of databases for exposures of humans to ionizing radiation, and far too many superficial assertions along the lines of "humans evolved in a radioactive world, so we have adapted to radiation exposure." Scholarship seeking to explain why we are in this situation is sparse. Specifically, answers are not readily found for the question of how people have engaged with the relationship between dose and effect in advancing their personal and societal agendas, as well as what strategies and tactics they have employed to obtain the outcomes they seek. These social actions and reactions constitute the push and pull that have shaped—and have been shaped by—the prevailing dose-response model. The uneasy equilibrium established by the interplay of the laws of nature and social forces appeared tailored for analysis using actor-network theory and the concept of co-production of science and social order. Scholarly literature did not appear to include prior efforts along that avenue of research; accordingly, this dissertation attempts to make a contribution in that area.

Second, as I amassed reference material to develop lines of inquiry for engaging with the linear no-threshold model, I soon discovered that no available history traced the precise path through the past century needed to form the backbone of this dissertation. In particular, no one had assembled the entire story of how and when the various elements of the modern regulatory scheme had taken shape to the degree of precision that practitioners in the nuclear field insist upon. It was particularly difficult to establish exactly how, when, and by whom the linkages had been established between exposure to various sources of ionizing radiation and development of various health effects, particularly the delayed appearance of leukemia and solid cancers sometime after exposure to radiation. The vast majority of sources were content to discuss such developments in general and approximate terms; however, the analysis for this dissertation required precision to establish how and when the emerging actor-network had given rise to key developments, such as recognition that radiation could cause delayed effects including cancer, acceptance of the inability to specify safe tolerance doses (i.e., thresholds), and establishment of the practice of keeping exposures as low as reasonably achievable. Accordingly, regardless of how history will judge the contribution of this dissertation to the field of Science and Technology Studies, it will nonetheless provide a fairly unique resource for the history of radiation science.

1.2 Structure/Overview

I have structured the dissertation as follows: Chapter 2 reviews the relevant literature on risk as a social construct, safety standards and regulation of risk, and citizen science, and articulates the theoretical framework for my research. Chapter 3 establishes the epistemological space that is open to contestation by describing how radiation interacts with matter, how living tissues can be damaged by radiation, and the uncertainties in the human health effects of radiation exposure. Chapter 4 applies actor-network theory to identify the actors involved in the science and regulation of the human health effects of radiation. Chapters 5 through 9 constitute the heart of the dissertation, applying actor-network theory, the idiom of co-production, and the concept of sociotechnical imaginaries to analyze the actors involved in the identification, application, and contestation of the dose-response model for the human health effects of radiation and limits for radiation exposure. Finally, Chapter 10 summarizes my research and draws conclusions regarding the co-production of science and social order in the regulation of radiation safety in the United States.

2 Literature Review

2.1 Introduction

This dissertation investigates the social processes at work in the development and stabilization of the approach taken in the United States for regulation of the hazard posed by human exposure to ionizing radiation. Some argue that a modest amount of ionizing radiation may be safe or even beneficial to human health, but it is universally agreed that any more than a small amount is hazardous to human health. While the inherent characteristics of radiation—invisible and capable of causing injury and death either immediately or long after an exposure occurs—may make it appear uniquely dreadful, the social processes that translate that invisible hazard into a perceived risk and then converge upon controls for that risk are the same processes that societies employ to address the countless other hazards associated with being a living entity on planet Earth.

We live surrounded by hazards representing both natural and human-made sources of danger. The likelihood that a given hazard may actually result in the feared harm ranges from virtual certainty to near impossibility. Hazards can be immediately apparent, such as ice on a sidewalk, or completely invisible, like ionizing radiation. Hazards can threaten our physical well-being or the physical well-being of something or someone we value, but hazards often have a social character, threatening values or institutions that we cherish.

These hazards are numerous beyond any person's ability to count. Moreover, they may be beyond any individual's control or even beyond the control of society. Social scientists have extensively investigated how people, social groups, and institutions manage this potentially overwhelming onslaught of threats. The hazards that we choose to treat as the most important, and how we structure our lives and our social institutions to address them, are a fundamental element of our personal identity and play an important role in establishing and maintaining the bonds within our social groups. The social processes by which a hazard—tangible or intangible—becomes recognized as a *risk* requiring some form of management has been the subject of extensive study.

2.2 Literature on Risk

A significant body of scholarship has sought to define the term "risk" as a starting point for such analyses. Beck observed that risk once connoted bravery and adventure but that it is now used in a manner focused on the potential for negative outcomes.[1] Lupton identified six categories of risks as the predominant concerns identified by contemporary Western individuals and institutions:[2]

- *Environmental risks* such as fires, floods, pollution, chemicals, radiation, and road hazards

[1] Ulrich Beck, *Risk Society: Towards a New Modernity* (Los Angeles: Sage, 2012), 21.

[2] Deborah Lupton, *Risk* (New York: Routledge-Taylor & Francis Group, 2005), 13-14.

- *Lifestyle risks* resulting from personal choices such as food choices, drug use, sexual activities, driving style, leisure, and stress
- *Medical risks* including various surgical and diagnostic procedures, childbirth, and medications
- *Interpersonal risks* involving relationships, sexuality, gender roles, parenting, and so forth
- *Economic risks* such as unemployment, property loss, debts, bankruptcy, and failure of a business
- *Criminal risks* associated with being a victim of or perpetrator of crime

Althaus considered how the concept of risk was applied in twelve different disciplines including logic and mathematics, science and medicine, six branches of the social sciences, history and the humanities, religion, and philosophy.[3] For example, mathematics, science, and economics treat risk as a calculable quantity (with a focus on defining "acceptable risk"), whereas anthropology views risk as a "political, moral, and aesthetic evaluation," and legal scholars view risk as a real or potential fault of conduct that creates harm and can be adjudicated, with an identifiable perpetrator and a victim.[4] Althaus described sociology's descriptions of risk as "a diverse patchwork," with the unifying theme that risk "explains, shapes, delineates, and defines society and vice versa," such that "only with risk can we understand society and only with society can we understand risk."[5] Bridging across all those disciplines, Althaus proposed defining risk as "the application of some form of knowledge to the unknown in an attempt to confront uncertainty and make decisions" and observed that each discipline created its own types of risk.[6]

Lupton characterized the varying approaches toward describing risk in terms of where they fell on the spectrum of positivist (realist) versus relativist (constructionist) epistemological positions.[7] She described the technoscientific approach used in mathematics, economics, and engineering as taking the positivist position that risks are preexisting in nature and thus are (in principle, at least) measurable and calculable.[8] She observed that the technoscientific approach tended to lead to an "ill-masked contempt" for lay persons' risk perceptions, with the attitude that the public's "subjective" and "unscientific" responses to risks resulted from a lack of "correct" or "appropriate" knowledge.[9] She noted that the question typically not asked in a technoscientific risk analysis was "How are risks constructed as social facts?"[10]

The technoscientific position on the nature of risk goes hand-in-hand with a "deficit model" for communication of scientific information. As described by Gross, the deficit model embodies an asymmetric relationship in which communication flows from science to the public,

[3] Catherine E. Althaus, "A Disciplinary Perspective on the Epistemological Status of Risk," *Risk Analysis* 25:3 (2005), 567-588.
[4] Althaus, 517-575, 578-579.
[5] Althaus, 577-578.
[6] Althaus, 580.
[7] Lupton, 35.
[8] Lupton, 17-18.
[9] Lupton, 19.
[10] Lupton, 18.

and the public passively consumes and trusts the information.[11] Gross highlighted that this model discounts ethical and political attributes as not relevant to the scientific facts being conveyed.[12] Gross found fundamental defects with communication of scientific information using a deficit model: He disagreed that science routinely produced "truths about the material world," on the grounds that history has shown science to be eminently fallible.[13] Moreover, he argued that separating scientific facts from the social context that makes them significant can lead to the mistaken conclusion that the public is ignorant of science, when in reality the public is disinterested in information presented without explanation of why it is socially relevant.[14] As will be illustrated in this dissertation, effective and ineffective attempts to engage with the public on the risks of radiation exposure played a significant role in the development of America's regulatory system for radiation safety.

Lupton considered anthropological (cultural) and sociological treatments of the concept of risk as embodying constructionist epistemological positions of varying strengths.[15] In contrast to the positivist position that risk could be "measured independently of social and cultural practices," constructionist positions analyze risk as intimately connected with social and cultural processes.[16] Lupton described weak constructionist approaches as acknowledging that risks exist as "an objective hazard, threat or danger" but that they are "inevitably mediated through social and cultural processes and can never be known in isolation from these processes."[17] On the strong end of the constructionist spectrum, however, "nothing is a risk in itself," with hazards and dangers achieving "social existence" only when society recognizes and categorizes them.[18]

Lupton further described two concepts that, because of the social character of risk, are central to contemporary analysis and management of risk: reflexivity and discourse.[19] *Reflexivity* describes the tendency of citizens to actively respond to circumstances giving rise to anxiety or fear, instead of passively accepting them as part of their lot in life. Lupton further elaborated that reflexivity involves "the weighing up and critical assessment of institutions and claim-makers, including those who speak with 'expert' voices about risk."[20] As will be demonstrated in this dissertation, reflexivity of citizens and social groups has played an important part in shaping the regulation of radiation safety in the United States.

Lupton described *discourse* as "a bounded body of knowledge and associated practices, a particular identifiable way of giving meaning to reality via words or imagery."[21] Discourses on risk therefore provide meaning to hazards that otherwise may be too intangible to prompt a response from the audience of the discourse. Discourse translates a concept such as climate

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[11] Alan G. Gross, "The roles of rhetoric in the public understanding of science," *Public Understanding of Science* 3 (1994), 6.
[12] Gross, 6.
[13] Gross, 8.
[14] Gross, 8.
[15] Lupton, 35.
[16] Lupton, 35.
[17] Lupton, 35.
[18] Lupton, 30, 35.
[19] Lupton, 15.
[20] Lupton, 15.
[21] Lupton, 15.

change into a risk that people and institutions can evaluate alongside myriad other risks to decide whether it is worth worrying about and whether they should take some action or demand action from their society's institutions to protect against the risk. Analysis of the public discourse in America on the risk of ionizing radiation forms the heart of this dissertation.

Three prominent constructionist interpretations of risk merit review here for potential relevance to this dissertation: Risk society, cultural theory, and governmentality, discussed below in order of increasing strength of the associated constructionist positioning as judged by Lupton.[22]

Risk Society

Althaus observed that technology has given rise to risk problems that are difficult or impossible to resolve scientifically, such as those related to nuclear power and biotechnology.[23] Beck termed the condition that results from a myriad of these indeterminate but potentially catastrophic risks as the "risk society." In the risk society, "incalculable threats add up to an unknown residual risk which becomes the industrial endowment for everyone everywhere."[24] Importantly, because these risks are invisible, they only exist in terms of society's knowledge of them.[25] As a result, they are highly susceptible to "social definition and construction."[26] Furthermore, the experts fail to come to consensus on the risks, leaving scientists open to challenge by individuals and social groups.[27] Therefore, both reflexivity and discourse on risk are central to the risk society.

Beck considered these developments to signal the arrival of "reflexive modernity," in which the fundamental challenge for society is how to resolve in a democratic manner the disputes that science cannot settle.[28] He cited the precautionary principle—which advises erring on the side of caution in case of doubt—as an example of reflexive modernity in action.[29] Beck suggested the following motto for reflexive modernity: "Even when we don't know what we have to know, we still have to decide – or at the very least to decide that we won't decide now, and to decide on a date when we will."[30] Giddens independently described similar societal developments of globalized risk and reflexivity in writings contemporaneous with Beck's.[31]

Radiation exemplifies the type of hazard that Beck viewed as giving rise to the risk society. Worldwide fallout from atmospheric testing of megaton-scale thermonuclear weapons produced exactly the "unknown residual risk … for everyone everywhere" that Beck called out in *Risk Society*. Ionizing radiation is invisible, and the precise health effects of low doses of

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[22] Lupton, 35.
[23] Althaus, 572.
[24] Beck, 29.
[25] Beck, 23.
[26] Beck, 23.
[27] Lupton, 64.
[28] Ulrich Beck, Wolfgang Bonss, and Christoph Lau, "The Theory of Reflexive Modernization: Problematic, Hypotheses and Research Programme," *Theory, Culture & Society* 20:2 (2003), 21.
[29] Beck, Bonss, and Lau, 20.
[30] Beck, Bonss, and Lau, 20.
[31] Anthony Giddens, *The Consequences of Modernity* (Cambridge, England: Polity Press, 1990).

ionizing radiation are unknown and may well be unknowable. Consistent with Beck's vision for the rise of reflexive modernity, individual activists and nongovernmental organizations have responded to this situation by mounting successful challenges to official pronouncements on the risk of radiation exposures, as will be demonstrated in this dissertation.

Cultural Theory

Douglas (an anthropologist) and Wildavsky (a political scientist) first articulated cultural theory in their analysis of the rise of environmentalism in the United States, seeking to explain "the rise in alarm over risk to life at the same time health is better than ever before."[32] As described by Wildavsky and Dake, cultural theory is based on the proposition that individuals and organizations choose "what to fear (and how much to fear it)" based on "deeply held values and beliefs" that defend their particular "patterns of social relations."[33] Wildavsky and Dake described three fundamental types of social organization—hierarchical, egalitarian, and individualist—and the cultural biases that reinforce them as central to how various sectors of society identify risks. Their research found that "Cultural biases provide predictions of risk perceptions and risk-taking preferences that are more powerful than measures of knowledge and personality and at least as predictive as political orientation."[34] Douglas and Wildavsky further proposed that ideas about pollution, both technical and non-technical, play a strong role in a social group's identification of risks.[35]

Douglas and Wildavsky characterized the model types of social organizations in terms of "grid" (the extent of "social distinctions and delegations of authority" within the social organization) and "group" (the strength of group identity and barriers between the group and outsiders).[36] Supplementing this theory with further development by Rayner and by Thompson, Ellis, and Wildavsky, the features of each of the model forms of social organization can be summarized as follows:[37]

- *Hierarchical* social relations feature strong internal structure and strong group identity. This is a bureaucratic system concerned with rules and order. It will tend to view human nature as something that needs to be controlled. The risks perceived by hierarchical sectors of society tend to be factors that indicate that human nature is not under sufficient control, as well as factors that pose a threat to their hierarchical order. Given the strong group identity of a hierarchical order, pollution beliefs are likely to involve impurities (physical or metaphorical) that impinge upon the group from outside. Examples of the hierarchical entities to be considered in this dissertation include the Atomic Energy Commission, Congress' Joint Committee on Atomic

[32] Mary Douglas and Aaron Wildavsky, *Risk and Culture: An Essay on the Selection of Technological and Environmental Dangers* (Berkeley: University of California Press, 1982), 15.
[33] Aaron Wildavsky and Karl Dake, "Theories of Risk Perception: Who Fears What and Why?" *Daedalus* 119:4 (Fall 1990), 43.
[34] Wildavsky and Dake, 50.
[35] Douglas and Wildavsky.
[36] Douglas and Wildavsky, 138-139.
[37] Steve Rayner, "Cultural Theory and Risk Analysis," in Sheldon Krimsky and Dominic Golding, eds., *Social Theories of Risk* (Westport: Praeger Publishers, 1992), 83-115.; Michael Thompson, Richard Ellis, and Aaron Wildavsky, *Cultural Theory* (Boulder: Westview Press, 1990).

Energy, branches of the U.S. military, the U.S. court system, and standards-setting organizations such as the National Council on Radiation Protection and Measurements.

- *Individualist* social relations feature weak internal structure and weak group identity. This is typified by the free market approach in which people are free to pursue their self-interest and to reap (or suffer) the results of their actions. Individualists resist regulation and control, except for what is needed to provide a level playing field and preserve the conditions that allow the market to work. Risks perceived by individualist sectors of society tend to be factors that work against these ideals, and pollution beliefs likewise tend to center on potential corruption of individualist ideals. In the case of radiation protection, individualist entities include the private companies operating research and production sites for the Atomic Energy Commission, operators of nuclear power stations, researchers working with radiation and radioactive materials, radiologists and nuclear medicine practitioners, and private citizens with an individualist perspective on society.

- *Egalitarian* social relations feature weak internal structure but a strong group identity. Egalitarian groups tend to unite around a particular interest and to base their group's existence on advancing that interest. Such groups tend to view human nature as fundamentally good but at risk of being corrupted by the institutions that other types of social organizations create. Risks perceived by egalitarian sectors of society tend to focus on institutions that threaten their interest. Pollution beliefs tend to focus on the corrupting influence of bad institutions as well as actual environmental pollution. Examples of the egalitarian groups involved in radiation safety include nongovernmental organizations advocating for public health, environmental protection, and either for or against nuclear technologies, as well as private citizens with an egalitarian perspective on society.

Cultural theory also describes a fourth category of social relations, often called isolates or fatalists, as "less coherent, being a repository for social fallout" from the three influential social types.[38] This disenfranchised segment of society is viewed as having little influence on what risks are identified or how they are addressed. The fatalist segment of society did not make itself apparent in the public debate over radiation protection; however, nongovernmental groups with egalitarian social relations often acted on behalf of the disenfranchised. Conversely, hierarchical groups have worked to enroll the disenfranchised into the hierarchical order, rather than leaving them to their own devices.

The development of cultural theory by Thompson, Ellis, and Wildavsky advanced the notion of the hermit, who voluntarily withdraws from social involvement and notably rejects the duality of nature and society implicit in the other forms of social relations.[39] The hermit leads them to the following conceptualization of the relationship between nature and society: "our myths of physical nature and our concepts of human nature reinforce and enter into each

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[38] Wildavsky and Dake, 41-60.; James V. Spickard, "A Guide to Mary Douglas' Three Versions of Grid/Group Theory," *Sociological Analysis* 50:2 (Summer 1989), 151-170.
[39] Thompson, Ellis, and Wildavsky, 7-11, 29-33.

other."[40] This constructivist concept parallels the idiom of co-production, discussed below, that forms the basis for this dissertation's analysis of the science and regulation of radiation safety.

Governmentality

Foucault asserted that "we live in the era of a 'governmentality' first discovered in the eighteenth century."[41] He described this conception of government as being concerned with a complex composed of people and things, and particularly with "men in their relations, their links, their imbrication" with things.[42] Among other relationships between people and things of concern to government, Foucault specifically included "men in their relation to that other kind of things, accidents and misfortunes such as famines, epidemics, death, etc."[43] Foucault proposed that government manages these relations not through "imposing law on man" but instead by "employing tactics … to arrange things in such a way that, through a certain number of means, such and such ends may be achieved."[44] The general meaning of "government" is therefore taken to be "the conduct of conduct."[45] Lupton described governmentality in neo-liberal states as associated with government discourses that position citizens to be active in self-discipline (self-regulation) for their own best interests, as opposed to being policed by the government.[46] The implementation of the As Low As Reasonably Achievable principle in radiological work, in which each worker is expected to conduct themselves in a manner that minimizes their exposure to radiation at all times, exemplifies such self-regulation.

Dean further explained Foucault's governmentality as approaching risks by creating "representations that render reality in such a form as to make it amenable to types of action and intervention."[47] Through a collection of "practices, techniques, and rationalities," risk becomes "a governable entity."[48] Lupton expressed the practices and techniques of governmentality in more concrete terms as the gathering and analysis of data by "medical researchers, statisticians, sociologists, demographers, environmental scientists, legal practitioners, statisticians, bankers, and accountants, to name just a few."[49]

Dean described three types of rationalities for constructing risk under governmentality's model for social regulation and control: insurance risk, epidemiological risk, and case-

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[40] Thompson, Ellis, and Wildavsky, 33.
[41] Michel Foucault, "Governmentality," in Graham Burchell, Colin Gordon, and Peter Miller, eds., *The Foucault Effect: Studies in Governmentality with Two Lectures by and an Interview with Michel Foucault* (Chicago: University of Chicago Press, 1991), 103.
[42] Foucault, 93.
[43] Foucault, 93.
[44] Foucault, 95.
[45] Colin Gordon, "Governmental Rationality: An Introduction," in Graham Burchell, Colin Gordon, and Peter Miller, eds., *The Foucault Effect: Studies in Governmentality with Two Lectures by and an Interview with Michel Foucault* (Chicago: University of Chicago Press, 1991), 2.
[45] Foucault, 93.
[46] Lupton, 87-88.
[47] Mitchell Dean, "Risks, calculable and incalculable," in Deborah Lupton, ed., *Risk and sociocultural theory: new directions and perspectives* (Cambridge, UK: Cambridge University Press, 1999), 132.
[48] Dean, 134.
[49] Lupton, 87.

management risk.[50] Insurance risk and epidemiological risk are both relevant to the regulation of radiation safety:

Insurance risk as a rationality of governmentality operates by defining risk as a characteristic of a population, with risk being borne collectively even if each individual is unequally subjected to the risk.[51] Insurance risk evaluates that which is at risk as a potential capital loss, even when the potential loss involves incalculable attributes such as suffering or emotional trauma.[52] Dean described social insurance that compensates for losses due to factors such as unemployment, accidents, and illness as expressing a form of "organic solidarity" that reinforces the bonds between members of social groups by socializing the risks they face.[53] The primary example of such socialization of risk discussed in this dissertation involves compensation awarded by acts of Congress to thousands of people belonging to groups exposed to radiation by the U.S. government's nuclear programs.

Epidemiological risk involves the prevalence of adverse medical conditions across populations.[54] Unlike insurance risk, which is used to determine compensation for individual members of a group who suffer a loss, epidemiological risk as a rationality of governmentality is used to identify preventive measures that can eliminate or reduce future adverse impacts of a risk across the affected population.[55] Preventive measures deployed by the government can include interventions such as sanitation, programs to inspect food producers, public vaccination campaigns, and quarantine of the sick.[56] Lupton added that governments now use information from epidemiological risk assessments as the basis for media campaigns aimed at persuading segments of the population to view themselves as at-risk, to encourage them to take responsibility for reducing their risk exposures.[57] As will be elucidated in this dissertation, the dose minimization philosophy that has been pervasive in the practice of radiation safety since the early 1900s embodies key aspects of this rationality for societal risk construction and management.

2.3 Literature on Safety Standards and Regulation of Risks

Returning to Douglas and Wildavsky's general conclusions, "public perception of risk and its acceptable levels are collective constructs."[58] In other words, not only is risk identification a social phenomenon, but so is the selection of ways to control risks. Modern Western society has chosen to identify and control risks using a regulatory system that Moore *et al* described as "scientized."[59] In a scientized system, regulatory actions are based primarily on

[50] Dean, 137-145.
[51] Dean, 139.
[52] Dean, 138.
[53] Dean, 141-142.
[54] Dean, 142.
[55] Dean, 142-143.
[56] Dean, 143.
[57] Lupton, 97.
[58] Douglas and Wildavsky, 186.
[59] Kelly Moore, David Hess, Daniel K. Kleinman, and Scott Frickel, "Science and neoliberal globalization: a political sociological approach," *Theory & Society* 40:5 (September 2011), 514.

scientifically derived standards which "rely heavily on scientific language and expert knowledge."[60] Moore *et al* argued that such an approach excludes social factors from being considered in regulation and tends to limit democratic participation in formulating regulations.[61]

In *Trust in Numbers*, Porter detailed how modern regulatory bureaucracies applied scientized regulation in order to carry out their duties with apparent objectivity by representing people, places, events, and natural processes in numerical form.[62] By comparing scientifically produced numbers against scientifically based requirements, the regulators seem to have eliminated subjectivity and bias from their actions. Theoretically, this ensures fair, science-based regulation of contentious subjects such as nuclear energy, nuclear materials, human radiation exposures, and cleanup standards for radioactive contamination.

Porter argued that this ideal has not been achieved, because the science may be incomplete and numbers cannot be relied upon to tell the whole story. Porter noted that "only a very small proportion of the numbers and quantitative expressions loose in the world today make any pretense of embodying laws of nature, or even of providing complete and accurate descriptions of the external world."[63]

Scientized regulation is also subject to problems with the representativeness of standards that underpin the regulations. For example, regulations that govern exposure of individuals and populations to hazardous substances or that seek to ensure the safety and effectiveness of drugs and medical treatments have been criticized for not adequately considering the diversity within the population. Much research in the past used white men as test subjects, which casts doubt on the applicability of the results to women, other races and ethnicities, the young or elderly, and other categories of people.[64] Majone further observed that in setting limits for toxicologically hazardous substances, it is necessary to consider the fact that human populations have heterogeneity that is social in origin, in addition to biological heterogeneity.[65] Social factors such as diet, exercise, smoking, and living conditions can have a strong effect on a social group's exposure to and susceptibility to chemically hazardous materials.

Majone postulated that efforts to establish scientifically valid health, safety, and environmental standards crossed into "trans science."[66] Majone cited Alvin Weinberg as describing trans science as the regime where questions can be asked using the language of science but cannot be answered in purely scientific terms.[67] Weinberg's essay on trans science

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[60] Moore *et al*, 516.
[61] Moore *et al*, 517.
[62] Theodore M. Porter, *Trust in Numbers: The Pursuit of Objectivity in Science and Public Life* (Princeton: Princeton University Press, 1995).
[63] Porter, vii-ix.
[64] Steven Epstein, "The Construction of Lay Expertise: AIDS Activism and the Forging of Credibility in the Reform of Clinical Trials," *Science, Technology, & Human Values* 20:4 (1995), 420-421.
[65] Giandomenico Majone, "Science and Trans-Science in Standard Setting," *Science, Technology, & Human Values* 9:1 (Winter 1984), 17.
[66] Majone, 15.
[67] Majone, 15.

elaborated that trans science questions needed to be settled through political processes, "because ultimately the decision to proceed or to desist is a matter of ethical or aesthetic values."[68]

"Trans science" is a fundamentally problematic concept because it creates an artificial boundary defending a realm of science free from social influence. This position is untenable; the concept that science is an inherently social activity has been supported by myriad works in the field of science and technology studies. Nonetheless, Majone and Weinberg's analyses provide useful insights into how regulators and the courts adjudicate issues that expose the social content of science.

Majone noted that even the basic paradigm for setting standards was socially determined, as illustrated by the different definitions for "nonadverse health effects" used in the Soviet Union and in the United States in the 1980s. In the United States, exposure to a toxicologically hazardous chemical was considered acceptable as long as it did not result in "a disturbance that overloads the normal protective mechanisms of the body."[69] Temporary effects were considered acceptable, as long they were recoverable after the exposure ended and did not increase the exposed person's susceptibility to other insults. On the surface, the Soviet approach appeared more cautious, deeming any detectible change or response as unacceptable, with particular attention to effects on the central nervous system.[70] However, the Soviet approach included the recognition that the resulting "hygienic" standards may or may not have been achievable.[71] As a result, they also defined less restrictive "sanitary" standards that took into account "economic and technical factors" and allowed them to be used with the understanding that the eventual goal was to achieve the ideal standard.[72]

Majone considered the definition of a dose-response relationship to be the "technical core" of procedures for establishing standards in contemporary Western societies and asserted that determination of such relationships fell into the category of trans-scientific problems.[73] He reached this conclusion because the usual procedures for establishing the dose-response relationship for a suspected harmful chemical involved laboratory experiments that exposed test animals to various relatively large doses of the chemical of concern and then extrapolated the results to identify a "virtually safe dose" several orders of magnitude smaller for exposures of human populations.[74] This approach is typically required because experimenting on human subjects is usually not an ethical option and because a prohibitively large experimental program would be needed to produce statistically valid estimates of the health effects for exposure levels closer to the expected safety standard (i.e., tens of thousands of test animals instead of several dozen, by Majone's estimation).[75] Because of this large extrapolation, the shape of the dose-response relationship for low level exposures—including whether or not there is a safe threshold dose below which no effects occur—typically cannot be definitively established.[76] Accordingly,

[68] Alvin M. Weinberg, "Science and Trans-Science," *Minerva* 10:2 (1972), 216.
[69] Majone, 16.
[70] Majone, 16.
[71] Majone, 18.
[72] Majone, 18.
[73] Majone, 16.
[74] Majone, 16.
[75] Majone, 17.
[76] Majone, 16-17.

the dose-response relationship becomes a trans science question that needs to be addressed by other means.

Weinberg considered the specific case of the dose-response relationship for genetic effects of low-level exposures to ionizing radiation as a trans science question. He speculated that statistically valid experiments on laboratory animals could need hundreds of millions to billions of test animals to produce the desired level of certainty in establishing the dose-response relationship, which would then still need to be extrapolated from mice to humans.[77] Weinberg suggested two approaches toward resolving such a trans science question: a scientific/technical approach and an adversary procedure.[78] The scientific/technical approach simply renders the debate moot by reducing potential exposure levels to *de minimis* levels that present virtually no risk. Weinberg asserted that this was how the controversy over potential radiation exposures of members of the public due to operations of nuclear power stations had been resolved.[79] This dissertation will comprehensively evaluate the social processes that led to the regulatory resolution for that issue.

The adversary procedure described by Weinberg involved "formal, legal or quasi-legal proceedings at which proponents, both scientists and non-scientists, of opposing views are heard before a body or an individual who is empowered to render a decision after having heard the conflicting contentions."[80] Examples of such interactions include hearings held by Congressional committees, debates in front of licensing boards for proposed nuclear power station construction projects, and court cases. This dissertation includes analysis of several examples of such proceedings over the course of several decades that dramatized the positions and arguments of the various actors involved in controversies over radiation exposures in the United States, some of which were pivotal in shaping standards and regulations.

Weinberg addressed the challenges that scientists face in such adversary procedures. He observed that in addressing a trans science question, it is vital to delineate the limits of scientific facts in order to establish the trans science domain which is open to debate.[81] Weinberg asserted that this sort of "selfless honesty" posed a challenge for scientists and engineers interested in maintaining their position or status.[82] In the case of the controversy over the effects of low-level radiation exposure, he specifically named "Professor Gofman and Dr. Tamplin"—both of whom feature prominently in the this dissertation—and numerous nuclear scientists who disagreed with them as all being unwilling to admit that "the question was simply unresolvable, that this was really a trans-scientific question."[83] This dissertation explicitly defines the radiation dose regime that is open to contestation in the linear no-threshold dose-response model controversy.

[77] Weinberg, 210.
[78] Weinberg, 214-217.
[79] Weinberg, 217.
[80] Weinberg, 214.
[81] Weinberg, 216.
[82] Weinberg, 216.
[83] Weinberg, 216.

Lastly, Weinberg discussed the importance of competence and credibility in science and trans science.[84] Weinberg found competence to be the deciding qualification for scientists operating within the realm of science. However, he judged credibility to be at least as important as competence in adversary procedures involving trans science questions. To some degree, this resulted from the fact that the mechanisms of adversary procedures are ill-suited to judge whether or not a scientist has the "ability to recognise and know scientific truth," but they are reasonably effective in establishing whether a witness is credible (defined by Weinberg as "stating the truth and nothing but the truth as he sees it").[85] As noted above, the notion of a "realm of science" free from social considerations is flawed, but Weinberg's conclusion about the importance of credibility is reasonable.

Ottinger described an element of circularity in credibility claims in such adversary procedures resulting from the fact that standards play an important role in establishing the "authority" of scientists and other technical experts when they appear outside of science circles, such as when they testify as expert witnesses in the courts and in public hearings.[86] In simple terms, the existence of a scientific standard reinforces the credibility of experts providing testimony consistent with that standard. The standards serve a boundary-keeping function that separates science and its practitioners from outsiders attempting to challenge the standards and the people responsible for them.[87] Ottinger asserted that this boundary work marginalized alternative processes for knowledge production, with negative consequences for nonscientists who seek to have a voice in such proceedings.[88] Standards are established through social processes, so determining an expert to be credible because they adhere to a standard may deny justifiable challenges to both the standard and the arguments of the expert who supports it. Issues of expert witness credibility and the facticity of standards figure prominently in the court cases on alleged injuries from radiation exposures examined in this dissertation.

2.4 Literature on Citizen Science and Standards

"Citizen science" has received enough recognition in recent years that Congress passed the Crowdsourcing and Citizen Science Act of 2016 to specifically authorize Federal science agencies to "utilize crowdsourcing and citizen science to conduct projects to advance the mission" of the agency or agencies involved.[89] The Act defines citizen science as participation in the scientific process through "(A) enabling the formulation of research questions; (B) creating and refining project design; (C) conducting scientific experiments; (D) collecting and analyzing data; (E) interpreting the results of data; (F) developing technologies and applications; (G) making discoveries; and (H) solving problems."[90] The Federal government has established a community of practice and a website (citizenscience.gov) to encourage such participation.

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[84] Weinberg, 216.
[85] Weinberg, 216.
[86] Gwen Ottinger, "Buckets of Resistance: Standards and the Effectiveness of Citizen Science," *Science, Technology, & Human Values* 35:2 (2010), 251.
[87] Ottinger, 251.
[88] Ottinger, 251.
[89] 15 U.S. Code § 3724, *Crowdsourcing and Citizen Science*, 2016.
[90] 15 U.S. Code § 3724, *Crowdsourcing and Citizen Science*, 2016.

Social science researchers have identified that citizen science can improve the appreciation of lay expertise by scientists while also improving the public's appreciation for the "practices and perspectives" of science.[91] Moreover, public involvement in scientific research can produce information leading to improved social justice outcomes for communities affected by a problem being studied. For example, Barbara Allen proposed that a "*strongly participatory* process," which includes stakeholders in all aspects of scientific research including the definition of the problem, can give communities a voice in policy-making that they may otherwise have lacked.[92] However, while citizen science can produce "contextual embodied knowledge rooted in subjective experience that can aid environmental justice advocacy," it can also encounter difficulty in gaining acceptance by scientists and policy-makers as "rigorous, trustworthy, and suitably scientific."[93]

Citizen groups in the United States have pursued citizen science to counter the undemocratic tendencies of scientized regulation by challenging official narratives on the risks presented by industrial activities and the standards that purportedly protect health, safety, and the environment. Ottinger observed that standards in particular have become "a site of struggle between citizens and experts."[94] In a well-known account of citizen science, Ottinger investigated citizen activists' efforts to conduct their own research program to characterize chemical exposures from a neighboring industrial facility and gain recognition of the problem.[95] Members of the community obtained bucket-based devices that met scientific standards for collecting a vapor sample which could be sent to a laboratory for analysis in accordance with applicable standards.[96] When a citizen volunteer with a bucket smelled a chemical odor, they would collect a sample to document the chemical release. This approach proved highly effective in drawing official attention to the releases from the offending facility, even if it did not succeed in changing government standards for transient air quality.[97] Ottinger found that the citizens' adherence to scientific standards for collecting and analyzing their air samples played an important part of the reason why officials took their local knowledge seriously. The standards served to bridge the divide between the lay public and the official experts.[98]

Citizen science features prominently in the historical discourse over the health effects of ionizing radiation. As detailed in Chapter 7 below, half a century before the "bucket brigades" were organized, citizen groups were independently operating a program for measuring and reporting children's body burden of radioactive fallout from atmospheric nuclear weapons testing, using protocols consistent with the scientific practices of that era. Furthermore, the same

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[91] James Wynn, *Citizen Science in the Digital Age: Rhetoric, Science, and Public Engagement* (Tuscaloosa, AL: The University of Alabama Press, 2017), 5.
[92] Barbara Allen, "Strongly Participatory Science and Knowledge Justice in an Environmentally Contested Region," *Science, Technology, & Human Values* (43:6, November 2018), 2-5.
[93] Thom Davies and Alice Mah, "Introduction: Tackling Environmental Injustice in a Post-Truth Age," in Thom Davies and Alice Mah, eds., *Toxic Truths: Environmental Justice and Citizen Science in a Post-Truth Age* (Manchester: Manchester University Press, 2020), 12.
[94] Ottinger, 249.
[95] Ottinger, 244-270.
[96] Ottinger, 256.
[97] Ottinger, 246.
[98] Ottinger, 246.

concerned citizens sponsored independent scientific publications on issues related to radiation safety, founding the "science information" approach to activism that persists to this day.[99]

In the case of the linear no-threshold model, instead of mounting challenges to it, citizen activism has repeatedly deployed the model to add credibility to advocacy against nuclear weapons and nuclear power. In return, discourse by scientific authorities has often sought to discourage placing literal "trust in numbers" that result when the linear no-threshold model is used to predict the outcome of exposing large populations to low levels of ionizing radiation. This dissertation will describe these somewhat counterintuitive aspects of the discourse over the linear no-threshold model.

2.5 Theoretical Framework for Investigating Social Processes Involved in Science and Regulation

As the next chapter of this dissertation will demonstrate, the science that underpins the regulation of low-level radiation exposures is by no means settled. As a result, questions regarding standards and regulations for protection against the health effects of low-level radiation constitute trans science questions as discussed above. Nonetheless, American society chose to proceed with a variety of technologies that result in such exposures and eventually implemented a regulatory system based on the linear no-threshold model for the health effects of radiation exposures. This includes applications such as nuclear power, manufacture and testing of nuclear weapons, and medical diagnostic and treatment procedures. Given the unsettled nature of the underlying science and the strong differences among social groups regarding nuclear power and nuclear weapons, the origins and durability of this regulatory system present an ideal situation for analysis using theories based on the social construction of knowledge.

A relatively recent article, written by Jeff Kochan to defend the "Strong Programme" of the sociology of scientific knowledge (SSK) observed that "the world can sustain diverse, and even contradictory descriptions of natural phenomena.[100] Given this starting point, the Strong Programme seeks to determine the social and historical events that led to acceptance of a particular conception of reality.[101] Steven Shapin similarly described SSK's analytical framework for interpreting varying beliefs about nature as being based on the premise that "one cannot … use one particular account—usually that of modern science—to gauge the validity of others."[102] Shapin also stressed the importance of "the specific processes of argumentation and political action whereby claims come to be accepted as true or rejected as false."[103] The development of the scientific understanding of radiation health effects and its application in

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[99] Sheldon Novick, *The Careless Atom* (Boston: Houghton Mifflin Company, 1969), 201.; Alan McGowan, "The Scientists' Institute for Public Information," *Environment: Science and Policy for Sustainable Development* 15:4 (1973), 16-20.
[100] Jeff Kochan, "Contrastive Explanation and the 'Strong Programme' in the Sociology of Scientific Knowledge," *Social Studies of Science* 40:1 (February 2010), 132-133.
[101] Kochan, 137.
[102] Steven Shapin, "Here and Everywhere: Sociology of Scientific Knowledge," *Annual Review of Sociology* 21 (1995), 304.
[103] Shapin, 305.

safety regulations provide excellent targets for two frameworks that apply the social construction of science: Co-production and Actor-Network Theory.

Co-Production

Sheila Jasanoff definitively developed the concept of co-production in *States of Knowledge: The Co-Production of Science and the Social Order*.[104] Jasanoff described co-production as an idiom that provides an analytical position between opposite extremes in the analysis of the relationship between science and society. On one side is technoscientific determinism, in which science and technology inevitably progress in a particular direction, and society evolves to accommodate them.[105] On the other side is social determinism (social construction), which in its extreme assigns "causal primacy" to the societal aspects of a technoscientific situation, and which in less extreme applications still tends to take important characteristics of society for granted (e.g., the state, gender, markets, etc.).[106] Jasanoff argued that the co-production idiom opens up avenues for inquiry that would be obscured by approaches rooted in either technoscientific determinism or social construction.[107] The co-production approach raises research questions such as whether a society's gender roles shaped the characteristics of a particular technoscientific development, and whether that technoscientific development in turn reinforced the gender roles that had shaped it; for example, co-production can be applied to evaluate how the construction of the technology of hand compositing for letterpress printing had served to demarcate that trade as the domain of men, and how/why that gender divide continued even after technological changes removed the heavy lifting from the work.[108] For the purposes of this dissertation, the co-production approach supports questions such as how social movements were shaped by the science and regulation of low-level radiation exposures, and how in turn social movements influenced the development of the science and the regulatory scheme.

Jasanoff portrayed the co-production idiom as a superior approach for analyzing the relationship between knowledge and power. She described co-production as again providing a middle ground between two oversimplified analytical approaches. On one extreme are approaches that treat power as being held by enduring social structures that constrain knowledge production.[109] The opposite extreme treats power as "fluid, immanent, and continually renegotiable" such that knowledge production is not constrained by preexisting social structures.[110] Jasanoff argued that the co-production idiom allows interrogating power structures to explain why they either endure or yield to change in various situations.[111] The co-production idiom can be used to investigate the mutual influences among the developing nuclear industry,

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[104] Sheila Jasanoff, ed., *States of Knowledge: The Co-Production of Science and Social Order* (New York: Routledge, 2006).

[105] Sheila Jasanoff, "Ordering knowledge, ordering society," in Sheila Jasanoff, ed., *States of Knowledge: The Co-Production of Science and Social Order* (New York: Routledge, 2006), 20.

[106] Jasanoff (2006), 19-20.

[107] Jasanoff (2006), 20.

[108] Cynthia Cockburn, "The material of male power," in Donald MacKenzie and Judy Wajcman, eds., *The Social Shaping of Technology: How the refrigerator got its hum* (Philadelphia: Open University Press), 127.

[109] Jasanoff (2006), 36.

[110] Jasanoff (2006), 36.

[111] Jasanoff (2006), 36.

the developing regulatory scheme, emergent social movements, and the uncertain science of the health effects of low-level radiation exposures.

Jasanoff described several "ordering instruments" that she perceived as "operating at the nexus of natural and social order" and serving important roles in stabilizing "both what we know and how we know it."[112] These ordering instruments therefore lie at the heart of the co-production idiom and are fundamental to how the mutual shaping of science and society takes place. The ordering instruments and how they operate are summarized below:

- *Making Identities*. Jasanoff considered identity an important ordering instrument on the grounds that "it is one of the most potent resources with which people restore sense out of disorder.[113] Accordingly, the emergence of technologies such as radiology, nuclear weapons, and nuclear reactors is accompanied by a reassessment of individual and group identities. The resulting interplay between science and technology and identities can lead to retrenchment that reaffirms identity and influences the direction of science and technology to accommodate the strongly held identity, reshaping of identity around the scientific/technological development, or an intermediate position of mutual influence.

- *Making Institutions*. Jasanoff held institutions as the means by which characterizations of nature become recognized and gain political effect.[114] Jasanoff described institutions as "stable repositories of knowledge and power" with "ready-made instruments for putting things in their places at times of uncertainty and disorder."[115] She further noted that the manner in which institutions know things is reproduced in new contexts, because they tend to be socialized into a society's actors and also because it may be "too disruptive" to reconsider them overtly.[116] Hilgartner, Miller, and Hagendijk succinctly observed that "Transforming laboratory science into societal reality depends on institutions and the political, legal and scientific cultures that they configure."[117] Accordingly, institutions strongly influence agendas for science and technology, and developments in science and technology are mediated through institutions (either existing institutions or new institutions established to cope with the new developments).

- *Making Discourses*. Jasanoff observed that discourse plays an important role as an ordering instrument by communicating novel phenomena, describing experiments, attempting to persuade skeptics and reassure concerned parties, and providing a link between knowledge and action.[118] She noted that such discourse tends to take

[112] Jasanoff (2006), 39.
[113] Jasanoff (2006), 39.
[114] Jasanoff (2006), 40.
[115] Jasanoff (2006), 39-40.
[116] Jasanoff (2006), 40.
[117] Stephen Hilgartner, Clark A. Miller, and Rob Hagendijk, "Introduction," in Stephen Hilgartner, Clark A. Miller, and Rob Hagendijk, eds., *Science and Democracy: Making knowledge and making power in the biosciences and beyond* (New York: Routledge-Taylor & Francis Group, 2015), 6.
[118] Jasanoff (2006), 40-41.

advantage of existing legal, medical, and ethical discourse and may embody the society's tacit understandings of science, culture, humanity, etc.[119] Jasanoff asserted that institutional discourse inevitably involves standardization, with associated potential for oversimplification, and demarcation of safe and unsafe (or natural vs. unnatural) regimes of science and nature.[120] Social groups and individuals that are not part of a society's institutions also engage in discourse aimed at influencing scientific and technological developments and how society accommodates them. While institutions may hold power and decision-making authority, other social groups in a democratic society do possess the ability to influence societal choices through effective discourse.

- *Making Representations*. Lastly, Jasanoff described the activity of making representations as a "core concern" of science and technology studies and advocated taking an expansive view when considering what categories of things are objects of representation.[121] Beyond making representations of nature for communication among scientists, to nonscientist institutions, and to the lay public, Jasanoff contended that the connection between making such representations and "political and social representation" also needed to be considered.[122]

Sociotechnical Imaginaries

Jasanoff built upon the concept of co-production and its ordering instruments in subsequent work that developed the idea of sociotechnical imaginaries. She offered that science and technology studies needed a means for evaluating "the biggest 'why' questions of history: why upheavals sometimes seem to come from nowhere and why attempts to remake the world sometimes fail despite much concerted effort and expenditure of resources."[123] She also stated that explanations were lacking for why different societies and different segments of society make such different choices and have such different views on new ideas in science and new technologies.[124]

Jasanoff proposed sociotechnical imaginaries as a novel approach to these problems and defined them as "collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and social order attainable through, and supportive of, advances in science and technology."[125] Jasanoff viewed a sociotechnical imaginary as "neither cause nor effect in a conventional sense but rather a continually rearticulated awareness of order in social life and a resulting commitment to that order's coherence and continuity."[126] She elaborated that imaginaries also work in the converse,

[119] Jasanoff (2006), 41.
[120] Jasanoff (2006), 41.
[121] Jasanoff (2006), 41.
[122] Jasanoff (2006), 41.
[123] Sheila Jasanoff, "Future Imperfect: Science, Technology, and the Imaginations of Modernity," in Sheila Jasanoff and Sang-Hyun Kim, eds., *Dreamscapes of Modernity: Sociotechnical Imaginaries and the Fabrication of Power* (Chicago: The University of Chicago Press, 2015), 3.
[124] Jasanoff (2015), 3-4.
[125] Jasanoff (2015), 4.
[126] Jasanoff (2015), 26.

being likewise animated by shared fear of harms.[127] Moreover, Jasanoff considered sociotechnical imaginaries to be "at once products of and instruments of the coproduction of science, technology, and society in modernity," adding to the list of ordering instruments defined in her prior scholarship.[128] By investigating these shared understandings and visions, Jasanoff asserted that researchers could answer the "why" questions that had proved so elusive. Jasanoff suggested the following methods for evaluating sociotechnical imaginaries:[129]

- Comparisons across social and political structures to help reveal situated epistemic and ethical assumptions, including comparisons across policy sectors and across time
- Evaluation of how individual actors manage to propagate visions such that they rise to collectively shared objectives
- Studying official policy discourses and processes for framing issues and setting agendas to see how they mold the public imagination in shaping "stories of progress" and convey expectations regarding science and technology
- Examination of legal disputes to reveal how people and institutions react when "contestation between disparate understandings of the good" threaten to disturb order, with judicial rulings "that often reproduce dominant sociotechnical imaginaries"
- Analyzing policy documents, as well as other discourse in the media, popular writings, advertising, etc., for insights into how desirable futures and undesirable outcomes are framed and to discover "specific verbal tropes and analogies" that can illuminate the components of the imaginary

This dissertation applies most of these methods in investigating how the linear no-threshold model became established as the basis for regulation of radiation safety in the United States. The significance of the ordering instruments of co-production is highlighted throughout the analysis that follows below.

Hugh Gusterson similarly argued that simply having "small platoons of scholars fan out across the territory of science to hunt down the social construction of everything from the virus to the gravity wave" was less meaningful than studying "the ways in which the meaning of … technology is constructed by different communities as the technology is incorporated into society."[130] Gusterson explained his approach as focusing on "the ways scientists remake society as they go about their scientific work" and on "the processes by which their projects may be appropriated, contested, and undermined by other social groups."[131] In applying this approach to the development of nuclear weapons technologies by Lawrence Livermore National Laboratory, he analyzed the contention between the opposing ideologies of the "technocratic wing of the middle class" that populated the laboratory and the "humanistic wing" of the middle class that dominated the anti-nuclear movement.[132] Gusterson's work further indicates the value of considering sociotechnical imaginaries as part of this dissertation.

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[127] Jasanoff (2015), 4-5.
[128] Jasanoff (2015), 19.
[129] Jasanoff (2015), 24-27.
[130] Hugh Gusterson, *Nuclear Rites: A Weapons Laboratory at the End of the Cold War* (Berkeley: University of California Press, 1998), 225.
[131] Gusterson, 225.
[132] Gusterson, 221.

Actor-Network Theory

Bruno Latour's development of actor-network theory in *Science in Action: How to Follow Scientists and Engineers Through Society* provides a useful framework for identifying and evaluating the major actors involved in the science and regulation of low-level radiation exposures.[133] Latour's development of ANT postulates that a scientific idea or technological innovation gains acceptance when the actors involved are joined together like parts of a machine.[134] This is the actor-network of ANT. Latour describes the network builder's role as follows: "The problem of the builder of 'fact' is the same as that of the builder of 'objects': how to convince others, how to control their behaviour, how to gather sufficient resources in one place, how to have the claim or the object spread out in time and space."[135] This builder works by convincing other actors that they have a problem for which the builder has a solution, or by leading the actors to adopt goals that can be met using the builder's scientific finding or technological innovation.[136] Latour describes this process as a translation of interests, "at once offering new interpretations of these interests and channelling people in different directions."[137] This process of problematization, enrollment, and translation is central to ANT.

Application of actor-network theory to the regulatory system for radiation safety is compatible with Jasanoff's articulation of the co-production idiom and sociotechnical imaginaries, in that both of these approaches seek to treat the social and the natural symmetrically. Just as Jasanoff described ordering instruments operating at the "nexus of natural and social order," Latour exhorted researchers to remove what he described as the "artificial boundary between social and natural."[138] In an article assessing the state of SSK, Shapin noted that a key problem for SSK is the apparent ease with which science travels, despite the fact that empirical research established science to be a local product.[139] Shapin turned to Latour and actor-network theory, with its enrollment of supporters, obligatory passage points, translations, and network building, as a means for understanding how science is institutionalized and circulated.[140] Likewise, the ordering instruments for co-production identified by Jasanoff are well-suited for describing the social processes underpinning the selection and durability of standards, as well as evaluating challenges to them.

The next chapter of this dissertation will summarize the historical development of the scientific understanding of the health effects of exposure to ionizing radiation. Most importantly, it will establish the exposure regime for which the health effects of ionizing radiation are universally regarded as known, as well as the exposure regime for which the health

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[133] Bruno Latour, *Science in Action: How to Follow Scientists and Engineers Through Society* (Cambridge, MA: Harvard University Press, 1987).
[134] Latour (1987), 128-129.
[135] Latour (1987), 131.
[136] Latour (1987), 114-115.
[137] Latour (1987), 117.
[138] Bruno Latour, *Reassembling the Social: An Introduction to Actor-Network Theory* (Oxford: Oxford University Press, 2005), 111.
[139] Shapin, 307.
[140] Shapin, 308.

effects are contested. In the latter exposure regime, the relationship between dose and consequence represents a trans science question. The remainder of this dissertation traces the decades-long evolution of the actor-network engaged in settling this question and elucidates the processes of co-production that led to establishment of the linear no-threshold model as the basis for regulation in the contested regime.

2.6 A Note on Sources

This dissertation is based on a broad range of reference materials that enable applying most of the methods Jasanoff suggested for investigating sociotechnical imaginaries and evaluating the full range of ordering instruments she described. I placed strong emphasis on locating records where actors spoke for themselves, enabling precise evaluation of their use of discourse that secondhand accounts may have distorted. I also cast a wide net for forms of discourse in order to fully understand the various actors' conceptualizations of the hazards of radiation as well as their strategies for enrolling others in their visions for science and society. Sources include:

- Journal articles and reports on the science of the health effects of ionizing radiation
- Standards and regulations on radiation safety issued since the early 1900s
- Relevant acts of Congress and Presidential statements
- Books and journal articles by historians and social scientists on the history and controversy of radiation health regulations and standards
- Transcripts and other records of testimony from public hearings and meetings held by Congress and the Atomic Energy Commission
- Records of court cases on radiation injury claims
- Opinion pieces written by various principals in the actor-network and other examples of public discourse (including a televised debate between scientists)
- Booklets, posters, newspaper advertisements, books, and films produced by institutions and social groups for public information campaigns on radiation safety and radiation hazards
- Public comments submitted for a regulatory rulemaking
- Positions and policies featured on websites for social groups, including professional societies, standards-setting bodies, and activist groups

3 The Space Available for Contestation

The linear no-threshold dose-response model is controversial because the underlying science is unsettled for low-dose radiation exposure. This chapter will establish the epistemological space that is open to contestation by describing the mechanisms by which radiation interacts with matter, how living tissues can be damaged by radiation, and where uncertainty in the human health effects of radiation exposure is sufficient to allow dose-response models to be contested.

3.1 Radiation

Radiation is energy in the form of subatomic particles or electromagnetic waves traveling through space. A variety of natural and artificial processes emit radiation. The nature of radiation and its interactions with matter are well-established and have not been subject to contestation in recent decades. Three types of radiation are known to produce responses in living organisms:

3.1.1 Electromagnetic Radiation

Electromagnetic radiation can be described either as waves traveling through space or as massless, chargeless particles known as photons. Regardless of whether it is modeled as a wave or as a particle, electromagnetic radiation always travels at the speed of light. The energy of electromagnetic radiation is unrelated to its velocity. Instead, the energy is a function of the wavelength of the electromagnetic wave. The energy of electromagnetic radiation is inversely related to its wavelength; waves with a shorter wavelength carry more energy. Figure 3-1 illustrates this relationship.

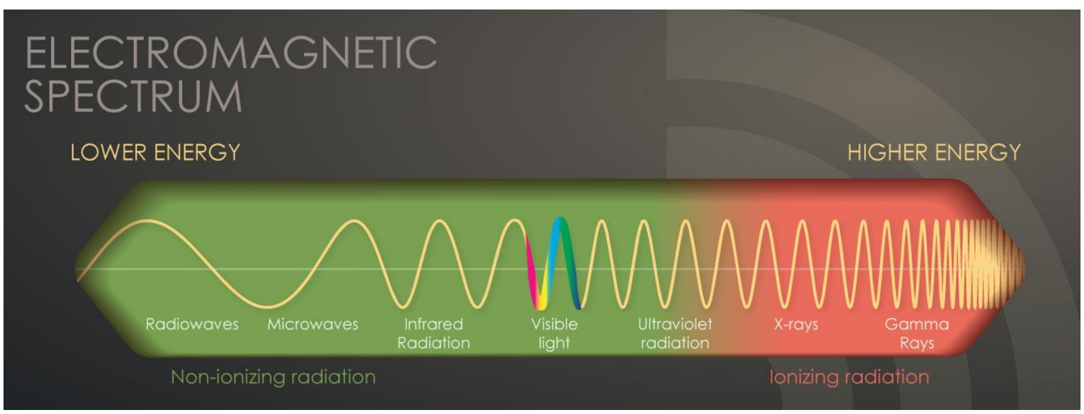

Figure 3-1 Electromagnetic Spectrum[141]

Electromagnetic radiation is integral to life and society. Visible light is electromagnetic radiation, with the color determined by the wavelength. Wavelengths longer than visible light begin with infrared (heat) waves, then continue into microwaves and radio waves. Long

[141] Centers for Disease Control and Prevention, *The Electromagnetic Spectrum: Non-Ionizing Radiation*, https://www.cdc.gov/nceh/radiation/nonionizing_radiation.html, accessed November 2, 2019.

wavelength electromagnetic radiation has not been involved in LNT controversies, although some research indicates potential health effects of exposure to intense radio waves.[142] This may result from the lack of an association between radio waves and nuclear medicine, nuclear power, or nuclear weapons. Without such a connection, their health effects are not a primary interest of groups in favor of or opposed to nuclear technologies.

Shorter wavelength electromagnetic radiation includes ultraviolet light, x-rays, and gamma rays. Ultraviolet light has been definitively identified as a cause of sunburn and skin cancer.[143] However, like radio waves, ultraviolet radiation has not been embroiled in the LNT controversy.

X-rays and gamma rays differ from lower energy electromagnetic radiation because of their ability to separate electrons from atoms and molecules in materials they encounter. This process—termed ionization—gives rise to the health effects of x-rays and gamma rays on living organisms. X-rays and gamma rays travel long distances in air but may be shielded by dense materials such as lead or concrete, or by sufficient thicknesses of less dense materials such as water. There is no specific dividing line in terms of energy or wavelength between x-rays and gamma rays. Customary terminology denotes gamma rays as originating from decay of the nucleus of certain radioisotopes and x-rays as originating from high-energy electrical apparatus such as a cathode ray tube or linear accelerator.

3.1.2 Charged Particle Radiation

Charged subatomic particles constitute a second category of ionizing radiation. Charged particle radiation can be emitted during decay of the nucleus of certain radioisotopes and by technologies such as cathode ray tubes and linear accelerators. The energy of charged particle radiation is determined by the particle's mass, charge, and velocity. Charged particle radiation creates ionization in materials exposed to it, giving rise to health effects in living organisms. The types of charged particle radiation of most interest in the LNT controversy are beta radiation and alpha radiation.

- Beta radiation is composed of negatively charged particles with a very small mass (less than 10^{-27} grams) and unit charge—essentially free electrons. Beta radiation has a shorter range in air than electromagnetic radiation and is easily shielded because of its charge. However, because of its charge, beta radiation deposits its energy across a very short distance once it encounters solid or liquid matter. As a result, an organism that inhales, ingests, absorbs, or is injected with a radioactive material that emits beta radiation may experience significant radiation exposure to the tissues surrounding the material.

- Alpha radiation is composed of positively charged subatomic particles that are much more massive than beta particles. An alpha particle consists of two protons and two neutrons held together by the strong nuclear force, essentially a helium atom without

[142] Richard Wakeford, "The cancer epidemiology of radiation," *Oncogene* 23:38 (2004), 6421-6423.
[143] Wakeford, 6420-6421.

its electrons. Its charge is twice the magnitude and opposite in sign compared to the charge of a beta particle, and its mass is more than 7000 times that of a beta particle (about 6.6 x 10^{-24} grams). Alpha radiation has an even shorter range in air than beta radiation, and it is easily shielded by any solid or liquid material. However, because of its charge and mass, alpha radiation deposits its energy across an even shorter distance once it encounters solid or liquid matter. As a result, an organism that inhales, ingests, absorbs, or is injected with a radioactive material that emits alpha radiation will experience more localized radiation exposure to the tissues surrounding the material than would be the case for intake of a beta emitter.

3.1.3 Neutron Radiation

Neutron radiation is simply a flux of neutrons—chargeless particles with a mass about one-fourth of an alpha particle. Like other particulate radiation, the energy of a neutron is determined by its velocity. Neutrons are emitted from atomic nuclei under a variety of circumstances, including decay of the nucleus of certain radioisotopes, nuclear fission (which may be spontaneous or induced), nuclear fusion, "alpha-n" reactions in which an atomic nucleus absorbs an alpha particle and emits a neutron, and photoneutron emission in which gamma radiation induces an atomic nucleus to expel a neutron. Because neutrons have no charge, they have long range and great penetrating power. Neutron radiation interacts with matter through collisions with and/or absorption by atomic nuclei. These interactions can ionize atoms and molecules, activate stable atoms into unstable radioisotopes that will decay and emit radiation, and induce fission of certain isotopes. Similar to gamma ray and x-ray radiation, the health effects of neutron radiation primarily result from ionization of tissues exposed to external sources of neutron radiation, as opposed to the internal hazard posed by intake of alpha and beta emitters.

3.2 Biological Damage from Radiation Exposure

The health effects of radiation exposure arise from the ionization of atoms and molecules in the tissues of a living organism and from the organism's response to such insults. These two stages—the immediate damage resulting from radiation exposure and the organism's subsequent response to the damage—are best considered separately in order to elucidate the space that is open to contestation.

The immediate impact of ionizing radiation on an organism has been broken down into direct effects and indirect effects.[144] The direct effects occur when charged particles freed by ionization along the track of the radiation through cells damage genetic material (DNA) by breaking the DNA strands or damaging the molecules in the DNA. Direct effects may also damage other important cellular components. Indirect effects occur when radiation ionizes other

[144] National Academy of Sciences – National Research Council, Committee on the Biological Effects of Ionizing Radiations, *Health Effects of Exposure to Low Levels of Ionizing Radiation: BEIR V* (Washington, DC: National Academy Press, 1990), 20-23.; National Academy of Sciences – National Research Council, Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation, *Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2* (Washington, DC: The National Academies Press, 2006), 29-30.

molecules such as water, salts, proteins, and oxygen in tissues.[145] Ionization of water is particularly important because living tissues are mostly water, and ionization of water produces several reactive species: "hydrated electrons" (freed electrons captured by polarizing water molecules), hydroxyl radicals ($OH^{\bullet}$), and hydrogen radicals ($H^{\bullet}$). The radicals can impact cells in several ways. For example, hydroxyl radicals act as an oxidizing agent, and if they form near enough to cellular DNA, they can extract hydrogen atoms from the DNA molecule. Radicals can also react with other parts of the cells, including the membrane of the cell nucleus and the outer cell membrane, disrupting their functions. Researchers currently believe that the indirect effects of water radicals cause most of the damage in irradiation of tissues.[146]

Direct and indirect effects of ionizing radiation can damage DNA in several ways, and the amount of damage increases with the absorbed radiation dose. One or both strands of the double-helix DNA molecule can be severed. Even if the DNA strand is not severed, molecular bases that constitute each DNA strand can be damaged or removed. The National Academy of Sciences – National Research Council concluded that double-strand breaks are of the greatest consequence and that the body's mechanisms for repairing them are "error prone," which can lead to chromosomal effects and mutagenesis (changes in DNA that can be replicated).[147]

3.3 Human Health Effects of Radiation Damage

Radiation damage phenomena appear straightforward, so controversy over the health effects of radiation might seem unlikely to be sustainable. Indeed, many aspects of the health impacts are not contested, because they are well characterized both in theory and in clinical and epidemiological observations. However, the body's response to radiation damage is extraordinarily complex, and it can be difficult to distinguish health impacts of radiation from naturally occurring disfunction of cellular processes and from the health effects of other natural and technological phenomena. Furthermore, in many cases, theoretical health impacts are not supported by statistically significant clinical or epidemiological evidence. Epidemiological studies investigating links between low-level radiation exposures and cancer are particularly challenging because the overall fatal cancer rate from all causes (about 20–25% of all deaths) is much larger than the increase in the cancer rate postulated for low-level radiation exposure.[148] The small effect of low-level radiation exposure is very difficult or impossible to discern against the inherent variability of the large overall fatal cancer rate. In other cases, observed clinical or epidemiological data are not supported by a satisfactory theory.

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[145] Elahe Alizadeh, Thomas M. Orlando, and Leon Sanche, "Biomolecular Damage Induced by Ionizing Radiation: The Direct and Indirect Effects of Low-Energy Electrons on DNA," *Annual Review of Physical Chemistry* 66:1 (2015), 380.

[146] John M. Herbert and Marc P. Coons, "The Hydrated Electron," *Annual Review of Physical Chemistry* 68:1 (2017), 449-450.

[147] NAS-NRC (2006), 65.

[148] Wakeford, 6405.; U.S. Nuclear Regulatory Commission, *Regulatory Guide 8.29: Instruction Concerning Risks from Occupational Radiation Exposure, Revision 1* (Washington, DC: U.S. Nuclear Regulatory Commission, February 1996), 8.29-4, 8.29-7.; NAS-NRC (1990), 161.

The observed health effects can be divided into two categories: deterministic effects and stochastic effects.[149] Sufficiently large doses of ionizing radiation consistently result in deterministic effects such as erythema, radiation sickness, cataracts, and birth defects, with the effects becoming more severe as the radiation dose increases. Stochastic effects—primarily various forms of cancer—involve random aspects of damage and repair at the molecular level. As a result, increasing the radiation dose will increase the likelihood of the health effect, but the severity of the effect (i.e., initiation of cancer) will remain more or less the same.[150]

These relationships between dose and effect have led to general consensus on the health effects of relatively large radiation exposures. Once an organism's ability to repair or recover from radiation damage is overwhelmed, confounding factors such as the variability from organism to organism and other internal or environmental factors recede in importance. Accordingly, there is little or no room for controversy at high exposure levels.

Well-documented cases of high radiation exposures such as early radiation experimenters, early medical radiologists, patients irradiated for medical treatments, radium watch dial painters, survivors of the atomic bombings in Japan, uranium miners, and other exposed groups have defined the high end of the dose-response relationship for humans.[151] The most prominent health effects resulting from such high radiation exposures are summarized in the following sections.

3.3.1 A Note on Units

This dissertation cites sources spanning nearly a century of humanity's investigation and application of radiation and radioactive materials. Units of measure related to radiation evolved over that timeframe, and the International System of Units entered into use by some practitioners in the United States. This dissertation retains the original units used in each cited source, primarily because the chosen units reflect the understanding of radiation at the time the source was produced. In places where it would facilitate understanding, equivalent units are provided to ensure the intended message is conveyed to the reader. In some cases, units were unclearly stated in the source. Such cases are noted when cited. An overview of units relevant to radiation health is provided below to assist the reader in interpreting the discussions in this dissertation.[152]

[149] William C. Inkret, Charles B. Meinhold, and John C. Taschner, "Protection Standards," *Los Alamos Science* 23 (1995), 122.
[150] Inkret, Meinhold, and Taschner, 122.
[151] J. Samuel Walker, *Permissible Dose: A History of Radiation Protection in the Twentieth Century* (Berkeley: University of California Press, 2000), 7-8.; U.S. NRC (1996), 8.29-4.; Wakeford, 6404.
[152] U.S. Nuclear Regulatory Commission, *Glossary*, https://www.nrc.gov/reading-rm/basic-ref/glossary.html (accessed February 7, 2021).

Measured Quantity	Pre-International System Units	International System Units
Radioactivity	Curie (Ci) – 3.7 x 10^{10} decays per second	Becquerel (Bq) – 1 decay per second
Exposure to ionizing radiation	Roentgen (R) – the amount of gamma or x-rays needed to produce ions resulting in a charge of 0.000258 coulombs/kilogram of air under standard conditions	No equivalent unit
Absorbed radiation (dose)	Rad (radiation absorbed dose) – 100 ergs of energy absorbed per gram of material For x-rays and gamma rays directed at soft bodily tissue, roentgen and rad are about equivalent	Gray (Gy) – 100 rad
Equivalent dose – absorbed dose adjusted for biological effectiveness of the type of radiation absorbed	Rem (Roentgen Equivalent Man) – dose in rad multiplied by quality factor for the type of radiation	Sievert (Sv) – 100 rem

Table 3-1 Units for Radiation Exposure and Dose

3.3.2 Radiation Sickness

Large acute exposures to the whole body produce immediate and catastrophic health effects. Acute exposures on the order of 300-500 rads cause vomiting, diarrhea, fever, hair loss, weight loss, and a chance of death of about 50 percent.[153]

3.3.3 Erythema

Before the threat of cancer from x-ray exposures was recognized, early radiation workers, particularly physicians and x-ray technicians, discovered the occupational hazard of skin inflammation (erythema) from excessive exposure to radiation in their work.[154] This led committees formed by physicians and radiologists in the 1920s (the International X-Ray and Radium Protection Committee and its American counterpart, the Advisory Committee on Radiation Protection) to establish "tolerance doses" for occupational x-ray exposures to the whole body and extremities in 1934. The term "tolerance dose" is significant because it

[153] U.S. NRC (1996), 8.29-5.
[154] Walker, 7-8.

suggested a threshold below which no health effects should be expected. These tolerance doses were very high by modern standards: 0.1-0.2 roentgen per day for whole body exposure and 5 roentgen per day for the fingers.[155]

3.3.4 Cataracts

Large acute or large chronic radiation exposures to the eye have been demonstrated to cause cataracts. Again, these doses are well beyond the realm of the LNT controversy, on the order of 100 rad for an acute exposure and on the order of 800 rad cumulative exposure spread over many years.[156]

3.3.5 Cancer

Cancer has been recognized as a delayed effect of exposure to ionizing radiation since the 1930s for solid tumor cancers and since the early 1940s (before the atomic bombings in Japan) for leukemia (cancers of the blood and lymph systems).[157] As detailed below, researchers and medical authorities discovered the linkage between radiation exposure and development of leukemia and of solid tumor cancers from studying the illnesses of radiologists exposed to significant x-ray doses and watch dial painters who ingested large amounts of radium. Subsequently, elevated rates of both categories of cancer were identified after World War II among the survivors of the atomic bombings in Japan.[158] As discussed in the sections on solid tumor cancers and leukemia below, long-term epidemiological studies of the bomb survivors formed the basis for the prevailing models for the relationship between radiation exposure and the risk of cancer. Epidemiological studies of other groups exposed to various forms of radiation have added to the models developed using the bomb survivor data but have not driven any fundamental changes.[159]

For higher radiation doses, these prevailing models are essentially uncontested. Definitions of high, medium, and low doses are somewhat arbitrary, but authoritative bodies such as the U.S. National Research Council, the National Council on Radiation Protection and Measurements, and the Radiation Effects Research Foundation describe doses below 100 mGy as low.[160] This is about forty times the average person's yearly background exposure to ionizing radiation.[161] Doses on the order of 1 Gy or more are considered high—based on epidemiological studies, doses of such magnitude are regarded as having a "causative" cancer risk.[162] Moreover,

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[155] Walker, 8.
[156] U.S. NRC (1996), 8.29-5, 8.29-6.
[157] Harrison S. Martland, "The Occurrence of Malignancy in Radio-Active Persons," *The American Journal of Cancer* XV:4 (October 1931), 2435-2516.; Wakeford, 6412.
[158] Wakeford, 6405-6409.
[159] NAS-NRC (2006), 12-15.
[160] NAS-NRC (2006), 62.; National Council on Radiation Protection and Measurements, *NCRP Commentary No. 27: Implications of Recent Epidemiological Studies for the Linear-Nonthreshold Model and Radiation Protection* (Bethesda, MD: NCRP, 2018), 1.; Kotaro Ozasa, Eric J. Grant, and Kazunori Kodama, "Japanese Legacy Cohorts: The Life Span Study Atomic Bomb Survivor Cohort and Survivors' Offspring," *Journal of Epidemiology* 28:4 (2018), 166.
[161] NAS-NRC (2006), 7.
[162] NAS-NRC (2006), 7.

the National Research Council's most recent report on the biological effects of low level ionizing radiation, BEIR VII, prominently and repeatedly presents the overall conclusion that "current scientific evidence is consistent with the hypothesis that there is a linear, no-threshold dose-response relationship between exposure to ionizing radiation and the development of cancer in humans" without any caveats about high or low doses.[163] Despite that unequivocal conclusion, however, BEIR VII included details about dose-response relationships that seem to warrant an asterisk. The sections on leukemia and solid cancers below explain these caveats.

3.3.5.1 Leukemia

Researchers documented excess incidence of leukemia—cancer of the blood, blood-forming organs, and lymph systems[164]—among radiologists in 1944, despite the institution of the "tolerance dose" ten years earlier.[165] The case of the radiologists illustrates one of the fundamental difficulties in linking cancer to radiation exposures: Years typically elapse between the radiation exposure and the diagnosis of cancer in exposed individuals, even for large acute exposures. The latency period for leukemia, estimated at 2 to 25 years, is typically shorter than that of solid tumor cancers, estimated at 25 to 40 years, but the delay between exposure and effect contributed to the late realization that x-rays could lead to leukemia.[166] The latency of cancer also opens the door to confounding effects such as exposure to other carcinogens during the latent period, which complicates attempts to definitively link cancer in any specific person to any specific exposure.

In the case of the atomic bombings of Hiroshima and Nagasaki, the excess incidence of leukemia among survivors was first noted in 1948.[167] Epidemiological study of the atomic bombing survivors provided a major portion of the data used to establish dose-response relationships for leukemia. These studies began with the founding of the Atomic Bomb Casualty Commission in 1947 by the U.S. National Academy of Sciences – National Research Council. This effort is ongoing, funded by the United States and Japanese governments via the Radiation Effects Research Foundation. It includes a cohort study of atomic bomb survivors known as the Life Span Study, which includes over 80,000 bomb survivors of all ages, including several thousand exposed *in utero*.[168]

In 1960, the U.S. National Academy of Sciences published the second edition of its definitive report on the health effects of radiation (the so-called "BEAR Report"), which found that the bomb survivor data showed a leukemia risk of about one case per year per million people per rad of dose, for survivors exposed to more than 100 rad. The report noted that the data were

[163] NAS-NRC (2006), 15.
[164] Richard J. Reynolds and Jay A. Schecker, "Radiation, Cell Cycle, and Cancer," *Los Alamos Science* 23 (1995), 74.
[165] Wakeford, 6412.
[166] Inkret, Meinhold, and Taschner, 120.
[167] Wakeford, 6405-6406.
[168] Ozasa, Grant, and Kodama, 162-169.

insufficient to confirm or deny a dose threshold below which leukemia would not be a concern.[169]

A journal article published three years before the 1960 BEAR Report developed a similar dose-response correlation using a larger data set that added leukemia incidence for other groups that had been exposed to high levels of ionizing radiation (over 11,000 patients treated with x-rays for ankylosing spondylitis—an inflammation of the spinal joints—during 1935-1954; 1400 patients irradiated as infants to treat an enlarged thymus; and radiologists receiving occupational exposures during 1943-1952). That researcher arrived at a result on the same order of magnitude as the National Academy of Sciences report: two cases per year per million people per rad of dose. Interestingly, that researcher applied his correlation to estimate what fraction of "spontaneous" leukemia cases in a population could be attributed to background radiation, assuming no threshold existed. He found that 10-20 percent of the leukemia incidence among the white population of Brooklyn could be attributed to ionizing radiation from background sources, assuming no threshold applied to his linear correlation.[170]

The exposed population in Japan, like the American radiographers, primarily suffered irradiation from external radiation sources, as opposed to ingesting radioactive materials. A recent study of more than 22,000 workers from the former Soviet Union's Mayak Production Association included workers with exposures to external sources of gamma rays and uptakes of plutonium that resulted in long-term internal exposures to alpha radiation.[171] This study found that the correlation between exposure to external gamma ray sources and leukemia risk primarily derived from exposures greater than 1 Gy (i.e., the regime generally regarded as "high" doses) but found no correlation between the body burden of plutonium and the risk of leukemia.[172] As a result, it appears that exposure from ingestion of radioisotopes such as plutonium does not have a detectable relationship to the development of leukemia.

Recent reports based on the Life Span Study have concluded that the dose-response relationship for leukemia is better represented by a linear-quadratic model instead of a simple linear model.[173] The BEIR VII report avoided providing a biological explanation for this result. The report simply observed that a linear-quadratic model fits the dose response data better and included a single statement conceding that "The etiology of leukemia is not well established."[174]

A simplified linear-quadratic relationship for dose response follows a general equation of the form $y = 1 - e^{-ax-bx^2}$. Applied to cancer, y is the likelihood of cancer, x is the radiation

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[169] National Academy of Sciences Committee on the Biological Effects of Atomic Radiation, *A Report to the Public on the Biological Effects of Atomic Radiation* (Washington, DC: National Academy of Sciences – National Research Council, 1960), 6.

[170] E.B. Lewis, "Leukemia and Ionizing Radiation," *Science* 125:3255 (May 17, 1957), 965-972.

[171] Irina S. Kuznetsova, Elena V. Labutina, and Nezahat Hunter, "Radiation Risks of Leukemia, Lymphoma and Multiple Myeloma Incidence in the Mayak Cohort: 1948-2004," *PLoS ONE* 11:9 (September 15, 2016), 1-14.

[172] Kuznetsova, Labutina, and Hunter, 9.

[173] NAS-NRC (2006), 6.

[174] NAS-NRC (2006), 244.

dose, and *a* and *b* are parameters selected to fit the dose-response curve to the data.[175] The actual relationships developed by cancer researchers are more complicated and include terms to adjust the result for the subject's age at exposure and the years elapsed since exposure, both of which have been found to affect the likelihood of leukemia.[176]

The linear-quadratic model for excess risk of leukemia presented in BEIR VII included no threshold dose but predicts lower risks of leukemia for low level radiation exposures compared to a linear model. Figure 3-2 below reproduces a summary graph from BEIR VII that presented the excess cancer risk as a function of radiation dose among the survivors of the atomic bombings of Hiroshima and Nagasaki.[177] The "excess relative risk" plotted on this figure indicates the fractional increase in cancer incidence expected to result as a function of radiation exposure. This term is calculated as the ratio between the expected increase in cancer risk due to a given radiation exposure and the baseline cancer risk with no radiation exposure (e.g., if radiation were expected to cause 10 additional cancers among a population that would otherwise have had 100 cancers, the excess relative risk would be 0.1).

The representation of the dose-response relationship for leukemia in Figure 3-2 is an interesting example of how scientific discourse can obfuscate while appearing to inform. Even though the figure includes graphs for both leukemia and solid cancers, it only shows cancer data for solid cancers. In fact, nowhere in the 406-page BEIR VII report can there be found a figure plotting leukemia data together with the BEIR committee's preferred linear quadratic model. Furthermore, the scale of the inset for leukemia is not simply smaller than the larger graph of solid cancer data—it is severely compressed in the vertical dimension, drastically understating the increase in relative cancer risk compared to the corresponding increase in relative risk for solid cancers. It is not clear whether this was done for aesthetic reasons or to downplay the increase in the risk of leukemia. It is possible that the authors sought to emphasize solid cancers, because the absolute number of additional solid cancers predicted for a given radiation exposure is much larger than the corresponding increase in leukemia cases. For example, for a population of 100,000 people exposed to 0.1 Gy, BEIR VII's preferred models predicted 61 additional leukemia cases but 510 additional solid cancers.[178]

[175] Adapted from Larry Bodgi, Aurelien Canet, Laurent Pujo-Menjouet, Annick Lesne, Jean-Marc Victor, and Nicolas Foray, "Mathematical models of radiation action on living cells: From the target theory to the modern approaches. A historical and critical review," *Journal of Theoretical Biology* 394 (2016), 93-101.
[176] NAS-NRC (2006), 308.
[177] NAS-NRC (2006), 16.
[178] NAS-NRC (2006), 282.

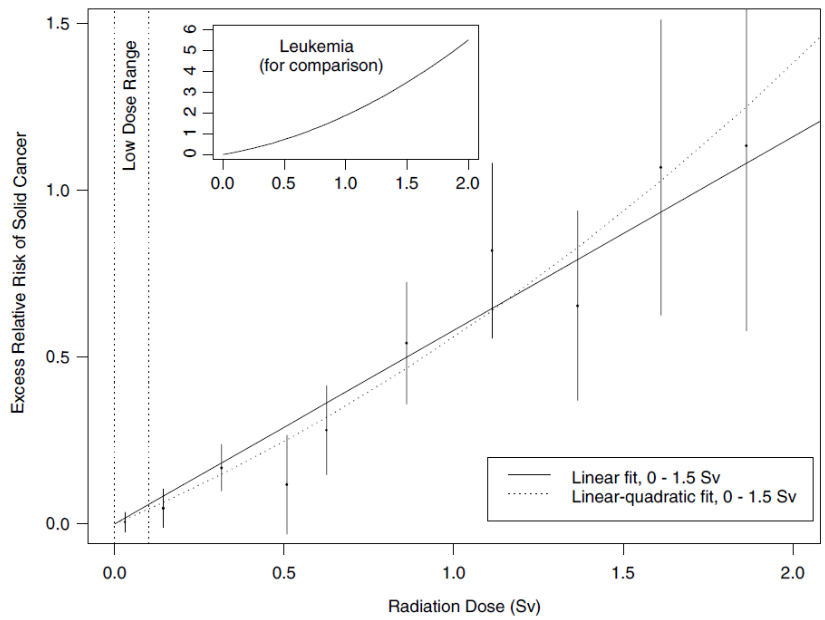

Figure 3-2 Cancer Risk vs. Radiation Exposure[179]

3.3.5.2 Solid Tumor Cancers

Solid tumor cancers include carcinomas (cancers of epithelial cells) and sarcomas (cancers of connective tissues or muscle cells).[180] Links between radiation exposure and solid tumor cancers emerged from studies of radium watch dial painters in the United States and the survivors of the World War II atomic bombings in Japan. As was the case for leukemia, the decades-long Life Span Study of the atomic bomb survivors provides the principal support for the uncontested portions of the dose-response relationship for the induction of solid tumor cancers from exposure to ionizing radiation. Numerous studies of other exposed populations have added to the dataset supporting the prevailing model.

Poorly controlled use of radium (an alpha-emitter) as a miracle drug during the early 1900s led to recognition of the deterministic hazards of ingesting radium in the late 1920s and early 1930s.[181] In 1931, the Essex County, New Jersey, medical examiner published a report linking radiation exposure from ingested radium not only to a host of deterministic malignancies (including anemia and necrosis of the jaw) but also to fatal and not-yet fatal bone cancer in workers who had painted watch and clock dials with radium-bearing luminescent paint at a factory in New Jersey during 1917-1924.[182] Autopsies found considerable radioactivity in the bones of workers who had suffered from cancer.[183] His report further speculated that lung cancers suffered by workers in cobalt and pitchblende (uranium ore) mines may have resulted from inhalation of radioactive dust or "emanation" (radioactive gas, likely radon).[184] In his

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[179] NAS-NRC (2006), 16.
[180] Reynolds and Schecker, 74.
[181] William Moss and Roger Eckhardt, "The Human Plutonium Injection Experiments," *Los Alamos Science* 23 (1995), 225-232.; Walker, 4-5.
[182] Martland, 2435-2516.
[183] Martland, 2450-2451.
[184] Martland, 2505.

conclusions, he noted that available technology could only measure relatively large body burdens of radioactive substances and that "a great deal less might produce malignant changes over a longer period of time."[185] Studies of the surviving radium watch dial painters continued into the 1950s and found that cancers typically appeared 12-23 years after radium ingestion, with radium body burdens considerably smaller than the amounts needed for deterministic malignancies.[186]

Following World War II, the follow-up studies on the health of the survivors of the atomic bombings in Japan established a link between radiation exposure and solid tumor cancers. The first such linkage was for thyroid cancers.[187] These initial studies were hamstrung by the lack of high-quality dose estimates for the bomb survivors and the long latency of solid cancers.[188] Interestingly, the journal article cited as first associating thyroid cancer with radiation exposure from the atomic bombings also evaluated evidence that medical treatments involving ionizing radiation had caused thyroid cancer.[189] Concern over the safety of medical exposures to radiation is a recurring theme in literature on the regulation of radiation safety, and it has engendered reactionary resistance from elements of the radio-medicine community to regulatory limits based on the linear no-threshold model.[190]

The 1960 BEAR report issued by the National Academy of Sciences considered a wide variety of historic radiation exposures, including information on the atomic bomb survivors, but did not offer much insight into the dose-effect relationship for solid tumor cancers. It stated, "There has been much discussion about a possible proportionality between radiation dose and tumor incidence, and also about the existence of a threshold for tumor production. Definitive experimental evidence is lacking, and the Committee does not consider it justifiable to predict human tumor incidence at low doses from the incidences observed after high doses."[191]

Continued epidemiological studies eventually confirmed a linear relationship between high ionizing radiation doses and the risk of solid tumor cancers. The data include a variety of cancers for males and females of all ages, including people who survived *in utero* radiation exposure. The team preparing BIER VII (as well as predecessor reports) also considered a wide variety of laboratory studies involving animals and studies of the response of human tissues to radiation at the cellular and DNA levels. They concluded that the dose-response for the risk of solid tumor cancers from ionizing radiation exposure was best represented by a linear relationship with no threshold, i.e., that any radiation exposure carried with it a risk of cancer,

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[185] Martland, 2513.
[186] Moss and Eckhardt, 229.
[187] Wakeford, 6409.
[188] Dorothy R. Hollingsworth, Howard B. Hamilton, Hideya Tamagaki, and Gilbert W. Beebe, "Thyroid Disease: A Study in Hiroshima, Japan," *Medicine* 42:1 (1963), 47-71.
[189] Hollingsworth *et al*, 47-71.
[190] U.S. Nuclear Regulatory Commission, "Linear No-Threshold Model and Standards for Protection Against Radiation," *Federal Register* 80:120 (June 23, 2015), 35870-35872.; Mervyn D. Cohen, "ALARA, Image Gently and CT-induced cancer," *Pediatric Radiology* 45 (2015), 465-470.; John J. Cardarelli and Brant A. Ulsh, "It Is Time to Move Beyond the Linear No-Threshold Theory for Low-Dose Radiation Protection," *Dose-Response* (July-September 2018), 11.; Steve Rayner, "Management of Radiation Hazards in Hospitals: Plural Rationalities in a Single Institution," *Social Studies of Science* 16:4 (November 1986), 573-591.; NAS-NRC (2006), 17, 172-173.
[191] NAS-NRC, BEAR *Report to the Public* (1960), 6.

and that the risk was directly proportional to the magnitude of the exposure.[192] The BIER VII report cautioned, however, that for doses judged to be in the "low dose" regime of 0-100 mSv, "statistical limitations make it difficult to evaluate cancer risk in humans."[193] In other words, the authors considered the proposed dose-response model to be valid for the low dose regime based on theoretical considerations and the preponderance of tangible evidence, but epidemiological studies have not provided statistically sound support for the model for exposures below 100 mSv. The contested portion of the dose-response model, and the factors that provide opportunities to contest the model, are discussed later in this section.

BEIR VII included an additional complication regarding the linearity of the dose-response model for solid cancers: a term known as Dose and Dose-Rate Effectiveness Factor (DDREF). This term was introduced in fine print in the caption of a figure in the "Public Summary" section of the front matter. The caption indicates that DDREF is a "multiplicative adjustment that results in a downward estimation of risk" in the low dose regime.[194] The body of the report stated that DDREF was intended to reflect the expectation that chronic and small doses of radiation are less effective in causing cancer than the single acute dose upon which the bomb survivor correlations were based.[195] The report cited precedent for this from the International Commission on Radiological Protection, the National Council on Radiation Protection and Measurements, the Environmental Protection Agency, the National Institutes of Health, and the United Nations Scientific Committee on the Effects of Atomic Radiation.[196] The BEIR VII dose-response model used a DDREF of 1.5 to reduce estimates of solid cancer rates for low level radiation exposure.[197] BEIR VII did not similarly adjust leukemia rates, on the basis that the linear quadratic model inherently makes an equivalent reduction in dose response for small doses. BEIR VII listed use of the DDREF as one of two "important sources of uncertainty" in applying data from the Life Span Study (the other important source of uncertainty listed was using risk estimates based on the Japanese population to formulate risk estimates for the American population).[198]

3.3.6 Birth Defects and Other Fetal Impacts

Studies on the atomic bomb survivors included over 3600 people exposed *in utero* to radiation from the nuclear explosions.[199] Studies have also evaluated the effects of prenatal exposure to ionizing radiation from medical procedures and among the offspring of female workers at the Mayak Production Association and female residents of Techa River villages.[200] Deterministic effects at higher radiation exposures (0.15 Gy and above, with a threshold that generally increases as the embryo/fetus develops) include malformations, mental retardation/impaired mental development, microcephaly, growth retardation, and miscarriage or

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[192] NAS-NRC (2006), 7.
[193] NAS-NRC (2006), 7.
[194] NAS-NRC (2006), 7.
[195] NAS-NRC (2006), 246.
[196] NAS-NRC (2006), 247.
[197] NAS-NRC (2006), 15.
[198] NAS-NRC (2006), 15.
[199] Ozasa, Grant, and Kodama, 164.
[200] NCRP (2018), 107.

stillbirth.[201] The studies found stochastic effects for smaller radiation exposures in which children exposed *in utero* had an elevated risk of developing leukemia or solid tumor cancers later in life. NCRP's guidance asserts that such risks have only been demonstrated for exposures greater than 0.5 Gy, and that any effects for exposures below 0.1 Gy are controversial.[202] The National Research Council's BEIR VII report acknowledges the controversy cited by the NCRP but concludes that excess cancers have been detected for *in utero* doses as small as 10-20 mGy.[203] The cancer risk for such exposures is considered to increase linearly with the size of the exposure.[204]

3.3.7 Life Shortening

Life shortening is not often highlighted in modern debate regarding radiation's health effects, but it was suggested early in the nuclear age and continues to be an object of some research. The original 1956 edition of the National Academy of Sciences' BEAR report noted that shortening of life had been observed in humans that roughly correlated with the magnitude of the radiation dose but not at low doses.[205] That report illustrated the phenomenon by noting that the average lifespan for radiologists was several years shorter than other occupations and the general population. The National Academy of Sciences' 1960 BEAR Report further addressed human life shortening as a potential consequence of radiation exposure based on experiments with animals. The 1960 BEAR Report postulated that "substantial doses of whole-body radiation" would be expected to produce a life shortening effect but stated that it had not been observed in humans subjected to small doses of radiation.[206]

More recent work has considered life shortening phenomena based on longer observation of populations exposed to radiation and more detailed understanding of the biological processes of radiation damage and of aging. In particular, free radicals have been implicated in aging processes, just as they have been identified as a primary means by which ionizing radiation damages tissues.[207] In addition to the shortened life span of radiologists noted in the 1956 BEAR Report, researchers have documented shortened life span for survivors of the atomic bombings in Japan, workers who ingested radium while painting luminescent dial faces, and patients injected with a radioactive thorium compound (Thorotrast) during the 1930s-1950s.[208] Researchers have also documented an increased incidence of cardiovascular disease in radiotherapy patients, radiation workers, and atomic bomb survivors that parallels the increased susceptibility to cardiovascular disease associated with aging.[209] Again, these correlations were definitively observed only for high radiation exposures (on the order of 50 rem or higher). One further factor

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[201] NCRP Report No. 174, *Preconception and Prenatal Radiation Exposure: Health Effects and Protective Guidance* (Bethesda, MD: NCRP, 2013), 3.
[202] NCRP (2013).
[203] NAS-NRC (2006), 6, 10, 172-173.
[204] NAS-NRC (2006), 172-173.
[205] National Academy of Sciences, *The Biological Effects of Atomic Radiation: Summary Reports* (Washington, DC: National Academy of Sciences - National Research Council, 1956), 34-35.
[206] NAS-NRC, BEAR *Report to the Public* (1960), 5.
[207] Richard B. Richardson, "Ionizing radiation and aging: rejuvenating an old idea," *Aging* 1:11 (November 2009), 887-902.
[208] Richardson, 889.
[209] Richardson, 889.; NAS-NRC (2006), 13.

that needs to be considered in statistical treatments of life span shortening is that shortened life spans from radiation exposure are often the result of radiation-induced cancer, which should not be confounded with the acceleration of other aging processes by radiation.

3.3.8 Heritable Genetic Damage

Concern over the potential for heritable genetic damage—mutations that would be passed down from irradiated people to their descendants—has not been substantiated for humans in any definitive manner. The original BEAR report of 1956 included a lengthy discussion by geneticists on the potential for accumulation of mutated chromosomes over generations of a population exposed to ionizing radiation. The report essentially concluded that radiation exposures should be minimized to protect the integrity of the gene pool.[210] The 1960 update of the BEAR report cited animal experiments that indicated the concern might be reduced compared with the statements in the 1956 report, but it continued to recommend further study and that the accumulated radiation exposure of the population young enough to participate in reproduction should be minimized.[211] More recent guidance (e.g., the BEIR VII report) based on long-term epidemiological studies of irradiated populations (primarily the Life Span Study of atomic bomb survivors) states that there is no evidence that radiation exposure has produced heritable mutations in humans.[212] The BEIR VII report supports this observation with the concept of the "doubling dose." Based on studies of spontaneous mutation rates in humans (i.e., naturally occurring genetic diseases) and radiation-induced mutation rates in animal studies, the BEIR VII report estimates that an accumulated exposure of 1 Gy per person would be needed to produce a radiation-induced mutation rate equal to the spontaneous mutation rate in a human population.[213]

3.4 The Arena of Contestation – Regulation of Ionizing Radiation at Low Doses

The discussion above shows that there is firm evidence of negative health consequences for radiation exposures on the order of 1 Gy or higher. The prevailing dose-response models accepted for decades by authoritative entities such as the U.S. National Research Council rely on epidemiological studies to define the relationship between dose and response—linear for solid tumor cancers and linear-quadratic for leukemia. Based on the observed data and the underlying theory for how radiation exposures lead to cancer, the prevailing models do not recognize any threshold below which there would be no added risk of cancer; nor do they recognize any potential for a beneficial effect of low doses of ionizing radiation ("radiation hormesis").[214]

Because of the high background rate of cancer, epidemiological studies have not been able to statistically quantify this dose-response relationship for low-level radiation exposures,

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[210] NAS-NRC, BEAR *Summary Reports* (1956), 11-30.
[211] NAS-NRC, BEAR *Report to the Public* (1960), 3-5.
[212] NAS-NRC (2006), 6-9.
[213] NAS-NRC (2006), 6-9.
[214] NAS-NRC (1990), 4.; NAS-NRC (2006), 6.; National Academy of Sciences – National Research Council, *Report of the Advisory Committee on the Biological Effects of Ionizing Radiations* (Washington, DC: National Academy of Sciences – National Research Council, November 1972), 1-3.

i.e., 100 mSv or less.[215] Furthermore, at lower exposure levels, factors come into play that complicate the dose-response relationship. Cellular repair mechanisms become relevant for lower doses, as do the variability in the radiation sensitivity of different organs and tissues, variability in the sensitivity of cells in different stages of the cellular lifecycle, variability in dose response for acute versus chronic exposures, and lifestyle factors (notably smoking). Additionally, the naturally occurring background radiation itself varies as a function of altitude and at different locations on the Earth's surface (typically ranging from 1-10 mSv/year), further complicating efforts to discern an effect of small exposures to artificial sources of radiation.[216]

Socially significant controversy has resulted when the models for radiation dose response have been applied by regulatory authorities setting limits on radiation exposure and release of radioactive materials and by social groups using them to critique national policy on nuclear weapons, nuclear power, and other activities involving radiation exposure. In the United States, regulations are based on recommendations published by the NCRP. The NCRP periodically updates its recommendations based on the latest scientific developments on dose response. The latest NCRP recommendations have not yet been implemented in regulation, but they are refinements of prior recommendations that remain consistent with the current regulatory approach.[217]

The NCRP includes the basis for each of its recommended limits for radiation exposure. Its most recent guidance indicates that numerous limits are based on stochastic effects. These include whole body occupational exposures, whole body exposures to members of the public, and occupational exposures to the embryo/fetus of a pregnant worker. Other limits are based on "tissue reactions" (deterministic effects). These include exposures to the skin and extremities and to the lens of the eye.[218]

Regulatory limits based on the NCRP guidance are imposed by the Nuclear Regulatory Commission, the Environmental Protection Agency, and (for certain federal facilities) the Department of Energy. Pertinent limits from the NRC's regulation are listed below:[219]

- Occupational exposure
  - Whole body total effective dose equivalent of 0.05 Sv annually
  - Skin and extremities shallow-dose equivalent of 0.5 Sv annually
  - Lens of eye dose equivalent of 0.15 Sv annually
  - Fetus/embryo dose equivalent of 0.005 Sv for the duration of the pregnancy
- Members of the public
  - Whole body total effective dose equivalent of 0.001 Sv annually

[215] NAS-NRC (2006), 7.
[216] NAS-NRC (2006), 30.
[217] NCRP Report No. 180, *Management of Exposure to Ionizing Radiation: Radiation Protection Guidance for the United States (2018)* (Bethesda, MD: NCRP, December 31, 2018).
[218] NCRP (2018), 5-6.
[219] *Standards for Protection Against Radiation*, 10 C.F.R. § 20 (September 30, 2015).

- Dose rate in any unrestricted area cannot exceed 0.02 mSv per hour

In addition, the NRC requires that all radiation exposures be maintained as low as reasonably achievable: "The licensee shall use, to the extent practical, procedures and engineering controls based upon sound radiation protection principles to achieve occupational doses and doses to members of the public that are as low as is reasonably achievable (ALARA)."[220] The ALARA principle is pervasive in implementation of radiation protection in the United States and is the topic of a later section of this dissertation.

EPA's regulations are expressed in terms of limits on the allowable radiation levels and concentrations of radioisotopes in drinking water and in airborne emissions via the Clean Air Act and the Safe Drinking Water Act. Similar to NRC's limits, the EPA limits have their basis in prevention of stochastic effects (cancer) among members of the public.[221]

The limits aimed at preventing stochastic effects, as well as the ALARA principle itself, have their roots in the low dose portion of the dose-response relationship. As a result, they have been an arena for contestation for decades. Nonetheless, these limits were adopted and have prevailed more or less unchanged for decades.

The theoretical framework elaborated in Chapter 2 above charts the course that the remaining chapters will follow in elucidating how and why American society arrived at this outcome. Chapter 4 applies actor-network theory to identify the actors involved in the science and regulation of the human health effects of radiation. It identifies the actors of interest by taking inventory of the participants in a variety of forums that attracted actors engaged in debate over the linear no-threshold dose-response model, including petitions for rulemaking by the U.S. Nuclear Regulatory Commission, hearings held by the Joint Committee on Atomic Energy of the U.S. Congress, and several landmark court cases.

[220] 10 C.F.R. § 20.

[221] U.S. Environmental Protection Agency, *EPA 402-B-00-001, Radiation Protection at EPA: The First 30 Years* (Washington, DC: EPA, August 2000).

4 Identification of Actors

4.1 Identifying the Actors

Latour takes a broad view of the people, organizations, artifacts, and phenomena that should be considered in the actor-network. He describes the need to cast a wide net and not prejudge which actors will be important in the network.[222] In order to compile such a comprehensive list, I heeded Latour's advice to follow the actors and observe their interactions. In the spirit of a naturalist who stakes out an oasis to study the creatures that come to drink, I conducted a broad literature survey to identify venues and forums dealing with regulation of radiation health and catalogued the various actors drawn to the debates, as well as others cited by those actors.

The literature shows that conferences, workshops, public hearings, court cases, and rulemakings pertaining to the science and regulation of radiation health and safety draw a broad range of actors ranging from individual concerned citizens to major scientific, academic, and governmental institutions. The records of these interactions provide a wealth of insight into the process of *making discourses* as American society sought to accommodate nuclear weapons, nuclear energy, and technological applications of radiation into its social order, while at the same time shaping those technologies to conform with American ideals. Moreover, analysis of the discourse in these interactions will show that "American ideals" varied among social groups and institutions organized around differing sociotechnical imaginaries, with the push and pull among the groups settling the approach to regulation even as the underlying science remained unsettled.

Three notable magnets attracting actors engaged in the LNT debate were petitions for rulemaking by the U.S. Nuclear Regulatory Commission, hearings held by the Joint Committee on Atomic Energy of the U.S. Congress, and a few landmark court cases:

Petitions for Rulemaking

In February 2015, the U.S. Nuclear Regulatory Commission received three petitions for rulemaking urging the agency to abandon the linear no-threshold dose-response model as the basis for regulation of radiation exposures for radiation workers and members of the public.[223] The U.S. NRC has not rendered any decisions regarding the petitions. These petitions were the inspiration for this dissertation; the petitions and the 640 public comments posted on the Regulations.gov website revealed a wide range of actors engaged in contemporary debate over the linear no-threshold model.[224] This round-up of the current participants in this debate provided an excellent starting point for tracing the actor-network back to the origins of the linear no-threshold model and its application in regulating radiation safety. Actors appearing in the petitions and comments include federal agencies, scientific institutions, advocacy groups, industry groups, academics, scientists, professional societies, and many others commenting as

[222] Latour (1987), 175, 258.
[223] U.S. NRC (2015).
[224] Regulations.gov Rulemaking Docket, *Linear No-Threshold Model and Standards for Protection Against Radiation*, Docket ID: NRC-2015-0057, https://www.regulations.gov/docket?D=NRC-2015-0057 (accessed March 1, 2020).

unaffiliated citizens. Representative members of each category of actors with an identifiable affiliation are summarized below:

Federal Agencies:
- U.S. NRC (target of the petitions)
- U.S. Environmental Protection Agency

State, Local, and Tribal Groups:
- Ute Mountain Ute Tribe
- National Tribal Air Association
- Arkansas Department of Health

Research Institutions:
- National Cancer Institute
- Mercatus Center at George Mason University

Nuclear Businesses and Industry Groups:
- National Mining Association
- EnergySolutions
- U.S. Chamber of Commerce
- Kennecott Uranium Company
- Radioactive Waste Management Associates
- American Chemistry Council
- Wyoming Mining Association

Professional Societies:
- Health Physics Society
- American Society for Radiation Oncology
- American Association of Physicists in Medicine

Academics:
- Professor of Radiation Oncology, Molecular and Medical Pharmacology, and Radiological Sciences at the University of California-Los Angeles School of Medicine (one of the petitioners)
- Professor (associate), University College Roosevelt, Middelburg, The Netherlands
- Professor of Human Toxicology, Maastricht University, The Netherlands
- Professor of Governance of Safety, Radboud University Nijmegen, The Netherlands
- Professor of Toxicology, University of Massachusetts, Amherst
- Fellow of the College of Public and International Affairs, University of Bridgeport, Connecticut
- Professor, Department of Biophysics, State University of New York, Buffalo
- Emeritus Professor of Physics, University of Oxford, United Kingdom
- Professor of Radiologic Physics
- Professor of Health Physics
- Professor of Biological Engineering, Massachusetts Institute of Technology
- Professor, The Scripps Research Institute

Professor, Department of Physics, Northern Kentucky University

Individual Scientists, Engineers, and Medical Professionals:

Certified health physicists (including one of the petitioners)
Nuclear medicine practitioner
"Geologist, environmental scientist, radiation safety officer, alpha/gamma spectroscopist, and commercial spacecraft radiation shielding design specialist"
Pediatrician
Engineers, including nuclear and materials engineers
Physicists, including nuclear and medical physicists
Pathologist
Registered nurse

Advocacy Groups:

Scientists for Accurate Radiation Information (one of the petitioners)
European Committee on Radiation Risk
Nukewatch
Citizen Action New Mexico
Natural Resources Defense Council
Committee to Bridge the Gap
Beyond Nuclear
Great Lakes Environmental Alliance of St. Clair County, Michigan
The Alliance for a Clean Environment
Catholic Charities of Gallup Diocese
Union of Concerned Scientists
Southern California Federation of Scientists
Sierra Club Nuclear Free Campaign
Nuclear Information and Resource Service
Food and Water Watch
Black Hills Chapter, Dakota Rural Action
Support and Education for Radiation Victims
The Ecological Options Network
Radiation Free Lakeland
Citizens for Alternatives to Chemical Contamination
Pilgrim Watch
Physicians for Social Responsibility
San Luis Obispo Mothers for Peace
Citizen Power
Nuclear Information and Resource Service, Southeast
Institute for Energy and Environmental Research
Teens Organized Against Deceitful Scientists
Greenpeace
Cape Downwinders and MA Downwinders
Great Rivers Environmental Law Center

In addition to the actors directly participating in commentary on the petitions, numerous other actors were cited as sources for compelling information related to regulation based on the linear no-threshold model. Prime among these were the U.S. National Academy of Sciences, the National Council on Radiation Protection and Measurements, the International Commission on Radiological Protection, the United Nations Scientific Committee on the Effects of Atomic Radiation, and the French Academy of Sciences. Individuals cited numerous times included Dr. John W. Gofman, Dr. Arthur Tamplin, Dr. Karl Z. Morgan, Dr. Edward J. Calabrese (who also submitted extensive commentary on the petitions), Dr. Richard R. Monson, Dr. Helen Caldicott, Dr. David Brenner, T.D. Luckey, and Dr. Alice Stewart.

The petitioners in the rulemaking also highlighted an artifact as an important actor in the regulation of radiation safety: the As Low As Reasonably Achievable (ALARA) principle (an approach for managing human radiation exposures ingrained throughout the nuclear industry and required in regulations).[225] Two of the three petitioners requested that the NRC remove ALARA from its safety regulations. Consistent with Latour's development of actor-network theory, the work performed by the ALARA principle needs to be considered symmetrically with the activities of the human actors and their institutions.

Viewed through the lens of Jasanoff's concept of imaginaries, ALARA can be evaluated as an ordering instrument for sociotechnical imaginaries that value environmental protection, because they may view any amount of artificial radiation exposure as dangerous. Counterintuitively, ALARA can also be viewed as an ordering instrument for sociotechnical imaginaries that prize scientific expertise and trust in experts, because deciding how much dose reduction is "reasonable" falls into the domain of expert judgment. These potential interpretations will be evaluated in the analysis of the development and institutionalization of ALARA.

Hearings of the Joint Committee on Atomic Energy of the U.S. Congress

The Atomic Energy Act of 1946 established the Joint Committee on Atomic Energy to preside over all bills, resolutions, and other matters relating to atomic energy and atomic weapons; the JCAE wielded this authority until Congress dissolved it and redistributed its functions to seven separate committees and subcommittees in 1977.[226] Numerous sources describe the JCAE as a uniquely influential actor in the promotion of nuclear technologies and in debates over the possible consequences of radiation exposures. Creation of the JCAE embodied the ordering instrument of *making institutions* in shaping the social order to accommodate nuclear technologies and to provide society with an instrument for directing the development and deployment of those technologies.

Like the petitions for rulemaking, hearings held by the JCAE attracted the actors engaged in debate over the linear no-threshold model and radiation safety. For example, the JCAE's 1957 hearing on fallout from atomic weapon testing included testimony (written or in-person) from about 50 expert witnesses, including representatives of the Atomic Energy Commission and its laboratories, university scientists, the Department of Defense, experts from other government

[225] *Occupational Radiation Protection*, 10 C.F.R. § 835 (2011).
[226] Stephen A. Atkins, *Historical Encyclopedia of Atomic Energy* (Westport, CT: Greenwood Press, 2000), 187-188.

agencies including the U.S. Weather Bureau, the RAND Corporation (a prominent think tank), medical professionals, and the National Council on Radiation Protection and Measurements, in order to represent "varied points of view within the scientific community."[227]

Court Cases

Jasanoff specifically recommended examining legal disputes to reveal how people and institutions react when "contestation between disparate understandings of the good" threatens to disturb order and to study judges' rulings that often reflect the dominant imaginaries.[228] Several landmark court cases in the 1970s and 1980s involving citizens suing the federal government or their employer for damages resulting from claimed health effects of radiation exposures—*Allen v. United States*[229], *Johnston v. United States*[230], and the famous case of *Silkwood v. Kerr-McGee*[231]—drew a host of actors relevant to radiation safety debates, including individuals whose names were prominent in the petitions for rulemaking and JCAE hearing detailed above.[232] Most importantly, the court cases highlighted a category of actor not represented in the previous examples: people exposed to radiation. *Allen v. United States* consolidated the individual claims of 1192 plaintiffs claiming injury from radioactive fallout from atmospheric testing of nuclear weapons in the United States, and *Johnston v. United States* consolidated cases of four employees of a government contractor who claimed their cancers resulted from occupational radiation exposures. *Silkwood v. Kerr-McGee* concerned plutonium exposure of a government contractor employee who died in an automobile accident on her way to meet with a news reporter.[233] Actors featured in these court cases included:

<u>Plaintiffs (the Exposed Individuals)</u>
- Radiation workers
- Members of the public

<u>Defendants</u>
- U.S. Government / Atomic Energy Commission
- Aircraft Instrument and Development, Inc.
- Kerr-McGee Corporation

<u>Principals in the Judicial System</u>
- Judges
- Attorneys

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[227] Joint Committee on Atomic Energy, *The Nature of Radioactive Fallout and its Effects on Man* (Washington, DC: U.S. Government Printing Office, 1957), v-vii, 1.
[228] Jasanoff (2015), 19.
[229] *Allen* v. *United States*, 588 F. Supp. 247 (D. Utah 1984), rev'd, 816 F.2d 1417 (10th Cir. 1987).
[230] *Johnston* v. *United States*, 597 F. Supp. 377 (D.C. Kan. 1984).
[231] *Silkwood v. Kerr-McGee,* 485 F. Supp. W. D. Okla. 566 (1979), aff'd in part, rev'd in part, 667 F.2d 908 (10th Cir.), verdict restored, 464 U.S. 238 (1984).
[232] Ralph E. Lapp, "The Fallout Controversy," in Kenneth R. Foster, David E. Bernstein, and Peter W. Huber, eds., *Phantom Risk: Scientific Inference and the Law* (Cambridge, MA: The MIT Press, 1999), 200-307.
[233] Bernard L. Cohen, "The Saga of Fernald," in Kenneth R. Foster, David E. Bernstein, and Peter W. Huber, eds., *Phantom Risk: Scientific Inference and the Law* (Cambridge, MA: The MIT Press, 1999), 351.

Expert Witnesses for the Plaintiffs (not an exhaustive list)

Dr. John W. Gofman, then a former Lawrence Livermore Laboratory scientist and professor at University of California, Berkeley

Dr. Karl Z. Morgan, then a former Oak Ridge scientist and professor at Georgia Tech

Dr. Arthur Tamplin, then a former Lawrence Livermore Laboratory scientist

Dr. Harold A. Knapp, then a former Atomic Energy Commission scientist

Expert Witnesses for the Defense (not an exhaustive list)

Dr. Lauriston Taylor, founder and long-serving president of the National Council on Radiation Protection and Measurements

Dr. Jacob Fabrikant, professor of radiology and scientist at Lawrence Berkeley Laboratory

Dr. John Auxier, Oak Ridge scientist

These actor magnets provided a superb starting point for delving into the historical and technical literature to map out the actors involved in the development and stabilization of the linear no-threshold model as the basis for regulating radiation safety. The sheer number of actors involved across the decades of interest precludes tracing the activities of each of them. To make this into a manageable but still meaningful research effort, I binned the actors into the groups described below for analysis. These actors do not always fit neatly within any single category. Examples of actors whose broader roles and potentially conflicted interests are likely to have played an important role in the development of the scientific understanding and regulation of radiation's health effects are highlighted in the discussion below.

Research Institutions and Scientists

Laboratories, academic institutions, other scientific institutions, and categories of scientists involved in developing nuclear technologies and studying the health effects of radiation exposures constitute an actor without which regulation of radiation safety would not exist. These actors developed the technologies that then needed to be regulated in the interest of safety of researchers, industry workers, and the public. They also pioneered the scientific research that underpins the models developed to describe the relationship between dose and effect for radiation. Such researchers investigated the health effects of radiation and proposed models that they favored, but other actors also have taken the results of the researchers' work to advocate for dose-effect relationships that they preferred to advance. Actors in the researchers' category include the following:

- America's national laboratories (Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Argonne National Laboratory, etc.). These institutions developed and promoted applications of nuclear technologies but also performed fundamental research into the health effects of radiation exposure.
- The National Institutes of Health, the National Academy of Sciences, and the National Research Council. These federally chartered institutions supported a broad range of research into nuclear technologies and the health effects of radiation exposure. They have also been responsible for distilling available knowledge into definitive reports on radiation health effects that have served as the scientific basis for

regulations. These began with the initial Biological Effects of Atomic Radiation (BEAR) report in 1956 and continued on as a series of reports on the Biological Effects of Ionizing Radiation (most recently BEIR VII, Phase 2, published in 2006).[234]

- Universities engaged in nuclear research (e.g., University of California, Massachusetts Institute of Technology). Similar to national laboratories, research universities developed and promoted applications of nuclear technologies and also performed fundamental research into the health effects of radiation exposure.
- Professional societies and specific categories of scientists (e.g., geneticists, biologists, physicists, health physicists, medical practitioners). Societies such as the American Medical Association, the Health Physics Society, the American Nuclear Society (ANS), and the American Association for the Advancement of Science serve various advocacy and educational purposes and, in some cases (notably the ANS), maintain standards relevant to radiation safety. Review of literature suggests that there may be meaningful differences in opinion among different branches of science when it comes to the health effects of radiation. For example, the geneticists' chapter of the 1956 BEAR report conveys much greater concern regarding the effects of radiation exposure compared to the portions written by other categories of scientific experts.[235] Unsurprisingly, modern critics of the linear no-threshold model for radiation dose effects specifically target geneticists as the source of disputable information.[236]

Regulatory Institutions and Standards-Setting Bodies

Regulatory institutions and standards-setting bodies developed in parallel with nuclear technologies and scientific research into the dose-response relationship for radiation. As briefly noted above for the creation of the JCAE, *making institutions* is one of the fundamental ordering instruments Jasanoff described as "operating at the nexus of natural and social order" to stabilize "what we know and how we know it."[237] As will be shown in the analysis of the actor-network, these institutions engaged in *making representations* about radiation, developing units of measure and exposure standards that gave radiation a place in society and established it as a tool that could be safety wielded in the name of progress. These standards represented radiation as known and controllable, even though its biological effects were poorly understood and permissible exposures were steadily reduced as the decades passed, as will be detailed in the analysis of the actor-network.

These institutions engaged in *making identities* such as nuclear engineers and nuclear weapon designers to turn nuclear physics into engineered products. Moreover, they also created the identity of "health physicist" during the wartime secrecy of the Manhattan Project. This deliberately vague term defined the cadre of informed specialists who protected rank and file

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[234] NAS-NRC (1956), BEAR *Summary Reports*.; NAS-NRC (2006).

[235] NAS-NRC (1956), BEAR *Summary Reports.*

[236] Edward J. Calabrese, "The Mistaken Birth and Adoption of LNT: An Abridged Version," *Dose-Response: An International Journal* (October-December 2017), 1-3.; P. C. Kesavan, "Editorial: Radiation Protection Policies and Practice Rest on a Thin Sheet of Ice called Linear, No-threshold Hypothesis," *Radiation Protection and Environment* 40:2 (April-June 2017), 51-59.

[237] Jasanoff (2006), 39.

workers from the "special hazard" (i.e., radiation) about which the workers were denied knowledge as they produced the nuclear materials for the first atomic bombs.[238] Health physicists remain pervasive in radiation protection in the United States, occupying a unique role in monitoring and control of radiological activities. People embracing these identities tend to likewise embrace the associated technologies and support discourse affirming their safety.

Facilitated by wartime secrecy, which continued into the Cold War, the AEC pursued top-down decision-making without public input until the atmospheric nuclear weapon testing program literally blew their cover, providing peace advocates a powerful line of discourse for contesting America's nuclear weapon activities. In this development, the AEC's activities had further *created identities* as an unwanted by-product, inciting citizens and even some experts who worked for the AEC to become "anti-nuke" actors who would oppose nuclear weapons, oppose nuclear power, and advance scientific arguments for tighter limits on radiation exposure. This new category of actors and social groups powerfully shaped the development, regulation, and deployment of nuclear technologies in the United States. These actors advanced their causes through creative and effective strategies for *making counter representations* of their own about nuclear technologies and radiation, as will be detailed in Chapter 7 of this dissertation. The collision of these conflicting sociotechnical imaginaries—the AEC's vision of a strong America with top-down decision-making and reliance on experts' assurances of safety versus the nongovernmental organizations' and individual activists' vision of America achieving security through disarmament—will play out in the analysis of the actor-network.

As noted in the preceding chapter of this dissertation, standards-setting bodies arose from industry groups before formal regulation by government institutions was established. In the United States, the first such national group was the Advisory Committee on X-Ray and Radium Protection, established in 1929. Over the decades, it evolved into the National Council on Radiation Protection and Measurements.[239] The American Nuclear Society also maintains a series of standards applicable to various aspects of radiation safety.

The Truman administration and Congress established the Atomic Energy Commission after World War II as the initial federal regulator of radiation safety in the United States, but it also had the mission of developing nuclear weapons and promoting nuclear power and other applications of nuclear technologies.[240] This conflicted situation persisted throughout the formative decades of the nuclear industry and regulation of radiation safety. It was partially addressed with the establishment of the Federal Radiation Council in 1959 as an independent but non-regulatory advisory body on radiation safety standards.[241] Truly independent federal regulatory agencies finally emerged in the late 1960s and 1970s: Congress assigned regulatory functions regarding radiation emissions from electronic products to the Food and Drug Administration in 1968.[242] The Nixon administration established the Environmental Protection

[238] Barton C. Hacker, *The Dragon's Tail: Radiation Safety in the Manhattan Project, 1942-1946* (Berkeley: University of California Press, 1987), 31, 54.

[239] Cynthia Gillian Jones, "A Review of the U.S. Radiation Protection Regulations, Recommendations, and Standards," *Health Physics* 88:2 (February 2005), 106-107.

[240] Jones, 107-108.

[241] Jones, 110-111.

[242] Jones, 111-112.

Agency in 1970, assigning to it the functions of the Federal Radiation Council and the authority to establish environmental standards for radioactive materials.[243] Finally, in 1974, the Nixon administration and Congress abolished the Atomic Energy Commission, replacing it with a true regulator for commercial nuclear activities (the Nuclear Regulatory Commission) accompanied by a self-regulating entity to operate federal nuclear facilities (the Energy Research and Development Administration, subsequently reconstituted as the Department of Energy in 1977).[244] All these organizations have had powerful roles in directing research related to radiation health effects, establishing and maintaining the regulatory system, and advocating for the official positions on issues related to radiation health effects. In particular, public hearings of the Atomic Energy Commission appear to have provided an important forum for debate over the science and regulation of radiation health effects.

Political Bodies

Congress and the various presidential administrations have taken many actions over the years to shape research and regulation for radiation safety. Key actions, as noted above, include establishing the JCAE and AEC in 1946, establishing the Federal Radiation Council in 1959, establishing the Environmental Protection Agency in 1970 and assigning to it the functions of the Federal Radiation Council, and finally replacing the AEC in 1974 with a true regulator for commercial nuclear activities (the Nuclear Regulatory Commission) and a separate self-regulating entity to operate federal nuclear facilities (originally the Energy Research and Development Administration, now the Department of Energy). As noted above, the literature review identified one political body that played a key role as both a decision-maker and as a forum for debate: Congress' Joint Committee on Atomic Energy. The JCAE's unique role and tremendous power made it a pivotal player in the development of the science of radiation health effects and the regulation of radiation safety.

Citizen Groups and High-Profile Activists

Numerous citizen groups have been prominently involved in the discourse regarding radiation health effects. Examples include the National Committee for a Sane Nuclear Policy, Physicians for Social Responsibility, the Federation of American Scientists, the Union of Concerned Scientists, the Institute for Energy and Environmental Research, the Scientists' Institute for Public Information, the Committee for Nuclear Information/Committee for Environmental Information, the International Dose-Response Society, Scientists for Accurate Radiation Information, and the Center for Public Integrity. These groups take a variety of positions on the science and regulation of radiation safety, in some cases advocating to relax regulation and allow greater radiation exposures of workers and the public (e.g., the International Dose-Response Society and Scientists for Accurate Radiation Information). A number of high-profile individual activists also merit discussion, such as Linus Pauling, John Gofman, Arthur Tamplin, and Karl Morgan. Gofman, Tamplin, and Morgan in particular stand out as examples of "expert dissenters" who began as researchers in nuclear science and technology before

[243] Jones, 112.
[244] Jones, 113.

adopting positions contrary to the immediate interests of the nuclear industry.[245] Conversely, Edward Calabrese is ubiquitous in recent years as a prolific opponent of the prevailing dose-response model and the resulting regulatory scheme.

Users of Nuclear Technologies

Government agencies such as the Department of Defense and corporate and industrial actors such as utilities, the Nuclear Energy Institute, the Institute of Nuclear Power Operations, the Radiology Society of North America, and the Society of Nuclear Medicine & Molecular Imaging have a vested interest in the safety of radiation exposures and how they are regulated. Nuclear medicine providers have a complicated relationship with radiation, because it is the means by which they seek to diagnose and treat their patients, yet at the same time it poses a hazard not just to the patients but also to the doctors, nurses, and other workers in the industry.

Exposed Workers and Members of the Public

Crucial information regarding the understanding of the health effects of radiation exposure comes from the people exposed to it, through monitoring of individuals and epidemiological studies of populations. Moreover, as highlighted in the prominent court cases, exposed workers and members of the public are not simply passive receptors of radiation. They can initiate action to challenge prevailing dose-effect models and regulatory standards, both in the courts and by forming advocacy groups, including workers unions.

Artifacts as Actors

Latour argues at length that artifacts must also be treated as actors in a sociotechnical network, removing the "artificial boundary between social and natural."[246] Two artifacts stand out as potent actors in the regulation of radiation safety: the linear no-threshold model itself and the As Low As Reasonably Achievable principle used to minimize radiation exposures throughout the nuclear industry. The linear no-threshold model is a double-edged sword that can be wielded by both supporters of nuclear technologies and their detractors. On the one hand, it can be cited to support arguments that any radiation exposure is hazardous, and it can be applied to produce calculations predicting significant numbers of cancer fatalities if large populations are exposed to a small amount of radiation. On the other hand, it can be applied to produce calculations showing that any individual's risk of cancer from a small radiation exposure is small. This dual nature makes it a useful ordering instrument for *making representations* about radiation to otherwise conflicting sociotechnical imaginaries (i.e., imaginaries which view radiation as a risk justified by the benefits of nuclear technologies and imaginaries which view the risk as too large or which find no value in nuclear technologies), which may help explain its durability.

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[245] Christian Joppke, *Mobilizing Against Nuclear Industry: A Comparison of Germany and the United States* (Berkeley: University of California Press, 1993), 27-28.

[246] Bruno Latour, "Where are the Missing Masses? The Sociology of a Few Mundane Artifacts," in Deborah G. Johnson and Jameson M. Wetmore, eds., *Technology and Society: Building Our Sociotechnical Future* (Cambridge, MA: The MIT Press, 2009), 150-180.; Latour (2005), 111.

The importance of the ALARA principle is apparent from the fact that the petitioners to the NRC singled it out for abolition in their submittals, and as discussed above, it too has attributes that are attractive to two otherwise conflicting sociotechnical imaginaries. The work that the human actors have delegated to these sociotechnical artifacts will be analyzed in the upcoming chapters along with the actions of people and their institutions.

4.2 Building the Actor-Network

The list above does not include every actor involved in this actor-network, but it does capture the most relevant categories of actors. Even this incomplete list is daunting. The actor-network is further complicated by actors that function as both users/proponents of nuclear technologies and shapers of regulatory policy, particularly entities such as the Atomic Energy Commission, the Joint Committee on Atomic Energy, and the national laboratories.

The subsequent chapters of this dissertation develop the actor-network by surveying the activities of these actors, establishing whether they were active and influential during the formative years of the regulatory system, further binning actors into groups with similar methods and objectives, and then focusing on the subset of actors and actor groups that appear to have played pivotal roles in the actor-network. A binning approach should be feasible and effective, based on review of pertinent literature. For example, social groups that opposed nuclear power and social groups that opposed nuclear weapons typically advocated for dose-response models that predicted greater danger from such technologies. Likewise, social groups that promoted nuclear medicine and social groups that promoted nuclear power typically advocated for dose-response models that predicted little danger for low-level radiation exposures.

Put in terms of Latour's development of actor-network theory, the subsequent chapters of this dissertation will evaluate whether and how these actors problematized the science and regulation of radiation health effects, enrolled supporters, and translated their interests in order to build a stable network of support to institutionalize and circulate a particular scientific model and regulatory approach. Put in terms of Jasanoff's co-production idiom, the resulting narrative will show the parallel development and coalescence of the scientific model for radiation health effects and the regulatory system that both depends on it and supports it, while highlighting the ordering instruments that operate at the nexus of natural and social order to stabilize what we know and how we know it. It will also highlight sociotechnical imaginaries that seem to animate different segments of American society engaged in discourse over nuclear technologies and radiation health effects.

The next five chapters explore the actor-network that developed and institutionalized the scientific basis for regulating exposures to ionizing radiation in the United States. They analyze the origins, motivations, actions, and interactions of prominent actors at key points in the history of radiation safety regulation. In particular, they consider how each actor deployed ordering instruments of co-production to influence other actors and shape the development and regulation of nuclear technologies and radiation safety, and how they were affected by ordering instruments in the hands of other actors. The chapters also evaluate how actors' expressed preferences and actions suggest the nature of the sociotechnical imaginary that motivates their actions. Building the actor-network and tracing the activities of the actors in this manner will illustrate the co-production of the scientific understanding of radiation effects on human health and the regulatory system and industry practices that formed together with it.

The actors I selected for analysis trace a long but narrow path through the history of radiation protection in the United States. I began with the first safety standards for radiation exposure and traced a path through history ending with the institution of ALARA as a regulatory requirement, then skipped ahead to several compelling court cases that involved prominent actors from the earlier discourse on radiation safety. History does not lack for additional actors and interactions that I could have included, particularly actors outside the United States, but the course I charted appears sufficient to elucidate how America arrived at a regulatory system based on the linear no-threshold dose-response model and why it has remained stable for *circa* the past 50 years. The actors to be discussed include the National Council on Radiation Protection and Measurements, America's leading authority on standards for radiation protection (Chapter 5); the federal institutions engaged in the development, application, and regulation of nuclear technologies and radiation from World War II through the early 1970s (Chapter 6); non-governmental actors engaged in public discourse over the health effects of radioactive fallout from nuclear weapon testing (Chapter 7); the actors involved in the public discourse over safety standards for nuclear power stations and the institutionalization of the As Low As Reasonably Achievable principle as a regulatory requirement (Chapter 8); and the plaintiffs, defendants, and judges in several lawsuits regarding claims of health impacts from radiation exposures (Chapter 9).

5 Construction of a Standards-Setting Institution

5.1 Overview

The National Council on Radiation Protection and Measurements (NCRP) has played a central role in the establishment and maintenance of standards for regulating human exposure to ionizing radiation in the United States. As detailed below, NCRP's standards served as an ordering instrument by *making representations* about radiation, conveying the idea that exposures below their officially endorsed limits were safe, even when they were essentially based on anecdotal observations and expert opinion. Moreover, as illustrated in the following analysis, the NCRP has gone beyond simply offering up a scientific consensus for industry and regulators to apply. It has offered guidance on balancing the risks of radiation exposure with the benefits of technologies that result in radiation exposure, particularly in the low-dose regime where risks are not well-characterized. Moreover, its leadership's decades-long campaign of *making discourses* through editorializing in various venues and testimony at administrative and legislative hearings, as well as expert testimony in the courts, has served as boundary work to affirm its position as the authoritative voice on radiation protection in the United States.[247] The NCRP effectively deployed the ordering instrument of *making institutions* to cement itself as the "stable repository of knowledge and power" for radiation safety.[248]

5.2 Advisory Committee on X-Ray and Radium Protection

Much of the history of the NCRP is connected to the activities of one individual, Lauriston S. Taylor, a physicist who played a pivotal role in the establishment of both the NCRP and its predecessor organization and remained a pervasive actor in the field of radiation protection for more than half a century.[249] Taylor represented the U.S. National Bureau of Standards in 1928 at the Second International Congress of Radiology in Stockholm along with representatives from two industry groups: the American Roentgen Ray Society and the Radiological Society of North America.[250] Because of the disunity exhibited by the American contingent, Taylor set out to organize a national committee that could authoritatively represent our nation in dealing with radiation protection issues.[251] After Taylor negotiated with various societies and associations, the Advisory Committee on X-Ray and Radium Protection was established in 1929, with Taylor as chairman. The committee included representatives from the following groups:[252]

- American Roentgen Ray Society

[247] Thomas F. Gieryn, "Boundary-Work and the Demarcation of Science from Non-Science: Strains and Interests in Professional Ideologies of Scientists," *American Sociological Review* 48:6 (December 1983), 781-795.
[248] Jasanoff (2006), 39.
[249] Nelson W. Taylor, Warren K. Sinclair, and Robert O. Gorson, *In Memoriam: Lauriston S. Taylor*, Health Physics Society, http://hps.org/aboutthesociety/people/inmemoriam/LauristonTaylor.html (accessed February 7, 2021).
[250] Lauriston S. Taylor, "Brief History of the National Committee on Radiation Protection and Measurements (NCRP) Covering the Period 1929-1946," *Health Physics* 82:6 (June 2002), 776.
[251] Taylor (2002), 776.
[252] Taylor (2002), 777.

- Radiological Society of North America
- American Medical Association
- X-Ray Equipment Manufacturers
- National Bureau of Standards
- International X-ray and Radium Protection Committee (in the person of Taylor)

The creation of this committee embodied the ordering instrument of *making institutions*, beginning the establishment of social structures and mechanisms to accommodate human interactions with radiation in an orderly fashion. It additionally served as an important element of *making identities* around radiation—America now had an officially sanctioned cadre of radiation safety experts, empowered to *make discourse* that provided authoritative advice on matters radioactive. As discussed below, the committee promptly began to engage in *making representations* about radiation, issuing standards that society accepted as showing that technologies involving radiation could be safely exploited for the betterment of humankind.

The committee issued its recommendations in the form of handbooks published by the federal agency that employed Taylor, the National Bureau of Standards. (Note that the numbers of the handbooks discussed here are discontinuous because the NBS published handbooks on myriad topics besides radiation safety.) Handbook 20, *X-Ray Protection*, and Handbook 23, *Radium Protection*, adopted in 1936 and 1938, respectively, provided exposure limits that served as the primary guides for work with radiation in the United States through World War II and the Manhattan Project.[253] Handbooks 20 and 23 recommended a daily dose limit of 0.1 roentgen for external exposure to x-rays and radium's gamma radiation emissions. Taylor later estimated that this daily limit corresponded to an annual exposure limit of about 30 rem.[254] By comparison, the U.S. Nuclear Regulatory Commission presently enforces an annual occupational limit of 5 rem whole body exposure in 10 CFR Part 20.[255]

Both of these handbooks reflected the then-prevailing belief that there would be no ill health effects if exposures remained below a threshold dose. The Advisory Committee on X-Ray and Radium Protection relied on surveys, calculations, and exercises of expert judgment to decide that one percent of the dose expected to produce skin erythema represented a safe daily exposure threshold.[256] The committee rounded the resulting value of 0.24 roentgen down to 0.1 roentgen, in Taylor's words, to avoid to "appear to be implying an unreasonable knowledge of the subject."[257] Handbook 20 alerted the reader that the tolerance dose was "provisional" and advised applying generous safety factors.[258] Handbook 23 went further and presaged a message that the NCRP would reiterate numerous times in the future, stating that "The effects on the

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[253] Taylor (2002), 777.; National Bureau of Standards, *National Bureau of Standards HB20: X-Ray Protection* (Washington, DC: U.S. Government Printing Office, 1936).; National Bureau of Standards, *National Bureau of Standards HB23: Radium Protection* (Washington, DC: U.S. Government Printing Office, 1938).
[254] Lauriston S. Taylor, "Radiation Exposure as a Reasonable Calculated Risk," *Health Physics* 1:1 (1958), 65.
[255] 10 C.F.R. § 20.
[256] Catherine Caufield, *Multiple Exposures: Chronicles of the Radiation Age* (New York: Harper & Row, Publishers, 1989), 18-21.
[257] Caufield, 21.
[258] NBS Handbook 20, 10.

human body of continued exposure to low radiation intensities are not well known."[259] This practice of using expert judgment to estimate a threshold dose based on positive and negative outcomes of past exposures and then selecting the safety limit by rounding down to a lower number based on further expert judgment is replicated numerous times in the history of radiation safety standards.

Even though Handbook 23 dealt exclusively with radiation safety for radium, it focused on applications of radium as a gamma ray source and did not provide a limit for ingestion of radium. It only addressed the need to minimize inhalation of radon (a radioactive gas produced by radioactive decay of radium).[260]

The National Bureau of Standards subsequently commissioned a separate committee to develop a handbook applicable to protecting workers who handled radium-bearing paints. This committee included the Essex County medical examiner who had established the link between radium ingestion and myriad adverse health effects, along with a physicist from the Massachusetts Institute of Technology and representatives from several federal agencies and commercial entities. This effort culminated in issuance of Handbook 27, *Safe Handling of Radioactive Luminous Compounds*, in 1941.[261] This handbook repeated the external exposure limit of 0.1 roentgen per day specified in the earlier handbooks and further required limiting the worker's body burden of radium to 0.1 micrograms or less to avoid adverse health effects. The committee established the allowable body burden based on a study of 27 individuals who had ingested radium as watch dial painters or through medical treatments. Individuals with radium body burdens smaller than 0.5 micrograms had no detectable injuries, so the committee decided that a limit of 0.1 micrograms would provide adequate safety margin.[262] (In this case, the leader of the effort challenged his committee to set the limit at "such a level that we would feel perfectly comfortable if our own wife or daughter were the subject."[263]) Handbook 27 specified that the radium body burden should be estimated from the exhaled radon in the worker's breath, and also provided a limit on the allowable concentration of radon in the atmosphere of workrooms.[264]

Similar to Handbook 23, this handbook urged caution regarding the limits, warning that insufficient information existed to understand the combined effect of radium ingestion, radon inhalation, and exposure to gamma rays. It instructed users "to keep well below the tolerances stated, to insure safety."[265] Also similar to Handbooks 20 and 23, this Handbook served as the basis for establishing the allowable body burdens for other radionuclides, particularly plutonium, during the Manhattan Project.[266]

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[259] NBS Handbook 23, 4.
[260] NBS Handbook 23, 11-12.
[261] National Bureau of Standards, *National Bureau of Standards Handbook HB27: Safe Handling of Radioactive Luminous Compound* (Washington, DC: U.S. Government Printing Office, 1941).
[262] Caufield, 39-40.
[263] Caufield, 40.
[264] NBS Handbook 27, 3.
[265] NBS Handbook 27, 3.
[266] Caufield, 40.

The committee's actions before World War II created *representations* of the health effects of radiation and *discourse* over the proper use of exposure standards that have endured for more than 80 years. Specifically, the committee's handbooks represented radiation as a controllable and exploitable phenomenon but at the same time admitted its health effects were fundamentally mysterious. Likewise, its handbooks represented its standards as authoritative advice on radiation safety but at the same time encouraged users to apply large safety margins because of the uncertainties involved. It is also noteworthy that in establishing a limit on the human body burden of radium, Handbook 27 normalized ingestion and accumulation of radioactive materials in the body. This made a new *representation* of the relationship between people and radiation—ingesting radium and exhaling radon had become an accepted aspect of the human condition and an allowable workplace hazard.

5.3 National Committee on Radiation Protection

The Advisory Committee on X-Ray and Radium Protection went dormant during World War II, but Taylor led its reconstitution as the National Committee on Radiation Protection in 1946.[267] The name change reflected the vastly expanded array of radiation sources and radioactive materials unleashed by the Manhattan Project. Moreover, this new incarnation of Taylor's committee expanded its membership to enroll support from the institutions brought into the nuclear field by American's wartime activities. The NCRP included representatives from medical societies, x-ray equipment manufacturers, and nine government agencies, including the four branches of the military, the National Bureau of Standards, and the newly created Atomic Energy Commission. NCRP drew legitimacy from its relationship with that broad array of powerful institutions, supporting the *representation* that it was (again) the authoritative source for expertise on radiation safety in the United States, with its influence extending across both civilian and military uses of nuclear technologies and radiation.

Taylor, who continued to chair the refashioned committee, stated that the committee retained the National Bureau of Standards as its "central coordinating agency" because of NBS' perceived impartiality.[268] This emphasis on impartiality has been central to NCRP's position in the field of radiation protection—the NCRP has continued to represent itself as the definitive source of unbiased scientific guidance for radiation protection. The mission statement posted on the front page of the NCRP website 75 years later states that its purpose is "To support radiation protection by providing independent scientific analysis, information, and recommendations that represent the consensus of leading scientists."[269]

The NCRP made a small but significant change in its discourse on radiation safety during the postwar years, resulting in a fundamental change in the *representation* of the health effects of radiation: it stopped representing its standards as providing safe thresholds for radiation exposure (with the aforementioned caveats about uncertainty and suggestions to maintain exposures well below the threshold limits) and recast the specified limits as "permissible" doses. Handbook 59, *Permissible Dose from External Sources of Ionizing Radiation*, published in 1954,

[267] Taylor (2002), 778.
[268] Taylor (2002), 778.
[269] National Council on Radiation Protection and Measurements, *Our Mission*, https://ncrponline.org/ (accessed February 25, 2021).

made this change based on the rationale that the potential for genetic damage that could affect both the exposed individual and future generations meant that no true threshold for damage existed.[270] The handbook justified its recommended exposure limits as representing such a low probability of harm that the average person would accept the risk readily.[271]

The handbook carefully defined permissible (italicized in the original): "*Permissible dose may then be defined as the dose of ionizing radiation that, in the light of present knowledge, is not expected to cause appreciable bodily injury to a person at any time during his lifetime.*"[272] Given that the handbook acknowledged the potential for genetic damage, the phrase "during his lifetime" suggested the NCRP knowingly excluded heritable genetic damage from consideration in establishing the permissible dose. Moreover, the handbook also meticulously defined "appreciable": "As used here 'appreciable bodily injury' means any bodily injury or effect that the average person would regard as being objectionable and/or competent medical authorities would regard as being deleterious to the health and well being of the individual."[273] The handbook acknowledged that mechanisms by which radiation caused injuries were not well understood but argued that it was sufficient to understand what happens when people are exposed to radiation, noting that, "Nobody knows what life is or how it originated but a great deal is known about the human body and its behavior in health and disease."[274]

The NCRP's discourse in Handbook 59 made several important *representations* about radiation health and valid sources of knowledge. Instead of representing radiation as a hazard that could be controlled to harmless levels, the handbook recast radiation as always posing some risk, even below "permissible" exposure levels. This important concession opened the door to potentially conflicting views on the acceptability of the risk posed by radiation, particularly for groups and individuals uninterested in technologies that lead to radiation exposure. It appears that the handbook's authors anticipated the potential for differing risk perceptions, as they included *discourse* asserting that the "average" person would not perceive undue risk and additionally invoked expertise in the form of "competent medical authorities" to reaffirm their position. This discourse deploys the ordering instrument of *creating identity*, framing the "average" radiation worker as someone who agrees with the judgment of authorities regarding risks they face. In doing so, the handbook also establishes a *representation* of anyone who disagrees with its assessment of risk as defying "competent" medical advice and not conforming with the average person.

Handbook 59 and the corresponding updated handbook for internally deposited radioisotopes (Handbook 52, issued one year before Handbook 59)[275] differed from prior handbooks in stating the permissible dose in terms of rem instead of roentgen or rad. Whereas roentgen and rad are units of exposure, rem is calculated by adjusting exposure to account for the

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[270] National Bureau of Standards, *National Bureau of Standards Handbook 59: Permissible Dose from External Sources of Ionizing Radiation* (Washington, DC: U.S. Government Printing Office, 1954), 26.
[271] NBS Handbook 59, 27.
[272] NBS Handbook 59, 27.
[273] NBS Handbook 59, 27.
[274] NBS Handbook 59, 8.
[275] National Bureau of Standards, *National Bureau of Standards Handbook 52: Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water* (Washington, DC: U.S. Government Printing Office, 1953.

different biological effects of different types of radiation. NCRP did not invent this unit, but this was the rem's first appearance in its safety handbooks. Introducing the rem was a crucial development in *making representations* of radiation because, for the first time, the exposure standards used units of measure that explicitly factored in the potential for bodily harm. Whereas a roentgen simply represents a specific amount of ionization of air molecules, and a rad represents an absorbed dose in any material, the rem specifically is calibrated in terms of the capacity for health effects. This inherent meaning has been contained in radiation dose measurements and radiation safety standards ever since.

This change in units resulted from the vast expansion in the variety of radiation sources in the years since the NCRP developed Handbooks 20 and 23 to recommend limits for exposure to x-ray machines and radium. Radiation protection in post-WWII America needed to address the radiation produced by nuclear fission reactors and atomic bombs, as well as the radiation emitted by radioisotopes such as fission products and activation products created by irradiating stable materials with neutrons. Handbook 59 defined the health impact of various types of radiation in terms of the "relative biological effectiveness" compared to "ordinary x-rays."[276] The handbook recommended relative biological effectiveness factors ranging from 1 for x-rays up to 10 for neutrons and as high as 20 for alpha particle radiation.[277] Multiplying the radiation exposure in rad by the relative biological effectiveness factor yields the dose in rem. For chronic exposures continuing for an indefinite number of years, the handbook recommended a permissible dose of 0.3 rem per week for the blood-forming organs, gonads, and lenses of the eyes.[278] It allowed higher exposures to the skin and extremities and for people over the age of 45.[279] The handbook reasoned that persons more than 45 years old were generally no longer conceiving children, so concerns about sterility and heritable genetic damage did not apply to them.[280] It also specified a higher permissible dose of 25 rem "once in the lifetime of the person" for acute accidental or emergency exposure.[281]

The NCRP also used the concept of a permissible dose, instead of a safe threshold dose, in setting new limits for ingestion for a large number of radioactive isotopes in Handbook 52, issued in 1953 (one year before Handbook 59). The introduction to the handbook flatly states that "all unnecessary exposure to radioisotopes should be avoided."[282] Similar to Handbook 59, Handbook 52 established 0.3 rem per week as the permissible dose to most organs from radioisotopes in the body.[283] From this value, the handbook calculated maximum permissible body burdens of radioisotopes and maximum permissible concentrations of these radioisotopes "in the air and water one may take regularly into the body."[284] The handbook also articulated a risk minimization approach equivalent to the modern ALARA principle: "The goal should be no radioactive contamination of air and water and of the body if it can be accomplished with reasonable effort and expense. If such a goal cannot be attained, the average operating levels

[276] NBS Handbook 59, 43-44.
[277] NBS Handbook 59, 43-51.
[278] NBS Handbook 59, 61-62.
[279] NBS Handbook 59, 61-69.
[280] NBS Handbook 59, 51-52.
[281] NBS Handbook 59, 69-71.
[282] NBS Handbook 52, 1.
[283] NBS Handbook 52, 13.
[284] NBS Handbook 52, 11.

should be kept as far below these recommended values as possible, and not above them for any extended periods of time."[285]

The *representations* of radioactive body burdens conveyed in Handbook 52 differ sharply from those of Handbook 27, which it should be noted was written by a committee appointed by the NBS, not by the NCRP or its predecessor. Whereas the authors of Handbook 27 treated a body burden of radium as a normal condition, the authors of Handbook 52 strongly urged zero body burden and zero releases into air and water. This represented an internally contaminated human as an exception rather than a normal condition. Handbook 52 also specifically employed *discourse* that reinforced the status of the expert practitioner of radiation protection by stating that although the goal was zero intake of radioactive materials, practitioners could decide for themselves the point at which a reasonable level of effort and expense had been applied to protecting against intakes. This early expression of the ALARA philosophy performed important work in facilitating nuclear technologies by rationalizing that, even though all exposures were judged to pose some risk of health impacts, the experts in the field could be relied upon to take all reasonable measures to protect workers.

Although these NCRP handbooks adopted a "no threshold" philosophy to radiation protection, they did not characterize the shape of the dose-response relationship. This is not surprising, since as discussed earlier in this dissertation, there was no consensus on the appropriate model in the early 1950s. Handbook 59 does note that gene mutations had been shown to increase linearly with the radiation dose, but it does not apply that relationship to any other outcome of radiation exposure.[286] In fact, it asserts that the "permissible" dose limit it established was lower than the previous "threshold" dose because "it is desirable to be on the safe side," and not because exposures at the level of the higher threshold dose—which, as noted previously in this section, equated to a dose of about 30 rem per year—were suspected of having any potential to cause harm.[287] This *discourse* will be seen again in future statements by practitioners of radiological protection, perpetuating the *representations* of radiation as a commodity that has been safely controlled since the earliest activities of NCRP's predecessor committee.

The NCRP eventually articulated its support for the linear no-threshold dose-response relationship in a journal article published in 1960.[288] This article stated that "because of public concern over the possible effect of radiation from fallout" from atmospheric testing of nuclear weapons, the NCRP had undertaken an independent assessment of its recommendations for radiation protection.[289] The introduction to the article, credited to Taylor, made it clear that the NCRP did not expect to find fault with its handbooks. It emphasized that "The NCRP was unaware of any new basic information on somatic effects of radiation," but that "it appeared

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[285] NBS Handbook 52, 11.
[286] NBS Handbook 59, 17.
[287] NBS Handbook 59, 37-38.
[288] National Committee on Radiation Protection and Measurements, "Somatic Radiation Dose for the General Population: The Report of the Ad Hoc Committee of the National Committee on Radiation Protection and Measurements, 6 May 1959," *Science* 131:3399 (February 19, 1960), 482-486.
[289] NCRP (1960), 482.

desirable to make a new and independent examination of the problem for the purpose of affirming the views of the NCRP."[290]

The article reported that the committee concluded the following (italicized as shown in the original): "the present data are still *insufficient to establish the character of the dose-response* curve for somatic effects." The article discussed potential dose-response relationships very briefly, asserting that the possibility of a supra-linear relationship "seems very remote" and therefore concluding that a linear no-threshold relationship would conservatively predict consequences extrapolated from high doses.[291] The article emphasized that this is a "cautious *assumption*" made in the absence of information.[292]

Despite the begrudging language prevalent in the article, its final statement is a clear articulation of the As Low As Reasonably Achievable principle that helps reconcile the apparent contradiction between the assumption that any exposure is potentially harmful and a regulatory system that allows exposing workers, patients, and the public to ionizing radiation: "Any permissible level which may be chosen is essentially arbitrary and every effort should be made to keep the radiation dosage as far below the permissible level as feasible. On the assumption noted above, any radiation dose should be thought of as being tolerated only to obtain compensatory benefits."[293]

Even though the article was published over 60 years ago, the NCRP has continued in the years since then to treat the linear no-threshold dose-response model as conservative and useful but at the same time unproven and at risk of being misapplied. The NCRP has encouraged using the model as the philosophical basis for always seeking to minimize radiation exposures to the extent practical. However, the NCRP has continued to discourage using the model as the basis for quantitative estimates of the health effects of low dose exposure to radiation, especially for exposures to large populations. Such calculations would predict that small exposures to many people would yield a significant number of cancers, a conclusion that the NCRP has not supported as valid. The rationale embodied in NCRP's *discourse* across many documents and various venues is that the model is useful in providing bounding estimates for the risk to an individual, in order to ensure that radiation exposures are controlled such that the associated risk is consistent with (and typically much smaller than) other risks society has judged acceptable, but that the dose-response relationship for small exposures is too uncertain (and the associated cancer likelihood too small) for risk calculations across large populations to be meaningful.

For example, a review article authored in 2017 on behalf of the NCRP by its president articulated the same positions the NCRP had taken in 1960.[294] This article surveyed a wide range of epidemiological studies on groups including atomic bomb survivors, workers at the Mayak facility in Russia, American veterans exposed to fallout during atmospheric testing of nuclear weapons, populations on the Techa River in Russia, American radiological technologists,

[290] NCRP (1960), 482.
[291] NCRP (1960), 484.
[292] NCRP (1960), 485.
[293] NCRP (1960), 486.
[294] John D. Boice, Jr., "The linear nonthreshold (LNT) model as used in radiation protection: an NCRP update," *International Journal of Radiation Biology* 93:10 (2017), 1079-1092.

the U.S. Million Person Study, international workers (the INWORKS study), Chernobyl cleanup workers, children given computed tomography x-ray scans, and tuberculosis-fluoroscopy patients.[295] Based on this extensive body of research, the author concluded that "there is no alternative dose-response relationship that is more pragmatic or prudent than the LNT hypothesis for radiation protection."[296] However, the author further concluded that the linear no-threshold model was unlikely to be scientifically validated for low doses and provided a comprehensive statement on the position that the NCRP has maintained for decades:[297]

> It is also recognized that this assumption for radiation protection has been abused, e.g. when used with collective dose and applied to large numbers of people who received tiny doses for the prediction of thousands and tens of thousands of future theoretical cancer deaths. For risk assessment, you need individual organ doses and apply the best age, sex, and time-specific radiation risk estimates. Trivial doses like one microsievert (μSv) should not be multiplied by large population numbers to predict future excessive cancer deaths. The LNT model (or any model for that matter developed for radiation protection) is not for risk assessment, it is for radiation protection.

In the terms of Latour's actor-network, the NCRP cemented its authority and advanced its conclusions regarding the appropriate application of the linear no-threshold dose-response model in regulation of radiation exposures by enrolling other institutions into its program and establishing itself as an obligatory passage point for obtaining certified information on radiation protection.[298] In Jasanoff's terms, it deployed the ordering instruments of co-production, particularly *making institutions*, *making representations*, and *making identities*, to secure its position as the institution relied on to organize the relationship between radiation and society. Its very structure engages numerous interested organizations and institutions in its activities. As noted above, when reconstituted after World War II, the NCRP initially included representatives from medical societies, x-ray equipment manufacturers, and nine government agencies, including the four branches of the military, the National Bureau of Standards, and the Atomic Energy Commission. Furthermore, the NCRP published its radiation protection recommendations as National Bureau of Standards handbooks in the 1940s and 1950s, implying the government's endorsement. Taylor noted that, despite disclaimers that the NCRP was an independent entity, "there were many people in the public who because of the government imprint on the cover of the report, assumed that the report represented government recommendations rather than those of an independent private body having no legal authority."[299] The cover of a typical handbook, shown in Figure 5-1 below, illustrates that it would be easy to mistake the NCRP's product for a government document.

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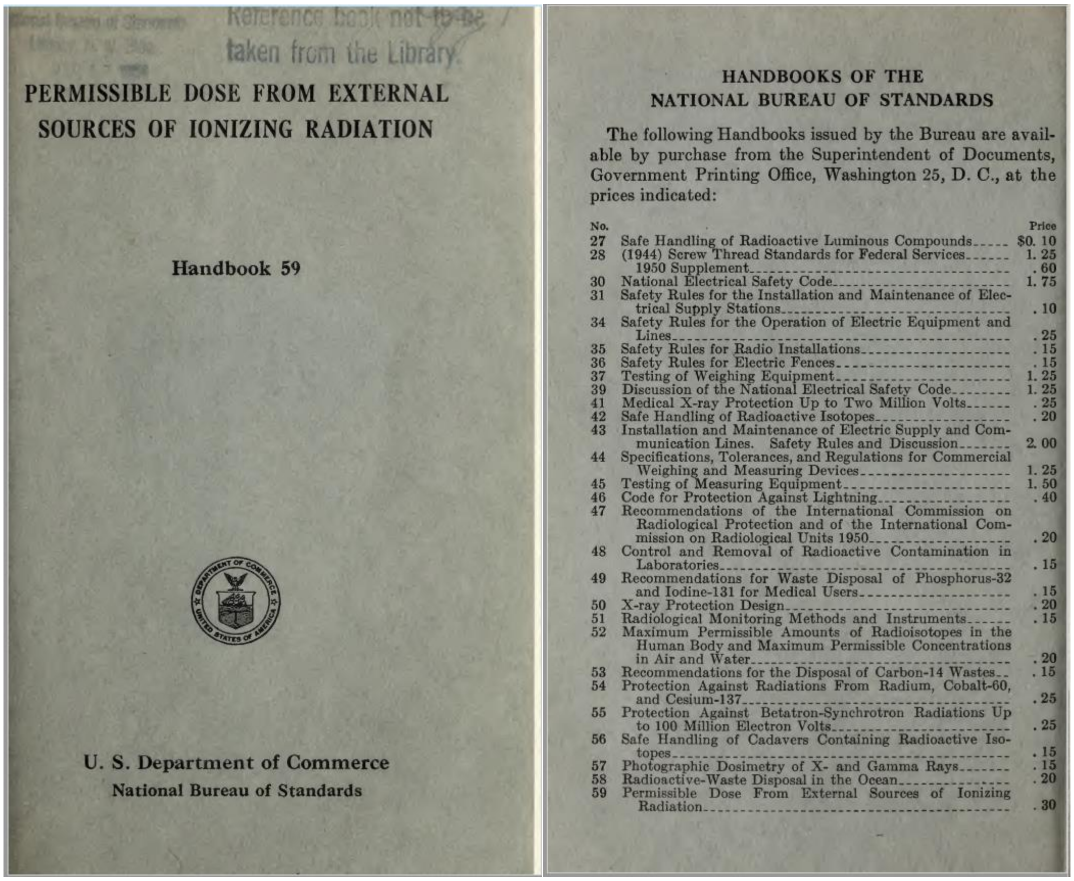
[295] Boice, 1079.
[296] Boice, 1099.
[297] Boice, 1099.
[298] Michel Callon, Pierre Lascoumes, and Yannick Barthe, *Acting in an Uncertain World: An Essay on Technical Democracy* (Cambridge, MA: The MIT Press, 2011), 62-64.
[299] Lauriston S. Taylor and Harold O. Wyckoff, "Radiation protection standards (Part 2)," *Critical Reviews in Environmental Science and Technology* 2:1-4 (1972), 150.



PERMISSIBLE DOSE FROM EXTERNAL SOURCES OF IONIZING RADIATION

Handbook 59

U. S. Department of Commerce
National Bureau of Standards

HANDBOOKS OF THE NATIONAL BUREAU OF STANDARDS

The following Handbooks issued by the Bureau are available by purchase from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., at the prices indicated:

No.		Price
27	Safe Handling of Radioactive Luminous Compounds	$0. 10
28	(1944) Screw Thread Standards for Federal Services	1. 25
	1950 Supplement	. 60
30	National Electrical Safety Code	1. 75
31	Safety Rules for the Installation and Maintenance of Electrical Supply Stations	. 10
34	Safety Rules for the Operation of Electric Equipment and Lines	. 25
35	Safety Rules for Radio Installations	. 15
36	Safety Rules for Electric Fences	. 15
37	Testing of Weighing Equipment	1. 25
39	Discussion of the National Electrical Safety Code	1. 25
41	Medical X-ray Protection Up to Two Million Volts	. 25
42	Safe Handling of Radioactive Isotopes	. 20
43	Installation and Maintenance of Electric Supply and Communication Lines. Safety Rules and Discussion	2. 00
44	Specifications, Tolerances, and Regulations for Commercial Weighing and Measuring Devices	1. 25
45	Testing of Measuring Equipment	1. 50
46	Code for Protection Against Lightning	. 40
47	Recommendations of the International Commission on Radiological Protection and of the International Commission on Radiological Units 1950	. 20
48	Control and Removal of Radioactive Contamination in Laboratories	. 15
49	Recommendations for Waste Disposal of Phosphorus-32 and Iodine-131 for Medical Users	. 15
50	X-ray Protection Design	. 20
51	Radiological Monitoring Methods and Instruments	. 15
52	Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water	. 20
53	Recommendations for the Disposal of Carbon-14 Wastes	. 15
54	Protection Against Radiations From Radium, Cobalt-60, and Cesium-137	. 25
55	Protection Against Betatron-Synchrotron Radiations Up to 100 Million Electron Volts	. 25
56	Safe Handling of Cadavers Containing Radioactive Isotopes	. 15
57	Photographic Dosimetry of X- and Gamma Rays	. 15
58	Radioactive-Waste Disposal in the Ocean	. 20
59	Permissible Dose From External Sources of Ionizing Radiation	. 30

Figure 5-1 Front Cover and Inside Front Cover of Typical NCRP Handbook

The NCRP's relationship with the NBS came into question in the late 1950s, when, in the words of Taylor, "certain writers in the public press and certain elements of organized labor began making individual attacks upon the NCRP, its mode of operation, its chairman [Taylor], etc."[300] The NCRP also began to encounter the need to consult with other affected government agencies in issuing its handbooks, culminating in this lengthy disclaimer in Handbook 69:[301]

> The conclusions in the present handbooks are to be considered only as recommendations of a group of experts in the radiological protection field. They carry no legal implications demanding or requiring adoption. Inasmuch as the recommendations of the National Committee on Radiation Protection and Measurements impinge upon the areas of statutory responsibility of both the U.S. Public Health Service and the U.S. Atomic Energy Commission, it was considered important to determine that these agencies would not object to the publication of these recommendations by the National Bureau of Standards. Such assurances were obtained although these involve no commitment on the part of these agencies to adopt the recommendations of

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[300] Taylor and Wyckoff, 150.

[301] National Bureau of Standards, *National Bureau of Standards Handbook 69: Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure* (Washington, DC: U.S. Government Printing Office, 1959), iv.

> the National Committee on Radiation Protection and Measurements. Nor should the publication be construed as a recommendation by the National Bureau of Standards for adoption inasmuch as the important medical and biological factors involved in developing the recommendations are clearly outside of the Bureau's area of technical competence.

5.4 National Council on Radiation Protection and Measurements

With neither the NBS nor the NRCP satisfied with this state of affairs, the NCRP undertook to reconstitute itself independent of any government agency.[302] The NCRP worked with the Chairman of the JCAE to introduce legislation to grant the NCRP a congressional charter.[303] This legislation passed in 1964, chartering the NCRP as the National Council on Radiation Protection and Measurements, a status it still holds today, with the mission of performing a host of functions related to developing and sharing advice on radiation protection.[304] One of these functions is to "provide a means by which organizations concerned with the scientific and related aspects of radiation protection and of radiation quantities, units, and measurements may cooperate for effective utilization of their combined resources, and to stimulate the work of such organizations."[305] This accomplishment embodies the ordering instrument of *making institutions*, with the NCRP established in law as the independent repository of "knowledge and power" with respect to radiation protection in America. This positioned the NCRP to reproduce its "institutionalized ways of knowing things"—particularly its complicated *representation* of the linear no-threshold dose-response model—throughout the varied applications of nuclear technologies and radiation in the United States.[306] Despite the representation that reconstituting the NCRP as a congressionally chartered council was intended to clarify that it was a non-governmental entity, the Congressional Research Service has reported that the opposite is generally true of such councils and corporations—confusion over which are governmental and which are private is one of their "enduring issues."[307]

In pursuing this function, the NCRP enrolled even more entities into its network (i.e., extended its institutional influence) by creating a category of affiliates termed "collaborating organizations," numbering 28 by 1970.[308] The NCRP's website now lists 79 collaborating organizations, including numerous government agencies, branches of the military, professional societies, industry groups, and trade unions.[309] The NCRP characterizes its relationship with these organizations in the following terms: "Collaborating Organizations provide a means by which the NCRP can gain input into its activities from a wider segment of society. At the same time, the relationships with the Collaborating Organizations facilitate wider dissemination of

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302 Taylor and Wyckoff, 168.
303 Taylor and Wyckoff, 168.
304 Taylor and Wyckoff, 169.
305 Taylor and Wyckoff, 169.
306 Jasanoff (2006), 40.
307 Kevin R. Kosar, *Congressional or Federal Charters: Overview and Enduring Issues*, RS22230 (Congressional Research Service, April 19, 2013), 3, 5.
308 Taylor and Wyckoff, 169.
309 National Council on Radiation Protection and Measurements, *Collaborating Organizations*, https://ncrponline.org/related-organizations/collaborating-organizations/ (accessed May 13, 2020).

information about the Council's activities, interests and concerns."[310] This use of the ordering instrument of *creating identities* realigned actors otherwise independent of the NCRP to be official "collaborators" who not only apply NCRP standards but are also willing participants in NCRP's *discourse* on radiation protection.

In addition to network building/extension of institutional influence at the organizational level, members of the NCRP networked at the individual level through cross-memberships with other organizations. For example, in addition to his decades with the NCRP and its predecessor organization, Taylor was an NBS employee until his retirement in 1965. He was the secretary of the International Commission on Radiological Protection from 1937 to 1950, a member until 1969, and an emeritus member for the rest of his life. He was also the secretary of the International Commission on Radiation Units and Measurements from 1934 to 1950, Chairman from 1953 to 1969, and Honorary Chairman and emeritus member for the rest of his life.[311] Similarly, Karl Z. Morgan was the chairman of both the NCRP and ICRP subcommittees that developed and published limits on the body burden for radioisotopes in the 1950s (i.e., NBS Handbook 52 and the corresponding ICRP report), served as the first president of the Health Physics Society, and worked at Oak Ridge National Laboratory for over 30 years, including serving as the director of the health physics division.[312] Similarly, Gioacchino Failla headed the subcommittees that issued recommendations on limits for external radiation exposure for both NCRP and ICRP (i.e., NBS Handbook 59 and the corresponding ICRP report).[313] Morgan and Failla are also both credited in the National Academy of Sciences 1956 BEAR report, Morgan as a consultant and Failla as a committee member.[314] Similar cross memberships of people among apparently separate organizations have continued in the relatively small radiation protection community. Shared members and, even more important, shared leaders can be expected to assist in enrollment and alignment of apparently independent groups into the actor-network (or in co-production terms, in deploying the ordering instruments of *making institutions* and *making discourses*).

In building its network of influence, the NCRP has engaged in boundary work to defend its status as the source of unbiased scientific information (i.e., the institutional "repository of knowledge"). The NCRP publishes its recommendations on its own website where, unlike government regulations, the reports documenting its recommendations must be purchased. Putting a price tag on its work can be expected to discourage laypersons from casually accessing the information, limiting discourse about the NCRP's recommendations to those willing to pay to participate. Similarly, other communications from the NCRP are typically delivered in the form of presentations at technical conferences and papers submitted to technical journals, which also have a cost of admission. The principal exceptions are when NCRP officials are called to testify at hearings as expert witnesses, an *identity* the NCRP has cultivated based on its membership, its

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[310] NCRP, *Collaborating Organizations*.
[311] Shunichi Yamashita, "Historical Role of Lauriston S. Taylor in American Radiation Safety and Protection," *Acta Medica Nagasakiensia* 50 (December 2005), 53-56.
[312] Kenneth L. Miller, Michael T. Ryan, and Genevieve S. Roessler, "A Tribute to Karl Z. Morgan," *Health Physics* 76:6 (June 1999), 599-603.
[313] Caufield, 68-72.
[314] NAS-NRC, *The Biological Effects of Atomic Radiation: A Report to the Public* (Washington, DC: National Academy of Sciences – National Research Council, 1956), 33, 40.

publications, and its stature as a congressionally chartered independent council. These factors all serve as ordering instruments in *making identity* for the NCRP and controlling *discourse* in its area of expertise. None of these characteristics are unusual for a professional society or industry group, but the NCRP is a congressionally chartered council, not a professional society or industry group.

In addition to such examples of positive boundary work that fortifies its institutional status in the radiation protection arena, the NCRP as personified by Taylor published articles critical of people and organizations with contrary views and also criticizing their choice of venues for raising concerns. This negative boundary work is particularly aimed at the media and those who apply the linear no-threshold model to predict negative health impacts for populations exposed to low doses of radiation (e.g., citizens exposed to fallout from atmospheric testing of nuclear weapons). In 1965, Taylor published an article criticizing "sensational writers" and "pressures on the public by 'recognized scientific' groups" regarding "heavy fallout from nuclear weapon tests."[315] He asserted that this led to the introduction of restrictions, "many of which are felt by experts to be unwise or unduly restrictive."[316] In 1971, he published a speech in which he objected to congressional committees that offered "noisy platforms to a few people with axes to grind," further characterizing the critics as individuals who "had not found acceptance among their professional colleagues for some of their ideas."[317] He further complained that the "standards of the ICRP and NCRP have been under attack but where the principal approach has been by releases to the newspapers and by communications to high level government administrators, and so on."[318] Similarly, in a presentation to the Fifth International Congress of the International Radiation Protection Association in 1980, Taylor urged that "we must find an acceptable means for stopping or counteracting the endless prattlings by a few individuals, with whatever motives they may have for keeping the public stirred up, confused and alienated from the very technologists who are in the best position to properly inform them and educate them."[319]

In a more specific attack, Taylor called out a half-dozen unnamed "individuals with some technical training whose ideas have failed of acceptance by their colleagues" and pejoratively termed them "the U.S. Six."[320] He disparaged their motives, asserting that "These are usually associated with cutbacks in funds, or rejection of their results by their professional colleagues," as well as their scientific contributions, stating that "it is believed to be correct to say that none has ever produced himself any of the data used for his particular promotion."[321] Taylor also negatively characterized the so-called U.S. Six's choice of venues for argumentation, saying that, "they have learned that they can always catch the ear of the press or a congressional committee or some government agency that may be thrown easily on the defensive."[322] Extensive searches have not found any other author making reference to the "U.S. Six" but I am confident that

[315] Lauriston S. Taylor, "Philosophical Influences on Radiation Protection Standards," *Health Physics* 11 (1965), 862.
[316] Taylor (1965), 862.
[317] Lauriston S. Taylor, "Radiation Protection Trends in the United States," *Health Physics* 20 (May 1971), 502-503.
[318] Taylor (1971), 503.
[319] Lauriston S. Taylor, "Some Nonscientific Influences on Radiation Protection Standards and Practice: The 1980 Sievert Lecture," *Health Physics* 39 (December 1980), 856-857.
[320] Lauriston S. Taylor, "Let's Keep Our Sense of Humor in Dealing with Radiation Hazards," *Perspectives in Biology and Medicine* 23:3 (Spring 1980), 326.
[321] Taylor (1980), 329.
[322] Taylor (1980), 329.

several of them appear among the actors to be discussed later in this dissertation (i.e., former AEC-affiliated scientists Arthur Tamplin, John Gofman, and Karl Morgan).

Taylor and the NCRP did confront their critics more directly in courtroom testimony on lawsuits making radiation injury claims and in hearings on regulation of radiation protection held by the JCAE and the Atomic Energy Commission. Those interactions will be addressed below in summaries of the most prominent hearings and court cases.

5.5 Sociotechnical Imaginaries of the NCRP

The NCRP's use of the ordering instruments of co-production in *making institutions*, *making identities*, *making discourses*, and *making representations* paints a clear picture of the sociotechnical imaginary that animates the NCRP. NCRP's handbooks and other discourse emphasize the technical expert and reinforce the expert's stature and authority in applying judgment in matters of radiation protection. In the NCRP's imaginary, standards are important, but the judgment of the technical expert is the deciding factor in managing radiation hazards. NCRP's handbooks and other discourse also represent radiation exposures as a necessary consequence of progress and as a risk that can be safely managed even if the exact degree of risk is not understood. This suggests an imaginary that has faith in science and believes in technology as key to human progress. Lastly, the NCRP's institution-building efforts indicate an imaginary that believes in society's institutions and sees them as instrumental in safely reconciling new technologies with society.

The NCRP's principal pollution metaphors are borne out in the public statements by Taylor and Boice, where they express dismay at intrusions into the domain of the technical expert by the scientifically inadequate and by people with non-scientific agendas. Taylor also expressed displeasure when issues of science were raised in non-scientific venues, such as in the media or in congressional hearings. His reaction indicates a similar pollution concern regarding contamination of science by debating it in a venue tainted by politics or other non-scientific influences.

6 Federal Actors

6.1 Overview

The U.S. Congress established the Atomic Energy Commission after World War II as the civilian successor to the military-led Manhattan Project that developed and operated the complex of nuclear facilities responsible for creating the atomic bomb.[323] This is a direct use of the ordering instrument of *making institutions* to give the government a repository of knowledge and power for shaping the development and implementation of nuclear technologies. As will be shown below, the AEC played a crucial role in *making discourses* about the safety of nuclear technologies and the health effects of ionizing radiation, *making representations* about the nature of radiation and radiation's place among the risks confronting America, and *creating identities* related to nuclear technologies and radiation (including *identities* which were unintended by-products of its activities). It went to great lengths to enroll the American public in its programs for both military and peaceful uses of nuclear technology, as will be illustrated below.

The AEC endured until 1975, when legislation passed in 1974 directed the establishment of the Nuclear Regulatory Commission to regulate commercial applications of nuclear technology and the transformation of the AEC into the Energy Research and Development Administration, which continued as the self-regulating operator of the nuclear weapons complex.[324] The Atomic Energy Act defined the AEC's mission and authorities. Congress passed the Act in 1946 and then amended it substantially in 1954 as discussed below.

6.2 Atomic Energy Act of 1946

The U.S. Atomic Energy Commission and Congress' Joint Committee on Atomic Energy were created together by the Atomic Energy Act of 1946.[325] The Atomic Energy Act empowered the AEC to pursue both military and civilian applications of atomic energy, with oversight by the JCAE. The Atomic Energy Act authorized the AEC to undertake research on protection of health during research and production activities, to license the manufacture, production, export, or utilization of "fissionable material or atomic energy," and to establish standards and instructions to "protect health or to minimize danger from explosions and other hazards to life or property."[326] The Atomic Energy Act identified the possibility of an explosion as the one named hazard of concern; the Act did not specifically address hazards of radiation exposure. The Atomic Energy Act called for the AEC to be led by five politically appointed commissioners, with the JCAE consisting of nine Senators and nine members of the House of Representatives. The Act further specified the organization of the AEC's staff into a Division of Research, a Division of Production (responsible for producing special nuclear materials and weapon components), a Division of Engineering, and a Division of Military Application.

[323] Alice L. Buck, *A History of the Atomic Energy Commission*, DOE/ES-003/1 (Washington, DC: U.S. Department of Energy, July 1983), 1.
[324] Buck, 8.
[325] Atomic Energy Act of 1946 (Public Law 585) 78th Cong. 1st sess.
[326] Atomic Energy Act of 1946 (Public Law 585) 78th Cong. 1st sess.

6.3 Atomic Energy Act of 1954

On December 8, 1953, President Dwight D. Eisenhower gave his famous "Atoms for Peace" speech to the United Nations General Assembly. He proposed sharing technical information and nuclear materials internationally to promote the peaceful use of nuclear energy.[327] Congress passed a substantially revised Atomic Energy Act in 1954 to align the Atomic Energy Commission's mission with these new priorities.[328] The revised Act provided more emphasis on developing peaceful applications of nuclear technologies, including encouraging greater participation in such development both domestically and internationally. It was less prescriptive than the original Act in defining the organization of the AEC, but it did continue to specify a Division of Military Application and added a new Inspection Division to ensure compliance with the Act and with rules and regulations defined by the AEC. The revised Act required the AEC to institute safety standards applicable to entities licensed to possess special nuclear materials for production or utilization activities "to protect health and to minimize danger to life or property."[329] It similarly authorized the AEC to issue licenses for medical therapy and medical research and development, and directed the AEC to "permit the widest amount of effective medical therapy possible with the amount of special nuclear material available for such purposes and to impose the minimum amount of regulation consistent with its obligations under this Act to promote the common defense and security and to protect the health and safety of the public."[330] The revised Act specifically exempted the Department of Defense and its contractors as well as the AEC's own contractors from licensing requirements. The revised act no longer singled out explosions as a hazard of concern, but like the Atomic Energy Act of 1946, it did not specifically address the hazards of radiation exposure.

Both versions of the Atomic Energy Act therefore empowered the AEC to set its own standards for radiation exposure of people and contamination of the environment. As will be detailed below, this led to decades of interactions ranging from cooperation to conflict with standards-setting bodies (e.g., the NCRP), other federal agencies, state and local governments, public interest groups, and private citizens. It also led to a fractured *identity* for the AEC. As the developer, user, and regulator of nuclear technologies and radiation safety, the AEC inevitably faced internal conflicts between divisions of the AEC and between the AEC and scientists at its laboratories. This perpetually unsettled identity eventually led Congress to create the NRC as a separate institution dedicated to regulation, but it also created decades of *discourse* on the health effects of radiation that proved ideal for analysis in this dissertation.

6.4 Activities of the AEC

The AEC took control of the programs and facilities of the World War II Manhattan Project on January 1, 1947.[331] This included extensive efforts to monitor occupational radiation

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[327] Buck, 3.

[328] J. Samuel Walker and Thomas R. Wellock, *A Short History of Nuclear Regulation, 1946-2009*, NUREG/BR-0175, Rev. 2 (U.S. Nuclear Regulatory Commission, October 2010), 3.; Atomic Energy Act of 1954 (Public Law 703) 83rd Cong.

[329] Atomic Energy Act of 1954 (Public Law 703) 83rd Cong.

[330] Atomic Energy Act of 1954 (Public Law 703) 83rd Cong.

[331] Hacker (1987), 160.

exposure of the thousands of workers and researchers involved in developing, producing, and testing nuclear weapons and to assess radiation's health impacts.[332] The wartime radiation safety program relied on NCRP's pre-war guidelines for radiation exposures.[333] However, given the scale of the program and the large number of workers involved, the first leader of the Manhattan Project's Health Division (Robert Stone) and "most of his colleagues" favored treating the exposure limits as permissible doses, rather than safe thresholds, even though the NCRP had not yet adopted that approach.[334] They likewise emphasized that exposures should be kept as low as possible.[335]

Despite this claimed emphasis, it is not clear that Stone's approach took hold throughout the project. For example, Karl Z. Morgan, a wartime head of the Health Physics Division at Oak Ridge National Laboratory, has stated that the threshold hypothesis underpinned radiation protection at Oak Ridge. His book *The Angry Genie: One Man's Walk through the Nuclear Age* included a section entitled "Research at ORNL: Our Mistaken Belief in a Threshold Hypothesis." That section described experiments in which researchers taped radioactive specimens to the wrists of nurses, doctors, and health physics professionals in an unsuccessful effort to validate that occupational exposures of radiation workers were below a safe threshold. Some of the nurses ended up with blisters and ulcerations on their arms.[336] Additionally, the military leadership of the Manhattan Project complained to the leadership of the Health Division that it was wasteful to control radiation exposures to levels lower than the established limits.[337]

The latter anecdote illustrates the *representations* on radiation safety that practitioners of nuclear technologies may have gleaned from the NCRP handbooks. The NCRP *represented* its numerical limits as acceptable exposures, so it is not surprising that users did not necessarily feel obligated to heed the accompanying language cautioning them to control exposures to levels well below the numbers because of the uncertainties involved.

The approaches taken by Stone and Morgan may have been influenced by their professional backgrounds. Stone was a trained radiologist and was recruited to lead the Manhattan Project's Health Division from the faculty of the University of California medical school.[338] Morgan was a physics professor and cosmic radiation researcher recruited into the Manhattan Project to develop techniques for radiation detection and dosimetry.[339] Later sections of this dissertation will note additional examples where particular professional and academic backgrounds appear to be associated with a preference for a particular dose-response relationship for radiation exposures. It is worth noting, however, that although he initially believed in a threshold for radiation effects, Morgan went on to establish the Health Physics Society and

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[332] Hacker (1987), 34-83.; Caufield, 46-56.
[333] Hacker (1987), 54-55.; Caufield, 48-49.
[334] Hacker (1987), 30, 38-39, 54-55.; Caufield, 48-49.
[335] Caufield, 48-49.
[336] Karl Z. Morgan and Ken M. Peterson, *The Angry Genie: One Man's Walk through the Nuclear Age* (Norman, OK: University of Oklahoma Press, 1998), 28-32.
[337] Morgan and Peterson, 51-52.; Caufield, 49.
[338] Hacker (1987), 30.
[339] Morgan and Peterson, 10-21.

eventually became a prominent advocate for people claiming health impacts from fallout and other radiation exposures.[340]

The Atomic Energy Act established the AEC as the regulator of its own activities, albeit subject to the oversight of the JCAE. This inherent conflict of interest was a recurring theme throughout the existence of the AEC and featured prominently in public debate over issues such as fallout from testing of atomic weapons and emissions from nuclear power stations.[341] Furthermore, its mission to develop military applications of nuclear technology meant that much of its work was shrouded in secrecy. This led to persistent accusations that the AEC kept secrets not just to protect national security, but also to avoid public scrutiny and criticism.[342]

Activities of the AEC that illustrate how it evaluated, applied, and advocated dose-effect models for radiation exposure include human radiation experiments, standards-setting for radiation exposures associated with its activities, and interactions with the public regarding radioactive fallout from atmospheric testing of nuclear weapons.

6.4.1 Human Radiation Experiments

The AEC and the Manhattan Project sponsored human radiation experiments for purposes such as establishing the technical basis for bioassay programs for radiation workers, establishing limits for ingestion of radioactive materials, and developing medical applications of radiation and radioactive materials.[343] Growing public awareness of the history of human radiation experiments in the United States led President Clinton to establish the Advisory Committee on Human Radiation Experiments, which published a comprehensive report on America's history of such experiments in October 1995.[344] The introduction to the committee's report made an important observation regarding the impacts of the official secrecy surrounding much of the experimentation: "Where official secrecy is coupled with expert authority, and both are focused on a public that is not privy to secrets and does not speak the languages of experts, the potential for distrust is substantial."[345] As discussed below, this observation applies broadly to the public's relationship with the AEC and its successors not only with respect to human radiation experiments but also on issues such as fallout from atmospheric tests of nuclear weapons and standards for radiation exposure and releases of radioactive material from nuclear power stations.

Over several decades, the AEC and its predecessors in the Manhattan Project sponsored experiments using human subjects exposed to external radiation sources and internally deposited

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[340] Morgan and Peterson, 109-110, 135-153.
[341] Walker (2000), 18-45.
[342] Caufield, 118-120.
[343]Assistant Secretary for Environment, Safety, and Health, U.S. Department of Energy, *Human Radiation Experiments Associated with the U.S. Department of Energy and Its Predecessors* (Washington, DC: U.S. Department of Energy, July 1995), 2.
[344] Advisory Committee on Human Radiation Experiments, *Advisory Committee on Human Radiation Experiments: Final Report* (Washington, DC: U.S. Government Printing Office, October 1995).
[345] Advisory Committee on Human Radiation Experiments, 14.

radioactive materials.[346] In support of the Advisory Committee's study, the Department of Energy identified more than 425 human radiation experiments sponsored, supported, or performed by the Manhattan Project, the AEC, and successor organizations.[347] The purposes of the experiments varied.[348] Some experiments used radioactive materials as tracers to study bodily processes such as absorption of nutrients from food. Others sought to develop cancer treatments and other medical applications of radiation and radioactive materials. Still others specifically sought to improve the understanding of the health effects of the intake of radioactive materials by establishing how radioactive materials were absorbed by the body, whether particular radioisotopes had a particular affinity for particular organs, and how long they would reside in the body. These concerns were also studied using laboratory animals, but the AEC-sponsored human experimentation eventually became notorious because of ethical failings, particularly regarding the lack of informed consent for some experiments.[349] In addition to clinical experiments, the AEC's activities included intentional experimental releases of radioactive material to the environment.[350]

The AEC kept experiments, or at least the radiological aspects of experiments, secret, despite the "Atoms for Peace" mission assigned to the AEC by the Atomic Energy Act of 1954. The Advisory Committee on Human Radiation Experiments found that such secrecy was often motivated by the desire to shield the AEC from the risks of litigation and embarrassment, and not by national security concerns.[351] The Advisory Committee found significant ethical failings in the human experimentation sponsored by the AEC and the Manhattan Project, by modern standards as well as the prevailing standards at the time of the experiments.[352] The Advisory Committee's report expressed particular concern regarding informed consent for procedures that had no potential to result in clinical benefits for the subject of experimentation. The Advisory Committee also reported significant social justice issues, including the selection of people from vulnerable populations for experimentation, including prison inmates and children with developmental disabilities.[353]

Despite the ethical and social justice failings of the human radiation experiments, the experimenters did consider the health risks to the people involved in the experiments.[354] The manner in which the experimenters considered and dealt with health risks provides insight into their beliefs regarding the relationship between radiation exposures and health effects. As discussed in the examples summarized below, the experimenters typically avoided radiation exposures with significant likelihood to harm research subjects. However, a number of experiments involved larger exposures. The following examples illustrate how the AEC dealt with the risks to the subjects of several of the more notorious nontherapeutic experiments (i.e., those with no intent to improve the health of the test subject):

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[346] U.S. DOE (1995), 2.
[347] U.S. DOE (1995), v.
[348] U.S. DOE (1995), 2.
[349] Advisory Committee on Human Radiation Experiments, 781-782.
[350] Advisory Committee on Human Radiation Experiments, 506-507.
[351] Advisory Committee on Human Radiation Experiments, 624, 626, 630, 649, 792-793, 802.
[352] Advisory Committee on Human Radiation Experiments, 780-781.
[353] Advisory Committee on Human Radiation Experiments, 3, 785.
[354] Advisory Committee on Human Radiation Experiments, 782-784.

6.4.1.1 Injections of Radioactive Materials

The Advisory Committee counted 29 human subjects who were injected with plutonium, polonium, or uranium during 1945-1947 in experiments sanctioned by the Manhattan Project and the AEC, and 11 more injected with uranium during 1953-1957.[355] These experiments were intended to help understand how these radioactive materials were metabolized. This information, together with animal experiments, could be applied in evaluating allowable body burdens for radioactive materials, interpreting bioassay results for workers exposed to these radioactive materials, and estimating the dose consequences of ingested radioactive materials.

The experiments used quantities of radioactive materials believed to be small enough to avoid acute health consequences based on experience with radium ingestion.[356] The Advisory Committee noted that the published reports for experiments involving the administration of radioisotopes prior to the early 1960s rarely discussed long-term risks.[357] According to the Advisory Committee's report, the experimenters recognized the potential for the resulting body burdens of radioactive materials to lead to cancers over the next 10 to 20 years, but believed the risk "could be minimized by the use of small doses and wholly avoided if the subjects were expected to die well before a cancer had a chance to materialize."[358] As a result, in most cases, the experimenters chose people who were suffering from health problems expected to be fatal in the near future (some of whom had the good fortune to unexpectedly survive their maladies, which was a welcome surprise to themselves that complicated the experimenters' projects).[359] The Advisory Committee found severe ethical problems with these experiments, notably in the failure to disclose to the subjects that they were being injected with radioactive materials and in some cases the failure to even disclose that they were being used in an experiment.[360]

6.4.1.2 Ingestion of Radioactive Materials

Another type of experiment used trace quantities of radioactive isotopes of elements like calcium and iron to study metabolic processes for applications unrelated to the nuclear industry. One of the best-known examples is the nutrition study sponsored by the AEC, the National Institutes of Health, and the Quaker Oats Company at the Walter E. Fernald School in Massachusetts in the late 1940s and early 1950s. Children with developmental disabilities institutionalized at the school were fed cereal that contained very small amounts of radioactive calcium and radioactive iron to study whether the body would successfully absorb nutrients from enriched cereals.[361] Similar to the experiments involving plutonium, polonium, and uranium, the AEC allowed one 10-year-old child at the school to receive 50 times more radioactive calcium than the other children in the study because that child was expected to die from a degenerative disease within a few months. The Advisory Committee discovered that the experimenter's request to the AEC for permission to administer this high dose cited the AEC's previous

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[355] Advisory Committee on Human Radiation Experiments, 262-265.
[356] Advisory Committee on Human Radiation Experiments, 238.
[357] Advisory Committee on Human Radiation Experiments, 334.
[358] Advisory Committee on Human Radiation Experiments, 334.
[359] Advisory Committee on Human Radiation Experiments, 240-252, 262-264.
[360] Advisory Committee on Human Radiation Experiments, 264-269.
[361] Advisory Committee on Human Radiation Experiments, 320.

approval of other investigators administering elevated doses to "moribund patients." The child at the Fernald School died before the experiment was completed.[362]

This experiment had extreme ethical and social justice issues. For example, the school told parents that participating children would be members of a Science Club who got a special breakfast, extra milk, blood tests, and perks including a trip to the beach, but failed to inform them of the radioactive materials in the special breakfast.[363] However, the very small amounts of radioactivity ingested by all but one of the students were highly unlikely to cause any adverse health effects. The Advisory Committee on Human Radiation Experiments estimated in 1995 that the average risk of latent cancers for the Fernald School children was 0.03 percent for radioactive calcium and 0.001 percent for radioactive iron.[364]

6.4.1.3 Exposure to Radiation Sources

The AEC also sponsored research in which humans were exposed to external radiation sources to study the health effects of potential worker exposures, exposures of the public due to nuclear accidents or nuclear war, and exposures of astronauts in space. A noteworthy series of such experiments sponsored by the AEC involved x-ray exposures of 131 prisoners in Oregon and Washington jails during 1963 to 1973.[365] In these studies, prisoners were paid to have their testicles exposed to x-ray doses up to 600 rad to determine the effect on sperm count, hormone production, and other biological functions.[366]

These doses were high enough to produce acute skin burns, but the more significant short-term effects experienced by the participants were side effects from biopsies.[367] The experimenters recognized the risk of damage to genetic material and therefore required prisoners participating in the study to consent to a vasectomy afterwards.[368] One of the researchers estimated about a one in a million chance of testicular tumors (i.e., cancer) resulting from the radiation exposures.[369] The Advisory Committee's 1995 report reasoned that a 600 rad dose to the testicles was equivalent to a whole body dose of about 1 rem and calculated that participants who received that amount of exposure would have a cancer risk of 0.04 percent.[370]

The Advisory Committee found considerable ethical and social justice issues in this study, primarily related to experimentation on imprisoned subjects. The committee also found deficiencies in how clearly the prisoners were informed that testicular cancer was an unlikely but possible outcome of the experiment.[371]

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[362] Advisory Committee on Human Radiation Experiments, 292.
[363] Advisory Committee on Human Radiation Experiments, 343.
[364] Advisory Committee on Human Radiation Experiments, 335.
[365] Advisory Committee on Human Radiation Experiments, 421.
[366] Advisory Committee on Human Radiation Experiments, 424-427.
[367] Advisory Committee on Human Radiation Experiments, 426.
[368] Advisory Committee on Human Radiation Experiments, 424.
[369] Advisory Committee on Human Radiation Experiments, 426.
[370] Advisory Committee on Human Radiation Experiments, 433.
[371] Advisory Committee on Human Radiation Experiments, 439-444.

6.4.1.4 Summary

The AEC's history of human radiation experiments provides insights into its conception of the health effects of radiation and its approach to risk communication to outside parties. The AEC's willingness to sponsor research that exposed human subjects to radiation that promised no therapeutic benefits to the subjects indicates that the researchers and those in the AEC who knew about the experiments accepted a *representation* of ionizing radiation as a tool that with proper controls could be safely wielded to advance scientific knowledge. They likewise appear to have internalized an *identity* of themselves and more broadly the AEC as experts exempt from external scrutiny of their experiments and empowered to accept risks on behalf of others. This latter aspect of AEC's *self-identity* is replicated in its actions and discourse regarding fallout from nuclear weapon testing, discussed in the next section of this dissertation.

Risks of the human radiation experiments included potential adverse health effects for the people exposed in the studies as well as the potential for negative publicity, litigation, career impacts, and other negative outcomes for the AEC and others involved in the experiments if the research were found to cause illness. Despite the NCRP's move away from the concept of a safe threshold for radiation exposure in the early 1950s, the AEC's actions were more consistent with a threshold approach. The AEC allowed experiments with small radiation doses to proceed, and only allowed experiments with larger doses to proceed if the people being exposed were expected to die of other causes in the near future. The researchers involved in testicle irradiation of prison inmates did perceive the potential for heritable genetic damage and dealt with it by requiring the subjects to undergo vasectomies afterwards.

The human radiation experiments also illustrate the AEC's readiness to withhold information about radiation exposures from outside parties. The AEC avoided having to explain its model for the health effects of radiation exposures in some cases by simply not informing research subjects that they were being exposed to radiation. The combination of official secrecy and decision-making that suggests a belief in a safe threshold dose is also evident in how the AEC evaluated and communicated the hazards of fallout from atmospheric testing of nuclear weapons.

6.4.2 Nuclear Weapon Testing

6.4.2.1 The Era of Atmospheric Nuclear Testing

The United States detonated the world's first nuclear explosive atop a tower in a remote area near Alamogordo, New Mexico, on July 16, 1945.[372] This test, named TRINITY, produced the largest manmade explosion the world had ever seen and demonstrated that the plutonium fission weapon developed by America's Manhattan Project would yield devastating results.[373] The AEC went on to conduct more than 1000 nuclear explosive tests after World War II.[374] More than 200 American tests were conducted in the open atmosphere before the United States

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[372] U.S. Department of Energy, *United States Nuclear Tests July 1945 through September 1992*, DOE/NV—209-REV 16 (September 2015), vii, 3.
[373] U.S. DOE (2015), vii, 3.
[374] U.S. DOE (2015), xiv.

and the Soviet Union agreed to the Limited Test Ban Treaty of 1963, which banned testing of nuclear weapons in the atmosphere, oceans, and space.[375] The AEC performed most of its tests on Pacific islands or at the Nevada Test Site north of Las Vegas, with roughly equal numbers of atmospheric tests conducted in Nevada and in remote Pacific islands.[376] President George H.W. Bush announced a voluntary moratorium on nuclear weapon testing by the United States on October 2, 1992; the moratorium is still in place.[377]

TRINITY took place under wartime secrecy, with only the scientists and other personnel involved in the project present to watch the explosion. Others in the vicinity saw an unexpected glow in the distant sky but did not know what they were seeing.[378] The bombings of Hiroshima and Nagasaki revealed America's nuclear weapons to the world. Unlike many of the human radiation experiments discussed above, post-war tests of nuclear weapons were spectacularly public, beginning with tests conducted by the U.S. Army and Navy at Bikini Atoll in the Pacific Ocean.[379] The Army and Navy hosted more than 150 representatives of the media and 16 members of Congress at Bikini Atoll in 1946 to observe for the first two tests (ABLE and BAKER).[380] The tests were intended to demonstrate the effects of nuclear bombs on warships, with a fleet of surplus vessels subjected first to the airborne detonation of a bomb dropped from an aircraft, and then to the detonation of a bomb anchored below the fleet.[381]

The immediate public response to news reports of the tests did not indicate alarm over the radiation from the bombs exploded at Bikini Atoll.[382] However, a special issue of *Life* magazine published on the first anniversary of the tests drew attention to the "awful ubiquity of radioactive elements" from the tests as well as the deaths of a multitude of rats, goats, mice, pigs, and guinea pigs stationed aboard the target ships to gauge the health effects of the radiation from the bombs.[383] A physician who served in the radiological safety organization for the tests drew further attention to the tests' radioactive legacy in 1948 when he published the best-selling book *No Place to Hide*, chronicling his personal experiences measuring the radioactive aftermath of the tests, including the lingering radioactive contamination on the ships and in the local environment.[384]

The American public was fascinated with the post-war weapon tests. Families and school groups travelled to see tests in Nevada, and people lined the beaches of Hawaii to watch the sky light up from distant hydrogen bomb testing in the Pacific.[385] The AEC even promoted one test as "an exciting holiday event."[386] Las Vegas offered views of atmospheric tests conducted about 65 miles away at the Nevada Test Site. Explosion viewing became a popular tourist activity, and

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[375] U.S. DOE (2015), x.
[376] U.S. DOE (2015), xv.
[377] U.S. DOE (2015), ix.
[378] Paul Boyer, *By the Bomb's Early Light* (New York: Pantheon Books, 1985), 6.
[379] Boyer, 90-92.
[380] Caufield, 90-93.
[381] Caufield, 90-93.
[382] Boyer, 84.
[383] Boyer, 90.
[384] David Bradley, *No Place to Hide* (Boston: Little, Brown and Company, 1948).; Boyer, 91.
[385] Boyer, 233-234.
[386] David E. Nye, *American Technological Sublime* (Cambridge: The MIT Press, 1996), 233.

the local Chamber of Commerce printed calendars advertising dates for planned tests.[387] A *New York Times* article published in 1957 offered prospective bomb watchers advice on how to get the most of the experience, including safety tips (e.g., do not look directly at the explosion through binoculars).[388] The article provided directions to choice viewing locations closer to the test site and reassured readers that fallout presented "virtually no danger" even if the cloud from the explosion drifted over the observer's head.[389] It identified "the omnipresent danger of automobile accidents" as the chief hazard in watching a nuclear explosion.[390]

These examples illustrate the AEC's powerful use of the ordering instrument of *making representations* to establish outdoor atomic bomb explosions as safe, exciting, educational, and even fun. This further *represented* radiation as part of a light show that presented no cause for worry, particularly compared to other everyday risks such as automobile accidents.

6.4.2.2 Hazards Posed by Fallout

Despite this *representation* of mushroom clouds as a safe spectacle for the public to enjoy, atmospheric testing of nuclear weapons exposed people around the globe to radioactive contamination in the form of fallout. A nuclear explosion releases several categories of radioactive materials, including highly radioactive isotopes resulting from fission of the nuclear fuel, leftover radioactive nuclear fuel materials (i.e., plutonium, uranium) that did not fission in the explosion, and other materials that become radioactive from exposure to the intense neutron radiation emitted during the nuclear explosion.[391] Compared to an explosion high above the ground, an explosion at or near the Earth's surface produces more fallout as a result of the large amount of soil and other materials vaporized or drawn up into the mushroom cloud.[392] Larger particles of fallout typically deposit on the ground within a day, resulting in relatively local impacts, but fine particles can rise to great altitudes and remain aloft for years, potentially depositing at distant points on the globe.[393] Once testing expanded to include hydrogen bombs with about 1000 times the explosive energy of fission weapons, the AEC identified two categories of delayed, worldwide fallout: tropospheric fallout that would typically deposit within a month after an explosion and stratospheric fallout that rose high into the atmosphere and could remain aloft for five years or more.[394]

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[387] Chris Leadbeater, "All eyes on the legacy of the bomb; Seventy years on from the strike on Japan, Chris Leadbeater tells how the 1950s tourists in Las Vegas celebrated the nuclear era," *The Sunday Telegraph* [London, England], February 22, 2015.
[388] Gladwin Hill, "Watching the Bombs Go Off: Tourists Can See Blasts In Nevada Test Area This Summer," *New York Times*, June 9, 1957.
[389] Hill.
[390] Hill.
[391] W.O. Caster, "From Bomb to Man," in John M. Fowler, ed., *Fallout: A Study of Superbombs, Strontium 90, and Survival* (New York: Basic Books, Inc., 1960), 38.
[392] U.S. Department of Energy, *Fact Book: A Perspective on Atmospheric Nuclear Tests in Nevada*, DOE/NV-296(Rev. 2) (June 1995), 7.
[393] U.S. DOE (1995), 7-8.
[394] C.L. Comar, *Fallout from Nuclear Tests* (Oak Ridge, TN: U.S. Atomic Energy Commission, Division of Technical Information, 1966), 7.

The nature of the hazard from fallout is strongly influenced by delay between a nuclear explosion and the time that a person or a population is exposed to its fallout. Fallout that reaches people in the immediate aftermath of a nuclear explosion contains both a host of short-lived fission products that present an acute exposure hazard as well as longer-lived radioisotopes that pose a longer-term cancer hazard if ingested.[395] Fallout that does not reach people until months or years after a nuclear explosion will only contain the longer-lived radioisotopes. Such fallout poses no acute exposure hazard but may pose a longer-term cancer hazard if ingested. The hazard posed by longer-lived radioactive materials in fallout depends on their abundance, their half-lives, and how they behave once ingested. The AEC identified radioactive isotopes of iodine, strontium, cesium, and carbon as "most likely to represent significant hazards to man" during the atmospheric testing era.[396] Modern analyses reach the same conclusion.[397]

Because of its half-life of eight days, iodine-131 can persist long enough in local and "tropospheric" fallout to enter the food supply via perishable foods that are consumed soon after they are produced (e.g., fresh milk from cows grazing on contaminated land), resulting in internal exposure potentially large enough to produce delayed health effects such as thyroid cancer.[398] (Iodine concentrates in the thyroid gland, making thyroid cancer a particular hazard of ingestion of radioactive iodine.[399]) The long half-lives of strontium-90 (29 year half-life), cesium-137 (30 year half-life), and carbon-14 (5730 year half-life) lead them to pose a long-term cancer hazard in all types of fallout and made them the primary concern for global "stratospheric" fallout from high-yield weapon tests.[400] Strontium-90's beta radiation emissions and affinity for depositing in bones made it the greatest internal exposure hazard from global fallout.[401] Cesium-137 does not have a propensity to lodge in the body but does emit gamma radiation, so it presented the greatest external exposure hazard from global fallout.[402] As will be elucidated in the discussion below, the magnitude of these hazards has been vigorously contested among the actors involved in the public discourse over radiation safety issues.

The most direct impacts on the American public from nuclear weapon testing involved downwinders in Utah and Nevada. Fallout from unconfined nuclear weapon tests at the Nevada Test Site landed on the communities surrounding the site, primarily those to the east due to the prevailing direction of winds. The map in Figure 6-1 below depicts the Nevada Test Site and nearby communities. A 1995 report issued by the Department of Energy (a successor agency to the AEC) states that radiation exposures from fallout produced by above ground nuclear explosions at the Nevada Test Site in the 1950s usually fell to levels slightly above natural background within about 200 miles.[403] Inverting DOE's verbiage, testing in Nevada produced radiation levels from fallout more than slightly above natural background up to 200 miles from

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395 W.O. Caster, 38-42.
396 Comar, 11.
397 Steven L. Simon, André Bouville, and Charles E. Land, "Fallout from Nuclear Weapons Tests and Cancer Risks," *American Scientist* 94 (January-February 2006), 53-56.
398 Simon, Bouville, and Land, 53-56.; Comar, 16-19.
399 Barton C. Hacker, *Elements of Controversy: The Atomic Energy Commission and Radiation Safety in Nuclear Weapons Testing 1947-1974* (Berkeley: University of California Press, 1994), 209.
400 Simon, Bouville, and Land, 55.; Comar, 19-27.
401 Simon, Bouville, and Land, 55.; Comar, 12, 19-24.
402 Simon, Bouville, and Land, 55.; Comar, 24-27.
403 U.S. DOE (1995), 17.

the site. The DOE report states that 95 tests conducted during the 1950s released fallout that was detected offsite, with 17 of them accounting for about 80 percent of the total dose to the offsite public.[404] Accordingly, people in the path of fallout from one or more of those 17 tests received a significant fraction of the cumulative radiation dose delivered to downwinders.

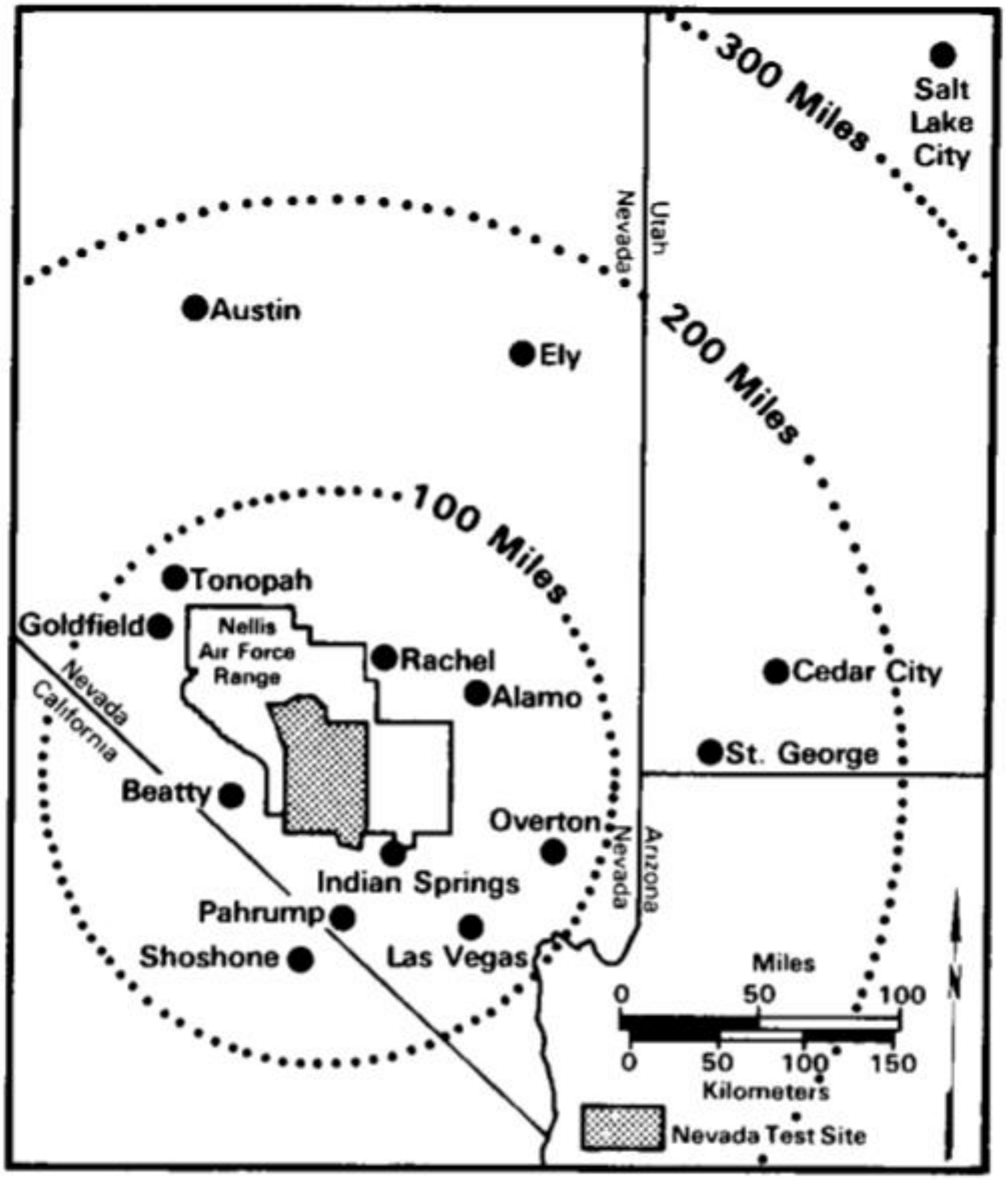

Figure 6-1 Nevada Test Site and Nearby Communities[405]

The AEC did consider the potential exposure to members of the public to fallout before beginning the nuclear tests at the Nevada Test Site. However, AEC's experts decided not to adhere to the NCRP's published guidance on safe limits for occupational exposure to radiation.

[404] U.S. DOE (1995), 17.

[405] Geneva S. Douglas, *A Community Monitoring Program Surrounding the Nevada Test Site: One Year of Experience*, EPA-600/3-83-040, DOE/DP/00539-049 (Las Vegas, NV: U.S. Environmental Protection Agency, May 1983), 5.

Instead, they rationalized that larger exposures were acceptable, because the public would only be exposed to radiation after nuclear tests, whereas radiation workers were continually exposed to radiation.[406] Moreover, the AEC sought to avoid rigid limits for exposures to the public and instead followed "[t]he guiding principle… to assure ourselves that no one gets hurt."[407] Based on the belief that 25 rem "will cause no disability," the AEC determined that members of the public would only be evacuated if exposed to more than 25 rem in four weeks.[408]

By comparison, the AEC at that time was limiting occupational exposures for workers at its nuclear facilities to 0.3 rem per week in accordance with draft guidance the NCRP released in advance of Handbook 59.[409] (Operational realities led the AEC to replace the weekly exposure limit with a quarterly limit of 3.9 rem for workers involved in nuclear explosives testing, as they could reach exposures of multiple rem during a single test.[410]) Additionally, the AEC focused only on the dose from external radiation sources, not from inhaled or ingested radioactive materials. Although the AEC was aware of the potential for intake of radioactive materials and the hazards of the ensuing internal radiation exposure, the AEC for years maintained the public stance that any such exposure was unlikely for members of the offsite public.[411]

In practice, the AEC monitored fallout clouds from tests at the Nevada Test Site and took action to prevent members of the public from being exposed to radiation levels judged at the time to be too high. Measures included stationing workers offsite to monitor radioactive plumes from tests and working with local authorities to take protective actions, which included closing roads and urging people to stay in their vehicles or go indoors when radioactive plumes were detected.[412] The AEC also engaged in mild cleanup such as washing citizens' vehicles that had been showered in fallout.[413] The AEC explained these actions by assuring the public that although they were not being exposed to hazardous levels of radiation, it was AEC policy "to limit unnecessary exposure to radiation."[414] The AEC's *discourse* and actions served as an ordering instrument *making representations* of radioactivity as possibly not having a safe exposure threshold but posing a small enough risk that stronger measures to reduce or eliminate public exposures were not warranted. Furthermore, the AEC's *discourse* and actions conveyed the *representation* that fallout's only hazard to the public came from external exposure to gamma rays in the immediate aftermath of a test. AEC conveyed a *representation* of fallout that did not include any hazards associated with potential inhalation or ingestion of radioactive materials released into the environment.

Over time, the AEC settled on an exposure limit for the public near the Nevada Test Site of 3.9 roentgen per year, one-fourth of the occupational exposure specified for AEC's workers at the site, but quietly established the policy that it would consider evacuating the public to escape

[406] Caufield, 104.
[407] Hacker (1994), 46.
[408] Caufield, 104.
[409] Hacker (1994), 46.
[410] Hacker (1994), 90, 119.
[411] Caufield, 125-126.
[412] Hacker (1994), 102-104.
[413] Hacker (1994), 103-104.; Allan M. Winkler, *Life Under the Cloud: American Anxiety About the Atom* (Urbana and Chicago: University of Illinois Press, 1999), 93.
[414] Hacker (1994), 103-104.

fallout only if exposures were predicted to exceed 30 roentgen after a test.[415] The AEC decided to adopt this reduced annual exposure limit on the grounds that exposures to large populations should be controlled to a lower level than allowed for occupational exposures.[416] This reflects a philosophy that the dose limits do not represent a safe threshold, and that the overall risk of adverse health effects is a function of the exposure's magnitude and the number of people exposed.

No immediate human injuries were reported as a result of fallout near the test site, but local ranchers complained that their livestock suffered injuries consistent with acute radiation burns as well as unexplained illnesses and deaths among their livestock after some tests.[417] The AEC investigated these claims and in some cases reimbursed ranchers for their losses.[418] However, the AEC also engaged in a protracted effort to prove that radiation was not responsible for "unusually large numbers" of sheep and lambs falling ill and dying in 1953 after the UPSHOT-KNOTHOLE test series.[419] This argument ended up in court, with the AEC prevailing over the ranchers in 1956.[420]

6.4.2.3 Military Participants in Nuclear Tests in Nevada

In addition to the AEC employees and contractors engaged in conducting the testing program at the Nevada Test Site, the various branches of the United States military forces sent officers and enlisted personnel there to experience nuclear explosions first-hand, in order to gain experience in fighting a nuclear war. From 1951 to 1962, thousands of ground troops witnessed above ground nuclear tests at distances ranging from 1-1/2 to 12 miles, in some cases advancing to within a few hundred yards of ground zero shortly after the explosion.[421]

Military leaders expressed dissatisfaction with the first tests involving soldiers, voicing the concern that the AEC needed to allow the soldiers to experience the blast from closer range in order to have a "tactically realistic" demonstration.[422] Military leaders further argued that AEC's occupational limits for radiation exposure should not apply to members of the military who would participate in a single exercise at the Nevada Test Site and leave, and that the then-prevailing limit of 3 roentgen per test (derived from the AEC's quarterly exposure limit of 3.9 rad) would "unduly hamper military experimentation."[423] In subsequent tests, the Army set its own limits for the military exercise participants: 6 roentgen per test for most troops and up to 10 roentgen per test for officers who volunteered to serve as special observers witnessing tests from as little as 2000 yards from ground zero (with a total limit of 25 roentgen for volunteers

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[415] Hacker (1994), 120, 163-164, 186.

[416] Robert A. Divine, *Blowing on the Wind: The Nuclear Test Ban Debate, 1954-1960* (New York: Oxford University Press, 1978), 121.

[417] Divine, 106, 107.

[418] Divine, 107.

[419] Divine, 107-115, 123-129.

[420] Divine, 129.

[421] Allan Favish, "Radiation Injury and the Atomic Veteran: Shifting the Burden of Proof on Factual Causation," *The Hastings Law Journal* 32:4 (1981), 933-936.

[422] Hacker (1994), 76, 92.

[423] Hacker (1994), 92.

witnessing multiple tests).[424] After all of these limits were exceeded by some troops and officers during a test series in 1953, military leadership recommended further raising the limits to ensure they did not constrain exercises at the test site.[425] (The AEC also regularly encountered overexposures among the people involved in conducting tests, notably the air crews who flew through the clouds from explosions to collect samples for analysis.[426]) Consistent with AEC practices at the test site, these limits did not account for the effects of inhaling or ingesting radioactive fallout from the nuclear explosions.

The military's preferred approach at the Nevada Test Site therefore was to establish training objectives and then set exposure limits that were compatible with those objectives. It is difficult to equate that approach with any reasonable interpretation of the ALARA concept. The military's approach appears to reflect a belief that a threshold dose existed at some level above the exposures allowed at the test site, or that those doses presented an acceptable level of risk relative to the benefits gained. Accordingly, the military operated under a *representation* of radiation as a risk that was smaller than the risk of not being prepared to fight a nuclear war with America's enemies. It also cultivated an *identity* for the American soldier as a warfighter unafraid to leap out of his trench and run toward a mushroom cloud to defend democracy. If this characterization seems facetious, consider the well-known propaganda film China released after its first nuclear weapon test in 1964, depicting an "atomic-age cavalry charge forward into the nuclear battlefield, soldiers shooting from the saddle."[427] Clearly, America's foes also employed the ordering instrument of *making representations* of fallout as less risky than being unready to wage a nuclear war.

6.4.2.4 An Aside on Compensation for Losses and Injury

The ranchers who lost their lawsuit seeking compensation for livestock losses successfully petitioned to have their case reopened in 1982 when previously unavailable AEC documents were declassified due to other litigation and congressional inquiry.[428] The newly available documents convinced the judge that the government had perpetrated "fraud upon the court" in 1956 by making false or misleading statements, pressuring witnesses, and withholding or misrepresenting information.[429] The decision to reopen the case was itself overturned on appeal by the government in 1985 on the grounds that fraud had not been demonstrated.[430] Although the ranchers' case and every other Nevada downwinder case ultimately failed in court, the downwinders won compensation through congressional action. President George H. W. Bush signed the Radiation Exposure Compensation Act into law in 1990. The law provides for downwinders who contracted specific diseases after living in specific places during specific

[424] Hacker (1994), 96.
[425] Hacker (1994), 97-99.
[426] Hacker (1994), 71, 80.
[427] Gerard J. DeGroot, *The Bomb: A Life* (Cambridge, MA: Harvard University Press, 2004), 266.
[428] James Rice and Julie Steinkopf Rice, "'Radiation is Not New to Our Lives': The U.S. Atomic Energy Commission, Continental Atmospheric Weapons Testing, and Discursive Hegemony in the Downwind Communities," *Journal of Historical Sociology* 28:4 (December 2015), 513.
[429] Rice and Rice, 513.
[430] U.S. DOE (1995), 28-29.

times to receive monetary compensation without needing to prove that their health conditions were caused by exposure to fallout.[431]

The National Defense Authorization Act for Fiscal Year 1991 amended the Radiation Exposure Compensation Act of 1990 to add benefits for people who "participated on site in a test involving the atmospheric detonation of a nuclear device." The amended law provides for members of the military and workers at the site who contracted specific diseases to receive monetary compensation without needing to prove that their health conditions were caused by exposure to radiation from the blast or fallout.[432] As of February 5, 2021, this program had awarded more than $2.4 billion to 23,959 downwinders, 4954 people exposed at the Nevada Test Site (including uniformed military personnel, civilian employees of the military and other government agencies, and contractor employees), and 8891 uranium industry workers.[433]

The Radiation Exposure Compensation Act was an important ordering instrument in formally validating identities taken on by people affected by the government's nuclear programs, notably the *downwinder* and the *atomic veteran*. It also formally recognized the *representation* of nuclear fallout as a health hazard, despite many years of efforts by the AEC to represent it as trivial. It is noteworthy that these representations of the identities of people and the nature of radiation were made in the political venue of Congress after the courts were unable to agree upon any such representations or identities.

6.4.2.5 Fallout in the Environment

Despite the public posture that the only hazard of fallout was exposure to external radiation from short-lived radioisotopes, the AEC did seek to understand the hazards of fallout released into the environment. The Manhattan Project had fortuitously been informed of how far radioactive fallout could travel by the Eastman Kodak Company soon after the 1945 TRINITY test explosion in New Mexico.[434] Following TRINITY, Kodak's customers complained about defective photographic film, leading Kodak to discover that cardboard packaging materials fabricated in Indiana in 1945 were radioactive. Radiation from the cardboard had ruined the film within. Kodak identified the radioactive contaminant as cerium-141, a radioisotope not found in nature, shared their findings with the Manhattan Project, and eventually linked the contamination to fallout from TRINITY.[435] Kodak again alerted the AEC to long-range fallout after the very first explosions at the Nevada Test Site in 1951. Even though the first two test explosions were less than 10 kilotons (smaller than TRINITY), Kodak detected radioactive particles in air filters at its plant in Rochester, New York, after the tests and immediately complained to the AEC.[436]

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[431] U.S. DOE (1995), 30-31.
[432] U.S. DOE (1995), 30-31.
[433] U.S. Department of Justice, *Awards to Date*, https://www.justice.gov/civil/awards-date-02052021 (accessed February 6, 2021).
[434] J.H. Webb, "The Fogging of Photographic Film by Radioactive Contaminants in Cardboard Packaging Materials," *Physical Review* 76:3 (August 1, 1949), 375-380.; Oak Ridge Associated Universities Health Physics Historical Instrumentation Museum Collection, *Kodak Film Fogged by the Trinity Test (1945)*, https://www.orau.org/ptp/collection/hiroshimatrinity/kodakfilm.htm (accessed February 27, 2021).
[435] ORAU Health Physics Historical Instrumentation Museum Collection.
[436] Hacker (1994), 51.

Subsequently, the AEC established a sampling network to monitor fallout across the country and eventually worldwide.[437]

The AEC commissioned two secret surveys, Project Gabriel and Project Sunshine, to investigate the health hazards of fallout in the late 1940s and early 1950s.[438] A scientist at the AEC's Oak Ridge National Laboratory undertook Project Gabriel in 1949, when America's nuclear weapon testing program was still based on remote Pacific islands.[439] Project Gabriel evaluated the broader consequences of nuclear war between the United States and the Soviet Union, concluding that ingestion of strontium-90 might be the greatest long-term hazard from the fallout from a large-scale exchange of nuclear weapons.[440] The AEC revived this study in 1953 and expanded it as Project Sunshine to include collection of samples of plants, soils, and human bones (with a particular emphasis on the bones of infants) from around the world to measure the actual uptake of strontium-90 from fallout by living things.[441] When the AEC published an unclassified summary of Project Sunshine in 1956, it stressed that America's nuclear testing program presented no health hazards to the public.[442] The summary concluded, "The weapons tests are conducted with great attention to this and the other dangers and every effort made to protect against misadventure. What we have learned from the studies I have described—which by the way have been conducted under the name Project Sunshine—is that these local precautions should be entirely adequate and the worldwide health hazards from the present rate of testing are insignificant."[443]

The AEC's use of the ordering instrument of *making discourses* in communicating the results of its fallout studies sought to continue to *represent* radiation as a manageable hazard and fallout as inconsequential. Moreover, it reinforced the AEC's desired *identity* as a collection of experts who placed great emphasis on controlling radiation so that the citizens need not concern themselves about it.

Before the AEC released information from Project Sunshine to the public, fallout made a grand entrance onto the world stage, not as a result of the AEC's activities at the Nevada Test Site, but from the AEC's detonation of a gargantuan hydrogen bomb at Bikini Atoll in the Pacific Ocean. This event, CASTLE BRAVO, performed on March 1, 1954, tested an early hydrogen bomb design.[444] The bomb's explosive yield was much larger than expected, and an unexpected wind shift deposited radioactive ash on ships in the U.S. Navy task force on scene to support the test, on several islands that had not been evacuated, and on a Japanese fishing vessel, the *Lucky Dragon*.[445] The U.S. Navy decontaminated its ships and evacuated the islands after the test but took several days to move all 236 of the Marshall Islanders affected by the fallout.[446] As a result, many of the Marshall Islanders received large enough radiation exposures to suffer

[437] Hacker (1994), 51.
[438] Caufield, 126.; Hacker (1994), 181.
[439] Hacker (1994), 181-82.
[440] Hacker (1994), 181-82.
[441] Hacker (1994), 183.
[442] W. F. Libby, "Radioactive Fallout and Radioactive Strontium," *Science* 123:3199 (April 20, 1956), 657-660.
[443] Libby, 660.
[444] Winkler, 93-94.; Divine, 3.
[445] Divine, 3-4, 6-7.
[446] Divine, 4.

painful radiation burns, hair loss, and low blood counts.[447] The AEC did not disclose the fallout problem until a letter from a serviceman in the Navy task force appeared in a Cincinnati newspaper ten days after the test.[448] At that point, the AEC issued a press release acknowledging the numbers of Americans and Marshall Islanders who had been exposed to radiation "during a routine atomic test" but asserting that all of them were well, none were burned, and they would return home after the CASTLE test series was complete.[449] This use of the ordering instrument of *making discourses* fell in the category of "*making false representations*," and it did not age well.

The unexpected presence of the *Lucky Dragon* just outside the defined exclusion zone for the test led to the public discovery of what really happened on March 1.[450] Only one member of the crew on the *Lucky Dragon* was on deck when the bomb detonated, and the crew did not realize that he had witnessed a nuclear weapon test.[451] As a result, the *Lucky Dragon* received no special attention until it arrived in Japan on March 14 with the crew of 23 suffering from radiation sickness.[452] One member of the crew eventually died in September.[453] Panic and furor erupted in Japan, including violent anti-American protests in the streets.[454] The situation became front-page news in America.[455]

On March 31, the head of the AEC addressed the news media after a Presidential news conference to provide an official statement on the CASTLE BRAVO test.[456] He primarily blamed the unexpected wind shift for the fallout problem and claimed that the *Lucky Dragon* had trespassed into the restricted zone for the test.[457] He extolled the excellent care being provided to the exposed Marshall Islanders and said that reports indicated that the Japanese fishermen would likewise recover.[458] He admitted that the test had caused a slight rise in radiation in the continental United States but asserted that it was "far below the levels which could be harmful in any way to human beings, animals, or crops" and that the test would provide enduring gains for America's military posture.[459] His statement continued the AEC's work of *making representations* of radiation as controllable and of fallout as presenting a risk far smaller than the risk of not testing ever-larger nuclear weapons.

6.4.2.6 Radioactive Iodine Recognized as a Hazard After CASTLE BRAVO

Despite the AEC's emphasis on the absence of evidence of prompt effects of external radiation exposures from fallout, ingestion of radioactive isotopes of iodine emerged as a

[447] Divine, 4.
[448] Divine, 6.
[449] Divine, 6.
[450] Divine, 4
[451] Divine, 4-5.
[452] Divine, 7.
[453] Divine, 30.
[454] Divine, 7.
[455] Divine, 8.
[456] Divine, 12.
[457] Divine, 12.
[458] Divine, 12.
[459] Divine, 12.

recognized fallout hazard in the years following CASTLE BRAVO. Several different sources of information led to this realization:

- In 1957, the nuclear reactor at Windscale in the United Kingdom suffered a fire that led to the release of large quantities of radioactive iodine. Radiation surveys after the fire showed the risk posed by the "forage-cow-milk-human" pathway for ingesting radioactive iodine.[460]
- In 1962, fallout from the SEDAN test—a "cratering" experiment using a 100 kiloton nuclear explosive buried 635 feet underground at the Nevada Test Site—resulted in iodine-131 levels in milk samples that alarmed state and city officials in Salt Lake City. In response, they urged milk producers take precautions such as providing dry feed for their livestock instead of allowing them to graze and processing the contaminated milk into cheese or powdered milk to allow time for the radioactive iodine to decay before it would be consumed.[461]
- As noted previously in this dissertation, researchers studying illnesses among the survivors of the Hiroshima and Nagasaki bombings published findings in 1962 that linked thyroid cancers to radiation exposure.[462]
- In the 1960s, evidence began to emerge of thyroid illnesses among the Marshall Islanders exposed to CASTLE BRAVO fallout. Thyroid tumors, hypothyroidism, and children not growing at normal rates all indicated harmful ingestion of radioisotopes of iodine.[463]

In the early 1960s, an AEC mathematician (Harold A. Knapp) attempted to estimate thyroid doses for children living downwind of the Nevada Test Site during the 1950s. His analyses were met with skepticism within the AEC, but he estimated that children may have suffered radiation doses on the order of hundreds of rads to their thyroids.[464] In an effort to resolve controversy over such exposures, the Public Health Service in the mid-1960s studied thyroid maladies among 2000 children in a part of Utah that had received significant fallout during the 1950s but reported overall inconclusive results and no cancers.[465]

6.4.3 AEC Articulation of the Health Effects of Fallout—Making Discourses to Enroll the Public

The AEC engaged in a vigorous public relations campaign to convince the American public that any health risks posed by fallout were small and justified by the importance of the nuclear testing program to national security. This effort began before the CASTLE BRAVO debacle and continued in the years afterward. As part of this strategy, the AEC distributed pamphlets in the communities downwind of the Nevada Test Site in 1953, 1955, and 1957.[466] An analysis of the AEC's pamphlets, published by Rice and Rice in 2015, found that the word "cancer" only appeared four times, "leukemia" once, and "thyroid cancer" also once, in nearly

[460] Hacker (1994), 209.
[461] Hacker (1994), 219-221.
[462] Hollingsworth *et al*, 47-71.
[463] Hacker (1994), 227.
[464] Hacker (1994), 222-225.
[465] Hacker (1994), 228-230.
[466] Rice and Rice, 492.

30,000 words of text.[467] Rice and Rice further noted that at the time the pamphlets were written, cancer and leukemia were known to be associated with radiation exposure,[468] so this omission appears to be part of the AEC's strategy for obtaining consent to the testing. They also found little mention of terms such as "chronic," "long-term," and "cumulative."[469] They attributed this to a desire by the AEC to focus discussion on the acute symptoms, which happen at higher levels of exposure, and to avoid discussing chronic and long-term health effects of radiation exposure from fallout.[470] Rice and Rice also observed that the pamphlets failed to discuss the fact that radiation affects children, infants, and pregnant women differently from women who are not pregnant and men.[471]

Rice and Rice also observed that the AEC pamphlets sought to naturalize radiation to the public. Rice and Rice found that the words "background" and "natural" frequently accompany the word "radiation" in the pamphlets.[472] The 1953 pamphlet emphasizes that "man always has lived in a sea of radiation." The pamphlets also discuss the everyday applications of manmade radiation, such as dental x-rays, other medical applications, and industrial uses.[473]

In addition to distributing pamphlets in the communities around the test site, the AEC produced films providing the government's view on the need for atmospheric testing of nuclear weapons in Nevada and the associated hazards and screened the films in the towns around the site.[474] For example, the film *Atomic Tests in Nevada: The Story of AEC's Continental Proving Ground* (preserved on the Internet Archive website)[475] argues that testing in Nevada is "essential in the world of today to our existence as a nation" and that the risk to citizens is negligible. The narrator acknowledges that fallout sometimes lands on communities near the site, such as St. George, Utah, but explains that radiation from space and from the earth is part of nature and that "radiation from fallout temporarily adds to that level." He then assures the viewer that the AEC takes stringent precautions to make sure that testing in Nevada adds as little as possible to the natural background radiation and that, while there is some potential risk, the added radiation is "far below harmful amounts" away from the "outdoor laboratory" that is the test site. The narrator points out that helicopters warn "hunters, hikers, and desert migrants" to avoid the test site region but admits that livestock near the test site suffered radiation burns and eye injuries in a few instances (while noting that the government compensated ranchers for any injured livestock). He further cites the support of the Public Health Service and "special Air Force planes" in measuring the radiation from tests and alerting towns when precautions such as sheltering indoors are warranted. He states that these sheltering instructions are issued, not because the levels of radiation from a fallout cloud that may reach a town pose any hazard, but because "it is the AEC's policy to keep to a minimum any exposure of persons to radiation" and that this represents "good common sense."

[467] Rice and Rice, 505.
[468] Rice and Rice, 505.
[469] Rice and Rice, 505.
[470] Rice and Rice, 505.
[471] Rice and Rice, 506.
[472] Rice and Rice, 508.
[473] Rice and Rice, 509.
[474] Hacker (1994), 190.
[475] U.S. AEC and Department of Defense, *Atomic Tests in Nevada: The Story of AEC's Continental Proving Ground* (circa 1955), https://archive.org/details/40982AtomicTestInNevada (accessed September 21, 2020).

Figure 6-2 Images from AEC's film *Atomic Tests in Nevada*

This film is an excellent example of how the AEC harnessed the organizing instruments of *making discourses*, *making representations*, and even *making institutions* to advance its vision for radiation safety and the development of nuclear technologies. The film *represents* the U.S. military as the AEC's partner in the entire atomic testing effort, beginning with sharing the opening credits of the film and including the military playing a key part in monitoring the spread of fallout from test explosions (and of course, being the customer for the nuclear weapon programs). It also cites the integral role of the Public Health Service in ensuring public safety with respect to the testing program, with the clear implication that the Public Health Service agrees with the AEC's views on radiation safety. These *representations* reinforce the AEC's status as the *institution* empowered to mediate America's relationship with nuclear technologies and radiation by connecting it to the power of the military and the trustworthiness of the Public Health Service.

The film *makes representations* of the hazards of radiation exposure consistent with the radiation protection philosophy embodied in the safety measures for the atmospheric testing program described earlier in this chapter. The film admits that radiation exposure carries with it some health risk (i.e., there is no safe threshold for radiation exposure) but also states that the exposures experienced by the public are "far below harmful amounts." Taken together, these statements could be viewed as contradictory (i.e., a safe threshold either does or does not exist), but the AEC uses this *discourse* as a means for *representing* radiation as having vanishingly small health risks at small levels of exposure. By *representing* nuclear weapon testing as essential to ward off existential threats to the United States, the film's *discourse* seeks to establish the risk from radiation as inconsequential in comparison. Moreover, the film continued the AEC's tactic of *making representations* that the hazard of concern for fallout was external exposure to gamma rays in the immediate aftermath of a test. By omitting any discussion of potential inhalation or ingestion of radioactive materials, particularly radioactive iodine, the AEC advanced a *representation* of fallout that did not include such hazards.

The AEC continued to publish a broad range of informational and educational materials intended to promote a wide range of nuclear activities during the 1960s. The series titled "Understanding the Atom" included more than 50 different booklets on topics including fallout from atmospheric testing of nuclear weapons and the health effects of radiation exposure that the AEC made available at no cost to individuals, teachers, and school or public libraries.[476]

The most pertinent of these booklets—*Fallout from Nuclear Tests*—opens with the assertion that "Apprehension and a degree of controversy" about fallout resulted from "lack of knowledge of the nature of fallout, from its association with nuclear armaments, and the involvement of personal convictions."[477] This opening therefore immediately discounts any potential health effects from exposure to fallout and establishes that the AEC viewed the controversy in terms of the deficit model of scientific understanding (i.e., the only reason the public was apprehensive about fallout was because they lacked the information needed to understand that it posed no hazard to them).[478] This can be viewed as an application of the ordering instrument of *making representations*—it *represented* persons concerned with fallout as being ignorant of the facts, being opposed to nuclear weapons, or being ruled by unspecified "personal convictions." Given that the citizens exposed to fallout had good reason to be concerned, it would be fair to conclude that the AEC's discourse constructed *misrepresentations* about them. Conversely, the AEC's booklet could be viewed at *representing* persons unconcerned by fallout as well-informed patriots.

By making this booklet available, the AEC sought to resolve public concern by remedying the deficit in understanding that it perceived among the public. It is important to note that unlike the pamphlets that Rice and Rice analyzed, this booklet was produced after the United States and the Soviet Union ceased atmospheric testing of nuclear weapons, so it was primarily concerned with the effects of radioactivity in the environment from previous years of atmospheric tests.

The booklet explained the types of ionizing radiation and described how a nuclear explosion produces local and worldwide fallout, including an acknowledgment that scientists did not fully understand phenomena governing how and when fallout propelled into stratosphere by megaton-scale explosions eventually finds its way back to the surface.[479] It further explained that local fallout can present a hazard in areas "far removed" from the blast effects of a nuclear explosion but noted that the hazard dwindles quickly due to radioactive decay and cites "civil defense experts" who recommended minimizing exposure by remaining shielded from local fallout for as much time as possible.[480] The booklet further explained that it is important to avoid

[476] Comar.
[477] Comar, 1.
[478] Molly J. Simis, Haley Madden, Michael A. Cacciatore, and Sara K. Yeo, "The lure of rationality: Why does the deficit model persist in science communication?" *Public Understanding of Science* 25:4 (2016), 400-414.
[479] Comar, 2-7.
[480] Comar, 9.

inhaling or ingesting air, food, or water contaminated by local fallout but related this danger to nuclear war, not nuclear bomb testing.[481] The booklet reassured the reader that local effects from fallout from American nuclear testing are no cause for concern, asserting that "Those responsible for nuclear tests have located test sites in places far removed from human habitation and have selected test times with due attention to weather conditions. Consequently, the local fallout from tests has produced relatively little hazard to human beings."[482] However, beginning 7 pages later, the booklet noted that radioiodine releases were poorly characterized during the atmospheric testing era and acknowledged "suggestive evidence" that radioactive iodine found in the United States beginning in the fall of 1961 may have "escape[d]" from underground tests of nuclear weapons in Nevada.[483]

Having thus dispensed with the concerns that later would lead to more than a billion dollars in reparations to downwinders and people exposed at the Nevada Test Site, the booklet then turned its attention to global fallout from megaton-scale weapons, upon which it said concerns have "properly" been focused.[484] It provided a discussion similar to that provided earlier in this dissertation to explain what characteristics make particular radioisotopes stand out as potential health concerns in global fallout, concluding that the primary radioactive materials of concern are iodine-131, strontium-90, strontium-89, cesium-137, and carbon-14.[485] The booklet noted that different radioactive materials can concentrate in different organs (e.g., iodine's affinity for the thyroid gland, strontium's affinity for bones).[486] It provided diagrams such as the example in Figure 6-3 below showing the pathways that lead to ingestion of each of these radioactive materials by the public.

After providing estimates for the level of radioactivity in the environment from past atmospheric testing, and noting that people on average in 1964 ingested much more radioactivity from naturally occurring potassium-40 in food than from cesium-137 and strontium-90 in fallout, the booklet turned its attention to the health effects of radiation exposure.[487] The booklet provided a basic summary of the units of radiation exposure, differentiated between somatic effects and genetic effects of radiation exposure (listing leukemia, bone cancer, and lifespan shortening as somatic effects), and noted that the average person's exposure to naturally occurring radiation is about 7 to 10 rads in a 70-year lifetime.[488] It further noted that there was "some belief that a very small portion of the number of cases of cancer and genetic abnormalities" could be attributed to naturally occurring radiation but contended that the available knowledge could not resolve whether or not this belief was true.[489] The booklet then addressed the dose-response relationship for radiation exposures, providing the diagram shown in Figure 6-4 below to guide the discussion.

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[481] Comar, 10.
[482] Comar, 10.
[483] Comar, 17-19.
[484] Comar, 17-19.
[485] Comar, 10-11.
[486] Comar, 16, 20.
[487] Comar, 27.
[488] Comar, 27-28.
[489] Comar, 28.

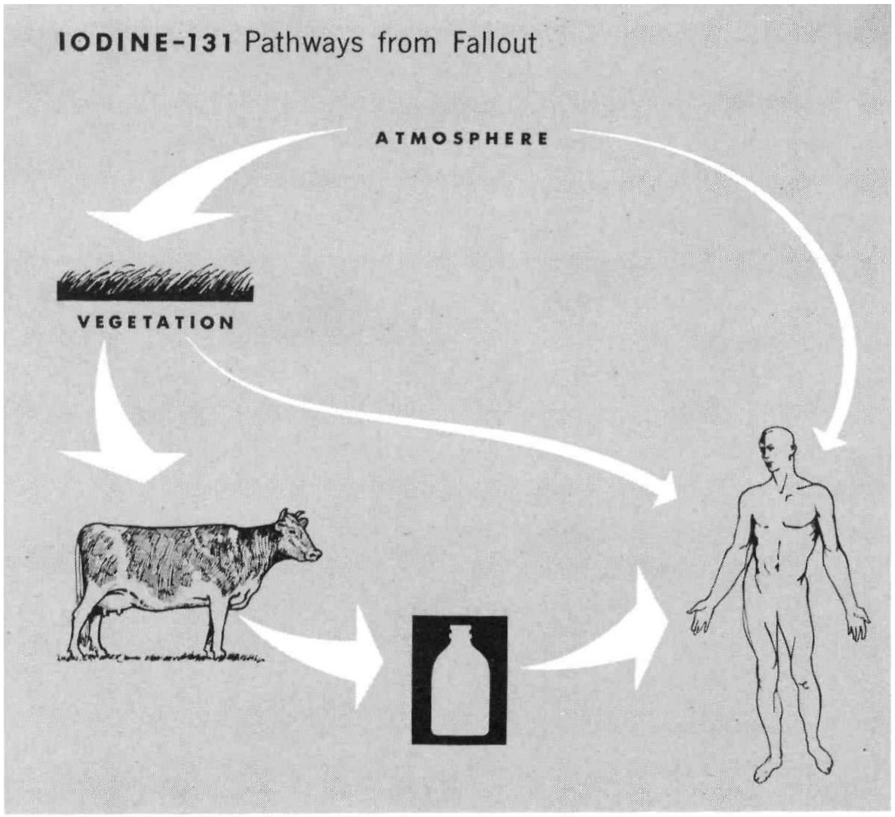

Figure 6-3 Pathways for Ingestion of Radioiodine from Fallout[490]

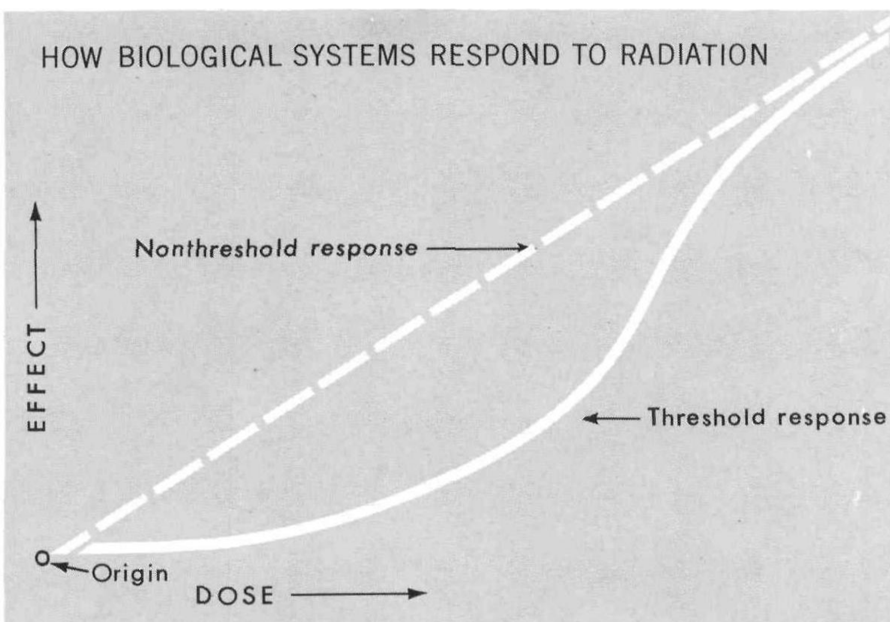

Figure 6-4 Biological Effects of Ionizing Radiation[491]

[490] Comar, 17.
[491] Comar, 30.

The booklet explained that scientists generally agreed there was no threshold exposure below which genetic effects would not take place (although they "may be minor or delayed for generations") but stated there was "scientific controversy" over whether or not a threshold existed for somatic effects.[492] It continued by providing estimates for average lifetime radiation doses in the United States from exposure to global fallout from past atmospheric testing produced by the Federal Radiation Council (another actor to be discussed later in this chapter): 0.46 roentgen to the bones, 0.22 roentgen to the bone marrow, and 0.13 roentgen to the reproductive cells.[493] The booklet included a footnote stating that these estimates excluded prior exposure to radioactive iodine, because it does not persist for a long time after a nuclear test, but acknowledged that doses from radioiodine after a test could average 0.1 to 0.2 roentgen per year for infants (and 0.01 to 0.02 roentgen for older people), with limited local areas having exposures many times larger.[494]

The booklet provided estimates for the health impacts for such exposures (excluding radioactive iodine), attributed to the Federal Radiation Council without any indication of how they were calculated. Review of FRC publications from that time period indicates that the AEC booklet had obtained the estimates from a 1962 FRC report on the health effects of fallout (see the discussion on the FRC later in this chapter).[495] The applicable table from the AEC booklet is reproduced below in Figure 6-5:

Table 2

ESTIMATED NUMBER OF GROSS DEFECTS, LEUKEMIA, AND BONE CANCER CASES IN THE UNITED STATES

Conditions	Time span	Causes other than radiation	Caused by Radiation: Background	Caused by Radiation: Fallout*
Gross physical and mental defects	Children of persons now living	4,000,000 to 6,000,000	no estimate given	20 to 500
Leukemia	In next 70 years	840,000	0 to 84,000	0 to 2,000
Bone cancer	In next 70 years	140,000	0 to 14,000	0 to 700

Source: Federal Radiation Council.
*Tests through 1962.

Figure 6-5 Estimated Genetic and Somatic Effects of Radiation vs. Other Causes[496]

These estimates allow for the possibility of a threshold for somatic effects by showing the number of cases of leukemia or bone cancer potentially being zero, but they do not similarly suggest the potential for a threshold for genetic effects (termed "gross physical and mental

[492] Comar, 30-31.
[493] Comar, 32.
[494] Comar, 32.
[495] Federal Radiation Council, *Report No. 3: health implications of fallout from nuclear weapons testing through 1961* (Washington, DC: U.S. Government Printing Office, May 1962).
[496] Comar, 33.

defects" in the table reproduced above). They further indicate that the estimated number of cases from fallout is much smaller than that attributable to background radiation, which in turn is a fraction of that attributable to other causes. The booklet stated in conclusion that "The consensus of informed individuals is that the present or anticipated levels of radiation exposure from fallout due to nuclear tests (through 1962) do not constitute a hazard that warrants anxiety."[497] However, in an apparent acknowledgment that a non-threshold model for radiation health effects may be correct, the booklet also concluded that fallout's cost to society is "probably not zero" and that any action that would produce fallout or other radiation exposure should consider whether the associated societal benefits are "well worth the biological cost."[498] The booklet closed with a list of aspects of radiation and fallout still under research, including the potential for differing sensitivity to radiation among the unborn, the sick, the young, and the old (a topic that Rice and Rice found unaddressed in the earlier AEC pamphlets distributed in downwind communities).[499]

Overall, the AEC booklet propagated *discourse* aimed at *making representations* of fallout as an inconsequential hazard compared to natural sources of radiation, backed up by the additional *representation* of nuclear weapon testing being essential to ward off even greater threats to the United States. The invocations of naturally occurring sources of radiation in the AEC's discourse appear aimed at *making representations* of artificially produced radioactive materials as not so different from the Earth's natural environment. Finally, it *represented* the AEC as the source of valid knowledge regarding fallout and *represented* those who may have disagreed as either uninformed or having some agenda other than the simple facts.

6.4.4 Sociotechnical Imaginary of the AEC

Analysis of the AEC's use of the ordering instruments of co-production suggests the core elements of the sociotechnical imaginary that animated the AEC through the years of atmospheric testing. Similar to the NCRP, the AEC's discourse emphasized the technical expert and reinforced the expert's stature and authority in making decisions in matters of radiation protection. The AEC's imaginary in particular endowed the technical authority with the unquestioned right to accept risk on behalf of others. More broadly, the AEC's imaginary included a government whose institutions made decisions on behalf of the public, as opposed to involving the public in its plans and decisions. The AEC's imaginary also had a clear vision of an America in which national security was achieved through military might, as opposed to other routes of achieving security. Like the NCRP, the AEC's imaginary had faith in science and believed in technology as key to human progress. Lastly, and again like the NCRP, the AEC's institution-building efforts indicate an imaginary that believed in society's institutions and saw them as instrumental in safely reconciling new technologies with society.

The AEC's principal pollution metaphors are borne out in its public *discourse* on fallout. The AEC's discourse on fallout often emphasized natural sources of radioactivity, so it appears that the AEC was disinclined to consider artificially created radioactive materials to represent pollution of nature. The AEC appeared most concerned that its plans for technological and

[497] Comar, 38.
[498] Comar, 38.
[499] Comar, 39.

scientific progress may be contaminated by interference from outsiders, particularly if intervention attempts involved political, social, or ethical concerns. And of course, the AEC appeared quite concerned about intrusion of foreign influence into America in the form of nuclear war.

6.5 National Academy of Sciences' BEAR Reports

The shift in messaging between the 1950s-vintage AEC brochures that Rice and Rice critiqued and the 1960s-vintage booklet reviewed above may reflect the impact of the National Academy of Sciences' BEAR report, issued in 1956 and updated in 1960.[500] Although the BEAR study was funded by the Rockefeller Foundation, the foreword to the 1956 BEAR report notes that "Primary mention should be made to the cooperation of the United States Atomic Energy Commission and the Department of Defense" in the conduct of the study.[501] This indicates that the AEC's efforts toward expanding its institutional reach had extended into the National Academy of Sciences and also suggests that the AEC would be receptive to the results of the BEAR study. Although not stated in the BEAR report, the Chairman of the AEC asserted to the National Security Council in 1955 that the BEAR study was being performed at the request of the AEC.[502] Moreover, many AEC scientists served on BEAR committees and subcommittees, and Shields Warren (who led the AEC's Division of Biology and Medicine from 1948 to 1952) led the 1956 BEAR study's Pathology Panel, which covered occupational exposure to radiation.[503] The actor-network legitimating the results of the BEAR report extended overseas to England, which engaged in a parallel effort led by its Medical Research Council (MRC). Even though the BEAR and MRC efforts were represented as independent reviews that arrived at similar conclusions, the two groups exchanged information and drafts of their reports and eventually released their reports on the same day, June 12, 1956.[504] This could hardly have been a coincidence, and it indicates mutual use of the ordering instrument of *making representations*, as both parties enhanced the credibility of their reports by representing them as independently reaching similar conclusions even though a high degree of coordination was at work.

The 1956 BEAR study's Genetics Panel (led by a mathematician not affiliated with the AEC and including members who had been critical of the AEC's public assertions about the safety of atmospheric testing of nuclear weapons)[505] reached conclusions that supported a linear no-threshold model for dose effects. Their section of the 1956 BEAR report states that for all sources of ionizing radiation, "Any radiation is genetically undesirable, since any radiation induces harmful mutations. Further, all presently available scientific information leads to the conclusion that the genetic harm is proportional to the total dose (that is, the total accumulated dose to the reproductive cells from the conception of the parents to the conception of the

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[500] NAS-NRC, BEAR *Summary Reports* (1956).; NAS-NRC, BEAR *Report to the Public* (1960).
[501] NAS-NRC, BEAR *Summary Reports* (1956), iv.
[502] Jacob Darwin Hamblin, "'A Dispassionate and Objective Effort:' Negotiating the First Study on the Biological Effects of Atomic Radiation," *Journal of the History of Biology* 40:1 (2007), 158.
[503] Hamblin, 150, 155.
[504] Hamblin, 158-165.
[505] Hamblin, 150-153.

child)."[506] Specifically with respect to fallout, the panel concluded that "First, since any additional radiation is genetically undesirable the fall-out dose is genetically undesirable" and "Second, the fall-out dose to date (and its continuing value if it is assumed that the weapons testing program will not be substantially increased) is a small one as compared with the background radiation, or as compared with the average exposure in the United States to medical X rays."[507] These findings—that all radiation poses a risk but that fallout on average is a low risk compared to other radiation sources—are mirrored in the AEC's 1960s era booklet on fallout.

Conversely, the Pathology Panel for the 1956 BEAR study did not find the dose from fallout to be undesirable. Headed by a former AEC executive, as noted above, the Pathology Panel argued that the Genetics Panel—in thinking of multigenerational impacts of mutations—had recommended radiation exposure levels lower than what could be safely tolerated by any one generation. The pathology section of the BEAR report therefore concluded that "There seems no reason to hesitate to allow a universal human strontium … burden of 1/10 of the permissible … since this dose falls close to the range of values for natural radiation background."[508] Not only was this advice in conflict with the recommendations of the Genetics Panel, it also defied the guidance of NCRP Handbook 52, which directly stated that that "all unnecessary exposure to radioisotopes should be avoided."[509] The AEC's publicity materials did not highlight the notion of a "universal human body burden" as an acceptable consequence of nuclear weapons testing, but such a thought process underpinned decisions that led to worldwide fallout. This harks back to the manner in which NBS Handbook 27 on radium normalized ingestion and accumulation of radioactive materials in the body prior to World War II. The discourse produced by the BEAR Pathology Panel advanced a *representation* of the relationship between people and radiation in which ingesting and accumulating radioactive materials from fallout would be viewed as a normal aspect of the human condition.

Newspaper reports covering the 1956 BEAR study emphasized the potential for harm to the general public. Sample headlines included "Nation's Top Scientists Call for Radiation Controls; Fear Shorter Life Expectancy and Mentally Defective Babies" and "Guards Urged against Rise in A-Deformities."[510] This led to debate in the media—the AEC tried to point out that the BEAR study's Genetics Panel had noted that the fallout doses thus far had been small compared to exposures to medical x-rays, only to be countered by scientists from the Genetics Panel who wrote to the *Washington Post* and *Science* to argue that the AEC itself had issued reports concluding that strontium-90 posed a genetic hazard.[511] As will be discussed in Chapter 7, the actors such as citizen groups who became involved in public discourse over the risks, benefits, and ethics of nuclear weapons testing focused heavily on the potential health consequences of the radioactive body burden resulting from global fallout.

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[506] NAS-NRC, BEAR *Summary Reports* (1956), 23.
[507] NAS-NRC, BEAR *Summary Reports* (1956), 27.
[508] NAS-NRC, BEAR *Summary Reports* (1956), 39.
[509] NBS Handbook 52, 1.
[510] Kelly Moore, *Disrupting Science: Social Movements, American Scientists, and the Politics of the Military, 1945-1975* (Princeton: Princeton University Press, 2008), 101.
[511] Moore, 101.

6.6 Joint Committee on Atomic Energy: Hearings on Health Effects of Fallout

The Atomic Energy Act of 1946 created Congress' Joint Committee on Atomic Energy specifically to provide oversight of the Atomic Energy Commission. The JCAE conducted countless public and closed hearings over its 30-year existence, but two public hearings on the health effects of fallout are of particular interest to this dissertation: The first was a one-day hearing held on April 15, 1955, in the aftermath of the CASTLE BRAVO fallout debacle, with the intent of reassuring the public that, unlike fallout from testing in the Pacific, fallout from the Nevada Test Site posed little hazard. The second was held across May 27 to June 7, 1957, as a response to the nation's reaction to the characterization of radiation hazards in the National Academy of Sciences' 1956 BEAR report.

These two hearings are each illuminating in their own right, but they are particularly informative when juxtaposed. The 1955 hearing provided the AEC an unchallenged forum in which deliver to the public its preferred message on fallout. It is the AEC's "deficit model" of discourse in its purest form. The 1957 hearing included a much larger and broader range of speakers, with the stated objective of representing all the scientific disciplines with expertise to bear on the topic of fallout. Both hearings were held in the Senate Office Building in Washington, DC, and both were aimed at providing information to the media and the concerned public. The tone of each hearing is succinctly captured in the opening remarks from the 1955 hearing and the introductory notes from the 1957 hearing:

- 1955 hearing: "There is a great deal of public misapprehension and unwarranted concern about the radiological effects of the test explosions of atomic devices at the Nevada test site…. This committee has called this hearing for the purpose of placing before the Congress and the public a connected statement of the facts that may dispel misconceptions."[512]

- 1957 hearing: "We will have before us in the next 2 weeks a representative group of top ranking scientists in their chosen fields who have generously consented to appear before the committee to give us their expert opinion on a problem which has caused untold concern and confusion among the people of this country and among our friends in foreign lands."[513]

6.6.1 1955 Hearing—*Health and Safety Problems and Weather Effects Associated with Atomic Explosions*

The Chairman of the JCAE set the tenor for the 1955 hearing with the opening statement quoted above. The hearing entertained testimony from AEC officials along with affiliated experts and did not include any dissenting viewpoints. AEC officials testifying at the hearing emphasized that the Nevada tests were dwarfed by the megaton-scale explosions then being

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[512] Joint Committee on Atomic Energy, *Health and Safety Problems and Weather Effects Associated with Atomic Explosions* (Washington, DC: U.S. Government Printing Office, 1955), 1-2.

[513] Joint Committee on Atomic Energy, *The Nature of Radioactive Fallout and its Effects on Man* (Washington, DC: U.S. Government Printing Office, 1957).

conducted in the Pacific islands and asserted that no civilian had been injured as a result of the tests.[514] They further asserted that fallout in communities near the Nevada Test Site "never in any instance approached a level which is hazardous to health" and that fallout in most American cities "barely added to the level of nature's normal background radiation," comparing it to radiation above normal levels that "sometimes" arises from harmless natural "cosmic showers."[515]

The AEC representatives proceeded to acknowledge that "we know of no evidence that radiation ever is beneficial to normal tissue" and stated that as a result, AEC's consistent policy was that "it is always desirable to minimize any exposure."[516] They described the potential somatic effects of radiation exposure as an increased chance of leukemia and a potential reduction in life expectancy. However, they assured the JCAE that while acute whole body doses as low as 100 roentgen could cause nausea and vomiting, exposures of several hundred roentgen spread out over weeks to months would result only in slight increases in the frequency of leukemia and "statistical" shortening of life expectancy, both of which would only be discernable if large populations were exposed and studied.[517] They concluded that there was "no possibility whatsoever" of recognizing such effects from the exposure levels resulting from fallout.[518]

The AEC representatives also addressed genetic effects of radiation exposures, including introducing a university scientist to provide a detailed account of genetics. The AEC representatives acknowledged that experiments with mammals and insects had shown a linear correlation between radiation dose and the frequency of gene changes and stated that genetic effects formed an important part of the studies of the bomb survivors in Japan.[519] However, they did assert that "at the lower exposure rates [among bomb survivors], it is quite evident that no changes can be recognized."[520] Furthermore, particularly with regard to fallout, the AEC representatives informed the JCAE that strontium-90 would have no genetic effect, because strontium that is ingested "goes to the bones, you see, which have no genetic significance."[521] Throughout this discussion and in the discussion of somatic effects, the AEC representatives characterized radiation as part of nature and described radiation from fallout as both small compared to natural sources of radiation and within the variability of natural sources from place to place on Earth.[522] This *discourse* was consistent with the AEC's use of that ordering instrument to *make representations* of radiation from fallout as a small and imminently manageable risk and further sought to *represent* a body burden of radioactive material as a normal condition for humans. Consistent with much of the AEC's discourse on fallout, the AEC's emphasis on naturally occurring sources of radiation sought to *make representations* of artificially produced radioactive materials as not-so-unnatural after all.

[514] JCAE (1955), 3.
[515] JCAE (1955), 4-5.
[516] JCAE (1955), 11-12.
[517] JCAE (1955), 12-13.
[518] JCAE (1955), 13.
[519] JCAE (1955), 13.
[520] JCAE (1955), 13.
[521] JCAE (1955), 34.
[522] JCAE (1955), 5, 17, 28, 31-32.

6.6.2 1957 Hearing—*The Nature of Radioactive Fallout and its Effects on Man*

The JCAE's 1957 hearing on fallout came after the release of the 1956 BEAR report with its emphasis on the potential for any radiation exposure to give rise to adverse genetic effects and the ensuing media uproar described above. In contrast to the 1955 hearing, the 1957 hearing included testimony (written or in-person) from about 50 expert witnesses, including representatives of the AEC and its laboratories, university scientists, the Department of Defense, experts from other government agencies including the U.S. Weather Bureau, the RAND Corporation (a prominent think tank), medical professionals, and Lauriston Taylor of the NCRP, in order to represent "varied points of view within the scientific community."[523] The JCAE charged the experts with presenting their views using layman's terms, so that the hearing record "may be understood by persons from all walks of life."[524] The hearing covered an extremely broad spectrum of topics in order to "trace the fallout cycle from the moment of the nuclear explosion, through the scattering of radioactive debris in the atmosphere, its descent to the ground, and finally its effect on human beings, livestock, and agriculture" and included thorough presentations on radiation fundamentals and nuclear physics to orient the public to those subjects.[525]

The Director of the AEC's Division of Biology and Medicine opened the testimony with a discussion of the general background of the fallout problem. Upon questioning from the members of the JCAE, his testimony veered into a high-level discussion of scientists who dissented with the AEC's perspectives on the hazards of fallout, with a senator asking, "How do you account for the fact these people can read all this nice literature that the AEC has put out, giving them absolute assurance, and still be scientists, and they are still worried?" The senator further noted that "Everytime one man comes out on one side, the AEC produces one on the other side, and we who stand in between are perplexed."[526] In response, the AEC official suggested that scientists who disagreed with the AEC on fallout hazards were "grossly exaggerating" the hazards because they were opposed to nuclear weapons.[527] Such assertions represent another instance of boundary work and an application of the ordering instrument of *making representations*, with the AEC representing itself as the source of scientific truth and representing its critics as biased.

During the second day of the hearing, an AEC expert described that the long-term hazards from inhaling and ingesting fallout included doses to the gastrointestinal tract from fission products, to the thyroid from radioactive iodine, and to the bones from isotopes of strontium and barium-lanthanum, but deferred discussion of the dose-response relationship to later witnesses.[528] He did note that for external exposures to large populations, the NCRP had recommended a limit of 10 million man-rem from manmade sources per million people over a 30 year period based on genetic considerations.[529] This equates to an average exposure of 10 rem

[523] JCAE (1957), v-vii, 1.
[524] JCAE (1957), 2.
[525] JCAE (1957), 1-4.
[526] JCAE (1957), 20.
[527] JCAE (1957), 20.
[528] JCAE (1957), 177.
[529] JCAE (1957), 181.

per person over the 30 year period, or an average annual exposure of 333 millirem per person across the population. Specific to genetic effects, the AEC expert stated that "it is believed that genetic effects or mutations, whether it be mutations of the gene cells or the somatic cells … are linear with dose."[530] Additionally, while deferring more specific discussions to others, he noted that because of natural biological repair mechanisms, the life shortening effect of a given total dose would be smaller for low doses delivered over a long period of time compared to large doses delivered in a short period of time.[531]

The hearing record includes written input provided by the AEC and the Public Health Service that described the safety measures they took in the communities around the Nevada Test Site for the TEAPOT series of tests in 1955. It included a section on public relations that emphasized the importance of stationing fallout monitoring personnel in the communities.[532] The writeup stated that the monitors carried out a continuous education program with local citizens, including appearing on the programs of civic clubs and other organizations, providing material for radio programs, and aiding in school programs."[533] Moreover, the writeup stated that a team including "the Test Manager, Scientific Advisor, Test Director, Support Director, Information Director, Off-Site Operations Chief, and the senior PHS officer" visited six local communities before the test series to deliver a series of talks on the importance of the tests to national security and the safety measures being taken to protect the public.[534] It is reasonable to assume that these interactions advanced the same positions regarding the effects of radiation exposure as the brochures the AEC produced for the public. The written hearing input further stated that virtually every local citizen listened to at least one talk and watched at least one film, and asserted that the then-new film *Atomic Tests in Nevada*, discussed earlier in this chapter, "received enthusiastic reception."[535] It also noted that a "little yellow booklet, Atomic Test Effects in the Nevada Test Site Region" was a particular favorite of the local populace, with thousands of copies handed out, including many copies taken by tourists who carried them home to all parts of the United States.[536] This booklet treats radiation exposures as having a safe threshold dose below which there is no health hazard and does not use the words "cancer," "leukemia," or "mutation."[537] The written input that the AEC and PHS provided for the hearing record does not mention these weaknesses in the booklet.

During the next day of testimony, a chemist from Columbia University reviewed how humans are exposed to radioactive materials released into the environment. In discussing the health effects of such exposures, he made the point that if one assumes a linear no-threshold dose-response model, then all arguments about the consequences of radiation exposures are simply a matter of degree: "whether there are a 100 or 10,000 [deaths] seems very irrelevant philosophically."[538] He further argued that in entering the nuclear era industrially, which he saw

[530] JCAE (1957), 200.
[531] JCAE)1957), 210.
[532] JCAE (1957), 346.
[533] JCAE (1957), 346.
[534] JCAE (1957), 346.
[535] JCAE (1957), 347.
[536] JCAE (1957), 348.
[537] U.S. Atomic Energy Commission, *Atomic Test Effects in the Nevada Test Site Region* (U.S. Government Printing Office, January 1955).
[538] JCAE (1957), 691.

as a foregone conclusion, society had to accept having "deaths in the world as a whole from peacetime application" of nuclear technologies, because it would be impractical to reduce radiation exposures to zero.[539] When a member of the JCAE tried to use a speed limit analogy to turn the discussion toward accidents instead of routine exposures, the university chemist countered with the observation that "people get killed below the speed limit."[540] A plutonium expert from Los Alamos Scientific Laboratory (now known as Los Alamos National Laboratory) offered a similar viewpoint later in the day, stating that absent a safe threshold for radiation exposure, pursuing nuclear technology involves "making a value judgment on how much is atomic energy worth in cases of leukemia and bone cancer on a probability basis, averaged over the entire population or a certain segment thereof."[541]

When the hearing resumed during the next month, the JCAE brought in Lauriston Taylor to explain the various units of radioactivity and radiation exposure that had been used in the first three days of the hearing. In addition to providing the requested information, Taylor opined that even though the NCRP and ICRP had progressively reduced recommended exposure limits since the 1930s, "I know of no causative relationship between damage that might develop in an individual, and the radiation to which we were exposed at any of these levels we have been talking about; in fact, even under some of the less conservative levels prior to 1935."[542] Upon questioning, he acknowledged that his observations did not prove that no damage had occurred, but rather that the likelihood of damage at occupational exposure levels was small and would require fine statistical techniques to discern. He explained the still-lower exposure limits for the general public as being based partly on genetic considerations, partly on somatic considerations, and partly because of the ethical considerations for exposing people who have no control over their environment.[543] His observation on ethics is noteworthy, because as noted earlier in this dissertation, the AEC's sociotechnical imaginary appeared to embrace that notion that technical authorities have the right to accept risk on behalf of citizens.

Following Taylor's presentation, a doctor from the Western Reserve University Medical School with extensive experience in radiation health effects (including serving in the Manhattan Project's medical division and on an AEC advisory board) testified on the health effects of radiation exposures. He stressed that there simply were no data for the health effects of low-level radiation exposures ("much below a hundred roentgens, or 25 roentgens in the case of mutations") not just for humans, but for "all complex biological systems."[544] When pressed by a member of the JCAE on what implications this situation had for the AEC's operations, he clarified that the exposure levels associated with nuclear weapons testing were far below the levels established as acceptable doses, and that he would hesitate to accept the concept that there was no safe threshold for radiation exposures.[545] When pressed further on whether his opinion included genetic effects, he offered that he felt the data for genetic effects were stronger than for

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[539] JCAE (1957), 692.
[540] JCAE (1957), 693.
[541] JCAE (1957), 751.
[542] JCAE (1957), 786.
[543] JCAE (1957), 790.
[544] JCAE (1957). 903.
[545] JCAE (1957), 904-905.

cancers or leukemia but were still lacking for exposures smaller than 25 roentgens.[546] He declined to offer an opinion on life-span shortening for such exposure levels.[547] He suggested that the best way to advance understanding would be to understand the mechanisms at work and how they fit in with the data, rather than studying ever-increasing numbers of mice at low exposure levels.[548]

Later that day, a biologist and geneticist from the California Institute of Technology (with no identified ties to the nuclear weapons complex) presented data on leukemia incidence for the survivors of the atomic bombings in Japan, for adults and children who had undergone radiation treatments for certain medical conditions, and for radiologists. He stated that the data showed a linear relationship between the dose and the rate of leukemia cases, and that if a threshold existed, which he doubted, it was well below 100 rem.[549]

Shields Warren, the chief pathologist at the New England Deaconess Hospital and the former director of the AEC Division of Biology and Medicine, discussed the consequences of large radiation exposures, the variability in background radiation levels around the world, natural biological repair mechanisms, and the lack of any apparent injury to his skin from his luminous dial wrist watch.[550] Based on these observations, he stated, "This power of the body to repair itself, other than the hereditary material, has important bearing on the amount of radiation that man can withstand without demonstrable evidence of harm."[551] He further noted that worldwide exposure levels due to fallout from weapons testing were much smaller than background radiation, but given the concern for genetic damage, "we should watch closely the levels of radiation." He expressed this concern in terms of the doubling dose, i.e., the accumulated exposure needed to produce twice the normal rate of mutations, and asserted that geneticists believed such a dose to be on the order of 30 to 50 r (he did not specify rem, rad, or roentgen).[552]

Lastly, the chairman of the biophysics department at Yale University discussed the likelihood of a threshold for radiation exposure effects. He argued that if a dose-effect relationship were linear at high doses, then "the probability is that it is linear down low," and that he knew of no aspect of fundamental radiobiology that would indicate otherwise.[553]

In a group discussion at the end of the day, he offered the following policy advice: "I think the linear line is rational. I would like to see policy momentarily at least based on it. If later on it seems there is a threshold, then we are not too badly off. But if there is not a threshold, and we bet there is one, we are in trouble."[554] Warren responded that threshold effects had been observed for carcinogenic chemicals, for medicines, for physical phenomena such as the force he needed to apply to slide the microphone in front of him across the table, and for the

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[546] JCAE (1957), 905.
[547] JCAE (1957), 907.
[548] JCAE (1957), 905-906.
[549] JCAE (1957), 956-961.
[550] JCAE (1957), 980-982.
[551] JCAE (1957), 982.
[552] JCAE (1957), 982-983.
[553] JCAE (1957), 996.
[554] JCAE (1957), 1004.

skin on his wrist exposed to his luminous dial watch.[555] A representative from the University of California Radiation Laboratory bridged the gap between these two positions by observing that because very small doses have such small effects in a linear model, it can be easy to disregard the effects. He noted that troubles ensue when those very small numbers are multiplied by "huge populations."[556] The biologist/geneticist from CalTech mentioned above weighed in at the end of the group discussion to suggest that the appropriate policy would be to inform the public that the "permissible dose" has the distinct possibility of harming some number or some percent of people, rather than implying that there is no danger from fallout or from exposure to the permissible dose.[557]

The JCAE published a summary analysis of the hearing in August 1957.[558] It presented the results of the discussions on the health effects of radiation as follows:

> *Biological effects of radiation*.—There was general agreement that any amount of radiation, no matter how small the dose, increases the rate of genetic mutation (change) in a population. There was, on the other hand, a difference of opinion as to whether a very small dose of radiation would produce, similarly, an increased incidence of such somatic (nongenetic) conditions as leukemia or bone cancer, or a decrease in life expectancy, in a population.
>
> *Tolerance limits*.—There was general agreement that there is a limit to the amount of radioactivity and, hence, to the amount of fission products that man can tolerate in his environment. The extent to which existing and future generations will be affected by manmade radiation was shown to be intimately tied to certain decisions, moral as well as scientific, that must be made as to how much radiation can be tolerated by the peoples of the world.[559]

The summary also noted that scientific knowledge alone would not be sufficient to determine policy for population-level radiation exposures. It asked and answered the question as follows:

> Should a distinction be made between absolute numbers of persons affected by fallout and percentages relating these numbers to the total population of the world, i.e., can we accept deleterious effects on a relatively small percentage of the world's population when the number of individuals affected might run into the hundreds of thousands? This question cannot be answered by

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[555] JCAE (1957), 1006.
[556] JCAE (1957), 1007.
[557] JCAE (1957), 1007-1008.
[558] Joint Committee on Atomic Energy, *Summary-Analysis of Hearings, May 27-29 and June 5-7, 1957 on The Nature of Radioactive Fallout and its Effects on Man* (Washington, DC: U.S. Government Printing Office, 1957). [JCEA (1957a)]
[559] JCAE (1957a), 3.

considering scientific data only. Overall national policy and great moral issues are also involved.[560]

Regarding communication of fallout hazards with the public, the summary concluded that "information on fallout itself has evidently not reached the public in adequate or understandable ways."[561] Given the AEC's extensive public outreach on the topic, this was a rather surprising conclusion and represented another instance of following a deficit model for communicating scientific information. The summary supported this conclusion by noting "That this is so is evidenced by the need for, the results of, and the interest in these hearings."[562] While that could have been true, another potential explanation is that the public's interest in the fallout hearings could have indicated that the public was well informed but was nonetheless dissatisfied with government policy regarding nuclear weapon testing and fallout. The knowledge and opinions of various nongovernmental organizations will be evaluated in Chapter 7 below.

One further aspect of the hearings that was not highlighted in the JCAE's summary report involved the manner in which different scientists sought to persuade the JCAE to trust their views on the hazard posed by radiation. In particular, scientists who supported a threshold model for radiation dose effects consistently offered up anecdotal information and analogies to support their views. As noted above, Shields Warren showed that his luminous watch had not visibly injured his wrist and further demonstrated the pervasiveness of threshold effects in nature by pushing his microphone across the table. Similarly, Lauriston Taylor asserted that no one he knew had ever suffered a negative effect from occupational radiation exposure. By comparison, geneticists and other scientists emphasized the theoretical basis for a no-threshold model and discussed data from experiments and observation of exposed groups. These differences could just be the result of personal preferences on how to argue a point to an audience of laypersons in a public hearing, but they may reflect different views on what constitutes valid scientific knowledge. More evidence to help evaluate this tentative observation is discussed in the analysis of expert testimony in three court cases in Chapter 9.

The development of the actor-network involved in discourse over models for radiation health effects will be most comprehensible by setting aside the AEC at this point and elaborating on the other actors involved in the public controversy over fallout from nuclear weapons testing. Following that analysis, this dissertation will move on to the discourse over establishment of regulatory requirements for nuclear power plants, in which the AEC again features prominently,

6.7 Federal Radiation Council

President Eisenhower established the Federal Radiation Council via an Executive Order in August 1959.[563] Per the Executive Order, the FRC consisted of the Secretary of Defense, the Secretary of Commerce, the Chairman of the AEC, and the Secretary of Health, Education, and Welfare. The Executive Order assigned two tasks to the FRC:

[560] JCAE (1957a), 4.
[561] JCAE (1957a), 19.
[562] JCAE (1957a), 19.
[563] Dwight D. Eisenhower, *Executive Order 10831—Establishing the Federal Radiation Council*, August 14, 1959.

- Advise the President with respect to radiation matters directly or indirectly affecting health, including matters pertinent to the general guidance of executive agencies by the President with respect to the development by such agencies of criteria for the protection of humans against ionizing radiation applicable to the affairs of the respective agencies.

- Take steps designed to further the interagency coordination of measures for protecting humans against ionizing radiation.

The press release that accompanied the Executive Order elaborated that the FRC would centralize responsibility for providing general standards and guidance to executive agencies to use in developing rules and regulations for radiation protection.[564] It further stated that the FRC would solicit the views of "competent scientific bodies" such as the NCRP and the National Academy of Sciences.[565] Congress enshrined the FRC in law in September 1959 and added the Secretary of Labor to the FRC.[566]

Historians report that Eisenhower created the FRC in part because he recognized that public confidence in the safety of nuclear weapons testing had been undermined by the inherent conflict in the AEC's roles as both the operator of the nuclear weapons testing program and the regulator responsible for establishing safety standards.[567] Eisenhower hoped that the FRC would "reassure the public as to the objectivity of Government announcements."[568] As a separate entity with representation from the Department of Health, Education, and Welfare (the parent agency for the Public Health Service), the FRC gave the appearance of independence from the nuclear weapons complex, even if actual independence was weakened by the inclusion of the Secretary of Defense and the Chairman of the AEC on the Council. Also, in contrast to the NCRP—a non-governmental entity that had originated as an industry committee—the FRC was a *bona fide* federal council.

The FRC produced publicly available reports and radiation protection guidelines in the early 1960s. The first FRC report provided background information for developing radiation protection standards and introduced a new term that it would use in its guidelines for federal agencies: "Radiation Protection Guide." As opposed to prior terminology such as tolerance dose or permissible dose, the FRC defined the radiation protection guide as "the radiation dose which should not be exceeded without careful consideration of the reasons for doing so; every effort should be made to encourage the maintenance of radiation doses as far below this guide as practicable."[569] This definition does not suggest that doses smaller than the guideline can be considered safe and accordingly represents a no-threshold dose-response relationship. The FRC

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[564] Lauriston S. Taylor, *Organization for Radiation Protection: The Operation of the ICRP and NCRP, 1928-1974* (Washington, DC: U.S. Department of Energy, 1979), 8-230.
[565] Taylor (1979), 8-230.
[566] George T. Mazuzan and J. Samuel Walker*, NUREG-1610, Controlling the Atom: The Beginnings of Nuclear Regulation 1946-1962* (Washington, DC: U.S. Government Printing Office, April 1997), 258.
[567] Walker (2000), 23.; Caufield, 130.
[568] Walker (2000), 23.
[569] Federal Radiation Council, *Report No. 1: background material for the development of radiation protection standards* (Washington, DC: U.S. Department of Health, Education, and Welfare, Public Health Service, May 13, 1960), 3.

report summarized research that supported a linear no-threshold model for genetic effects and explained that scientists had not reached consensus on the dose-effect relationship for somatic effects.[570] Accordingly, the FRC report concluded that it was "prudent to adopt the working principle that radiation exposure be kept to the lowest practical amount."[571] The FRC report further suggested that the "fundamental principles of radiation protection" should include not allowing "any made-made radiation exposure without the expectation of benefit resulting from such exposure," and that radiation protection standards should "strike some balance between maximum use and zero risk" (elements of the modern ALARA approach to managing radiation exposures).[572] The report provided radiation protection guides for occupational radiation exposures and exposures to the public which it characterized as being "in essential agreement with current recommendations of the NCRP and the ICRP."[573]

The second FRC report provided guidance for limiting the intake of radioactive materials. It applied the radiation protection guides developed in the first FRC report to develop "transient rates of daily intake" for iodine-131, radium-226, strontium-89, and strontium-90.[574] It identified low, medium, and high ranges for each of those radioisotopes, with corresponding recommendations for avoiding overexposure of the public for each category. For example, for the high range, the FRC report recommended surveillance to determine the level of intake, whether it was trending up or down, and the size of the exposed population coupled with control actions to reduce the rates of intake.[575] It emphasized, however, that it was the role of the responsible federal agency to determine the specific intake rates that would trigger particular control actions.[576]

In addition to publishing radiation protection guidance, the FRC in 1962 published an analysis of the public health effects of fallout from nuclear weapons testing.[577] This document was the source of the estimates of the health consequences of population-level exposures to fallout that later appeared in the AEC booklet *Fallout from Nuclear Tests*.[578] As noted in the analysis of the AEC booklet earlier in this dissertation, these estimates allow for the possibility of a threshold for somatic effects by showing a range for the number of cases of leukemia or bone cancer that starts at zero. The estimates do not, however, indicate the potential for a threshold for genetic effects. The FRC report refers to the National Academy of Sciences' BEAR reports as the basis for applying a linear no-threshold model for estimating the rate of genetic effects in an exposed population.[579] It references a 1958 report by the United Nations Scientific Committee on the Effects of Atomic Radiation as illustrating the method used to apply a linear dose-response relationship to develop an estimate of the upper limit estimate for the rate

[570] FRC (1960), 7-8.
[571] FRC (1960), 8.
[572] FRC (1960), 24.
[573] FRC (1960), 26-27.
[574] Federal Radiation Council, *Report No. 2, background material for the development of radiation protection standards* (Washington, DC: U.S. Department of Health, Education, and Welfare, September 1961), 5.
[575] FRC (1961), 5, 6.
[576] FRC (1961), 5.
[577] FRC (1962).
[578] Comar (1966).; FRC (1962), 9.
[579] FRC (1962), 7.

of somatic effects among an exposed population.[580] In addition to crediting the BEAR reports and the 1958 UNSCEAR report, the FRC report also acknowledged the assistance of seven consultants selected by the National Academy of Sciences, including Shields Warren, the former AEC official who testified at the 1957 JCAE hearing on fallout.[581]

Soon after issuing these reports, the FRC was drawn into controversy when fallout from nuclear weapon tests in Nevada and testing in the Soviet Union produced transient levels of iodine-131 that led state health officials in Utah and Minnesota to engage with dairy producers to prevent radioactive milk from reaching the public.[582] Proposed countermeasures included using milk expected to be high in iodine-131 to make cheese and butter to give time for the iodine-131 to decay before people consumed it and switching herds to stored feed until radioactivity in pastures had subsided.[583] In response, the AEC argued that the FRC guides were intended for peaceful operations, not weapon testing, and that evaluation of fallout from weapon testing required risk assessments that took into account the "absolute necessity to secure [its] benefits."[584] The FRC Chairman (the Secretary of Health, Education, and Welfare) weighed in to inform the JCAE that the FRC guides were "not specifically designed for fallout situations," and the FRC issued a public statement that "radiation exposures anywhere near the guides involve risks so slight that countermeasures [to reduce radioactivity in the food supply] may have a net adverse rather than a favorable effect on the public well-being."[585] Among other negative reactions, this led Congressman John V. Lindsay of New York to denounce the FRC guides as "doubletalk" in an address to the House of Representatives in September 1962 in which he called for President Kennedy to "put his policymaking house in order."[586]

In May 1963, the FRC produced an update of its estimates for radiation doses to the public from fallout that accounted for nuclear weapon testing during 1962.[587] The report attributed increases in global fallout primarily to weapon testing by the Soviet Union.[588] The report provided only updated dose estimates, not updated estimates of the associated population-level health impacts. However, the new estimates were comparable to the dose estimates the FRC had used to produce the estimated rate of cancers and genetic effects in its previous report. The report concluded that the "present and anticipated levels of fallout do not constitute an undue risk to the genetic future of the nation" and that the risks of cancer were too small to justify any "modification of the diet or altering the normal distribution and use of food" to reduce exposure to iodine-131 and strontium-90.[589] In the particular case of iodine-131, where there had

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[580] FRC (1962), 8.; United Nations General Assembly, *Report of the United Nations Scientific Committee on the Effects of Atomic Radiation* (New York: United Nations, 1958), 27-28.
[581] FRC (1962), 10.
[582] Mazuzan and Walker, 268, 269.
[583] Mazuzan and Walker, 268-269
[584] Mazuzan and Walker, 269.
[585] Mazuzan and Walker, 269.
[586] Mazuzan and Walker, 270.
[587] Federal Radiation Council, *Report No. 4, Estimates and Evaluation of Fallout in the United States from Nuclear Weapons Testing Conducted Through 1962* (Washington, DC: U.S. Government Printing Office, May 1963).
[588] FRC (1963), 2.
[589] FRC (1963), 25-26.

been concern for locally higher doses, the report stated the following:[590]

> Based on the advice of a special panel convened by the Council in the summer of 1962, it was concluded that radiation doses to the thyroid many times higher than those provided in FRC Report No. 2 would not result in a detectable increase in diseases such as thyroid cancer. No case of thyroid cancer in man ascribable to radioactive iodine used in the medical diagnosis and treatment of thyroid disease has yet been established.

The FRC issued four more reports (three on fallout-related topics and one on radiation hazards in uranium mining) during the next few years, then ceased to exist after President Nixon established the Environmental Protection Agency in 1970. Nixon's Reorganization Plan No. 3 became law in December 1970, abolishing the FRC and assigning the new EPA to "advise the President with respect to radiation matters directly or indirectly affecting health, including guidance for all Federal agencies in the formulation of radiation standards and in the establishment and execution of programs of cooperation with States."[591]

Overall, the FRC appears to have been held firmly in alignment with the AEC, and its publications largely followed existing radiation protection guidance from the NCRP, the NAS, and the ICRP. However, its first report on fallout from weapons testing represented a departure from other government and government-affiliated actors by applying the linear no-threshold model to estimate the number of people potentially suffering health effects from low-level radiation exposures to large populations. The *institutional discourse* would prove to be a powerful ordering instrument in *making representations* of radioactive fallout as potentially harmful, despite other government discourse to the contrary, and *making representations* of the linear no-threshold model as a valid dose-response model. This would figure prominently in the arguments advanced by actors voicing concerns about atmospheric testing of nuclear weapons and, later, nuclear power stations.

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[590] FRC (1963), 26.
[591] U.S. EPA (2000), 3-5.

7 Non-Governmental Actors Engaged in Fallout Debates

The contributions of non-governmental actors to the public discourse over nuclear weapon testing and the health effects of fallout provide further insight into the co-production of the science and regulation of radiation health effects. These actors included a wide range of individuals and social groups. Organized groups included the National Committee for a Sane Nuclear Policy, Physicians for Social Responsibility, the Federation of American Scientists, the Scientists' Institute for Public Information, the Committee for Nuclear Information/Committee for Environmental Information, and the Center for Public Integrity, among others. A number of high-profile individual actors also merit discussion, such as Adlai Stevenson (the Democratic Party's nominee in the 1952 and 1956 Presidential elections), Linus Pauling, Edward Teller, John Gofman, Arthur Tamplin, and Karl Morgan. Gofman, Tamplin, and Morgan in particular stand out as examples of "expert dissenters" who began as researchers in nuclear science and technology before adopting positions contrary to the immediate interests of the AEC and the nuclear industry—Chapters 8 and 9 will thoroughly review their engagements on radiation health issues.[592]

7.1 Public Figures

On September 29, 1956, Democratic Presidential nominee Adlai Stevenson declared that nuclear disarmament was the "first order of business in the world today," and that stopping nuclear weapon testing was the best way to start down that path.[593] He further asserted that "the actual survival of the human race itself" was at stake with nuclear weapon testing because of the potential for genetic damage in unborn children that scientists could not yet estimate.[594] Stevenson devoted a televised speech in October to nuclear weapons.[595] He argued that the United States already had adequate bombs, so there was no need for testing to develop more powerful ones; that a test ban was enforceable because nuclear explosions cannot be hidden; that a test ban would stop nuclear weapons from proliferating to other countries; and that, since the health threat from radioactive fallout was not understood, testing should be stopped as soon as possible.[596] President Eisenhower released a paper rebutting Stevenson's points, most notably citing the 1956 NAS BEAR report's conclusion that the potential dose from fallout was far less than natural background exposure or medical x-rays.[597] Eisenhower's paper also continued to advance the argument that nuclear weapon testing was needed to address the real risk: Soviet aggression.[598] In the end, the election was probably decided on issues unrelated to nuclear weapons, but the campaign debate well illustrated the contrast in sociotechnical imaginaries of those who viewed the tests as a risk and that the world would be safer with fewer nuclear weapons, versus those who viewed testing as an essential element of maintaining a fearsome

[592] Joppke, 27-28.
[593] Divine, 88.
[594] Divine, 88-89.
[595] Divine, 93.
[596] Divine, 95.
[597] Divine, 101.
[598] Divine, 101.

nuclear weapon stockpile in order to address a greater risk (deterring global thermonuclear war).[599]

Two years after the Eisenhower-Stevenson election campaigns, two noted scientists directly debated nuclear weapon testing, fallout, and disarmament on television. Linus Pauling, the 1954 Nobel Laureate in Chemistry, argued in favor of ending nuclear weapon testing and achieving peace through disarmament. Opposing him was Edward Teller, a physicist who had helped build the nuclear bombs that destroyed Hiroshima and Nagasaki and subsequently continued on with the development of the hydrogen bomb.[600] One month before the debate, Pauling had presented the General Secretary of the United Nations with a petition signed by 9000 scientists calling for a ban on all nuclear weapon testing.[601] Teller and an associate responded in a *Life* magazine article repeating the argument that radiation exposures from fallout from nuclear weapon testing were small compared to medical x-rays and background radiation, so the chance of developing leukemia or bone cancer from fallout was negligible.[602]

At the debate, Pauling stressed that small risk percentages become large numbers when world populations are involved. He claimed that an estimated 15,000 children annually would be born with harmful genetic mutations if nuclear weapon testing continued at the then-current rate.[603] He further asserted that there would be negative health effects for the present generation of people as well.[604] Moreover, he argued that the existing stockpiles of nuclear weapons were a credible deterrent to war, so there was no reason to keep testing more advanced designs (i.e., arguing that there was no demonstrable benefit to justify the health risk presented by weapons testing).[605]

Teller rebutted Pauling's points in several ways. He argued that no sound statistics had been produced to prove that small radiation doses can lead to negative health effects, and that it was possible that small amounts of radioactivity may actually be beneficial.[606] He further argued that genetic mutations in men's sperm could result from things as simple as their clothing (presumably tight-fitting trousers), so what then was the point of worrying about radioactivity?[607] Teller also challenged the idea that the deterrent value of the weapon stockpile could be maintained without testing and speculated that testing could lead to developing clean nuclear explosives that could be used for industrial applications for the benefit of mankind.[608] To remind the audience what in his mind was truly at stake, Teller closed with a rousing speech about freedom rooted in the lessons from the Soviet Union's occupation of his home country, Hungary.[609]

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[599] Divine, 108-109.
[600] Melinda Gormley and Melissae Fellet, "The Pauling-Teller Debate: A Tangle of Expertise and Values," *Issues in Science and Technology* 31:4 (Summer 2015), 78.
[601] Gormley and Fellet, 79.
[602] Gormley and Fellet, 79.
[603] Gormley and Fellet, 80.
[604] Gormley and Fellet, 80.
[605] Gormley and Fellet, 81.
[606] Gormley and Fellet, 81.
[607] Gormley and Fellet, 81.
[608] Gormley and Fellet, 81.
[609] Gormley and Fellet, 81.

Teller's *discourse* in the debate further illustrated the sociotechnical imaginary animating supporters of nuclear testing. Teller, like Eisenhower, viewed testing as essential in order to sustain and improve the weapon stockpile that he considered essential to deter America's enemies and that the real commodity at risk was human freedom. Teller additionally expressed viewpoints that considered technological advancement as the solution to problems, including making nuclear explosives safer and more broadly useful by inventing ways to make them cleaner. Lastly, there was no place in his imaginary for the precautionary principle. He saw no reason to alter America's course on testing nuclear weapons unless radiation from fallout were demonstrated to be hazardous. Opposing Teller, Pauling's *discourse* conveyed an imaginary that regarded technology as something to be handled with caution unless shown to be safe.

7.2 Organizations

7.2.1 Introduction

This section addresses the activities of two types of organizations—citizen activist groups and professional societies. Both types of organization employ the ordering instruments of co-production to achieve a variety of objectives, and both are animated by sociotechnical imaginaries that reflect the social causes or professional objectives that had drawn them together. As will be detailed below, the citizen activist groups in particular mounted challenges to the position of the experts in authority at the AEC that fallout was not a health concern for the public.

These challenges to institutionally endorsed scientific positions can be viewed in terms of Beck's risk society and the concept of trans science proposed by Weinberg, where science has reached a realm where calculations and experiments cannot provide definitive answers, so whatever answers are advanced are open to challenge. However, as discussed in Chapter 2, the concept of trans science presupposes a realm of science that is free of social influence, carving out a space for science to operate free from "nonscientific" challenges. This boundary work fails to recognize that basic elements of science such as what questions to ask, what questions not to ask, and what constitutes acceptable evidence are all socially determined. Accordingly, the challenges raised by citizen activist groups would be better described as resulting from their recognition of the social content of the scientific positions advanced by the AEC, as opposed to resulting from science having entered an altogether new realm.

Moore proposed that the contestable quality of science became evident in part "due to scientists' own efforts to more closely link science with public moral and political concerns," primarily with respect to scientists' relationships to the military in post-World War II America.[610] Moore argued that the questions raised by "scientist activists" challenged the notion that scientific knowledge "inevitably led to material and moral progress," the notion that scientists operated free from non-scientific influences, and the notion that the scientific community "agreed on the basic rules for judging the validity of scientific ideas and the

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[610] Moore, 190-193.

credibility of its practitioners."[611] In essence, where Beck and trans science considered uncertainty and contestation in areas where questions could not be adequately answered by traditional scientific processes, Moore focused on the political and moral content inherent in all science that came to prominence due to the action of "scientist activists" and the associated "unbinding" of scientists from scientific authority.

Moore described the activities of such scientists as having "exposed the ways in which science was implicated in broader political projects, and how it might be used for other ones."[612] Moore elaborated that she imagined this situation as "a network, rather than a series of fixed institutions that only occasionally encountered one another and/or change."[613] This conception of a network of actors mutually influencing one another appears quite consistent with Latour's articulation of actor-network theory. In the case of scientist activists, Moore particularly emphasized the influence of social movements and non-scientist activists as having "profoundly shaped the forms that scientists' claims took."[614]

Moore summarized the view of science that emerged from the work of scientist activists as follows: "science is both fallible and shaped by politics *and* produces reliable truths about nature."[615] This verdict captures an important element of the sociotechnical imaginary of the citizen activist groups discussed below.

7.2.2 SANE: The National Committee for a Sane Nuclear Policy

SANE emerged in the late 1950s from the post-World War II peace movement in America. Its formative meeting in the summer of 1957 included twenty-seven "churchmen, scientists, businessmen, labor representatives, authors, editors, and public figures."[616] SANE's overarching purpose was to work toward nuclear disarmament, but its leaders made the tactical decision to start with a campaign to oppose testing of nuclear weapons.[617] Implicit in SANE's messaging was the notion that there was no safe level of radiation exposure, particularly for activities like atmospheric nuclear weapon testing that resulted in population-level exposures. SANE advanced this concept through numerous public outreach activities, enlisting prominent national figures in an effort to provide legitimacy and draw attention to *discourse* intended to enroll the support of the public. They planned to prepare and reprint written materials, distribute films, issue public statements, arrange conferences, and sponsor interactions with policymakers.[618] As of the end of 1958, SANE had expanded to include 150 local committees around the United States and distributed its newsletter to tens of thousands of people.[619]

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[611] Moore, 199.
[612] Moore, 204.
[613] Moore, 204.
[614] Moore, 204.
[615] Moore, 214.
[616] Milton S. Katz, *Ban the Bomb: A History of SANE, the Committee for a Sane Nuclear Policy, 1957-1985* (New York: Greenwood Press, 1986), 23.
[617] Katz, 24.
[618] Katz, 26.
[619] Moore, 120.

SANE's outreach campaigns began with attention-grabbing full-page newspaper advertisements signed by nationally known people from many different walks of life. The first one, headlined "We Are Facing A Danger Unlike Any Danger That Has Ever Existed," ran in the *New York Times* in November 1957.[620] It did not attempt to use the linear no-threshold model to calculate deaths from fallout, but it did cite "grave unanswered questions with respect to nuclear test explosions—especially as it concerns the contamination of air and water and food, and the injury to man himself."[621] It sought to reinforce the validity of its *discourse* by including a long list of signatories, including university scientists, religious leaders, the Chairman of the Federation of American Scientists, the President of the National Farmers Union, a brigadier general, Eleanor Roosevelt, James Jones (author of *From Here to Eternity*), and Oscar Hammerstein II (who collaborated with Richard Rodgers to produce hit musicals including *Oklahoma!*, *Carousel*, *South Pacific*, *The King and I*, and *The Sound of Music*).[622] The advertisement undeniably brought attention to SANE's claims—SANE received requests for 25,000 reprints, and people unconnected with SANE ran the advertisement in 32 other newspapers.[623]

Other materials distributed by SANE included estimates of dose effects on the public exposed to fallout from nuclear weapons testing. Figure 7-1 below shows a newspaper advertisement and a subway poster that exemplify how SANE conveyed such estimates. The newspaper advertisement, which ran in April 1958 in the *New York Times*, covered half the page with a mushroom cloud and claimed that "Scientists warn that thousands of babies will be born malformed because of tests to date" and that "Many thousands more people will prematurely die of diseases of blood and bone" (presumably leukemia and bone cancer).[624] Notably, this newspaper advertisement added Linus Pauling, the aforementioned winner of the Nobel Prize in chemistry, to the list of signatories. SANE ran another advertisement later that year that included Martin Luther King, Jr., and Albert Schweitzer as supporters.[625] The subway poster appeared on railcars and train platforms in and around New York City in August 1962 and featured a silhouetted pregnant woman next to an alarming headline claiming that "1¼ Million unborn children will be born dead or have some gross defect because of Nuclear Bomb testing."[626] The text beneath the headline cites the 1962 FRC report on fallout as the source for the alarming number and further claims that other authorities believe the number could be even higher. It is not obvious how SANE arrived at the estimate provided in the poster—the claim of 1.25 million infant deaths and gross birth defects greatly exceeds the estimates provided in the cited FRC report. However, the claims in SANE's publications reflect a no-threshold concept for the health effects of radiation exposure and—if SANE truly did follow the FRC methodology—also a linear dose-effect relationship.

[620] Katz, 26-27.
[621] Katz, 27.
[622] Katz, 27.
[623] Katz, 29.
[624] Katz, 32.
[625] Katz, 35.
[626] Katz, 77.

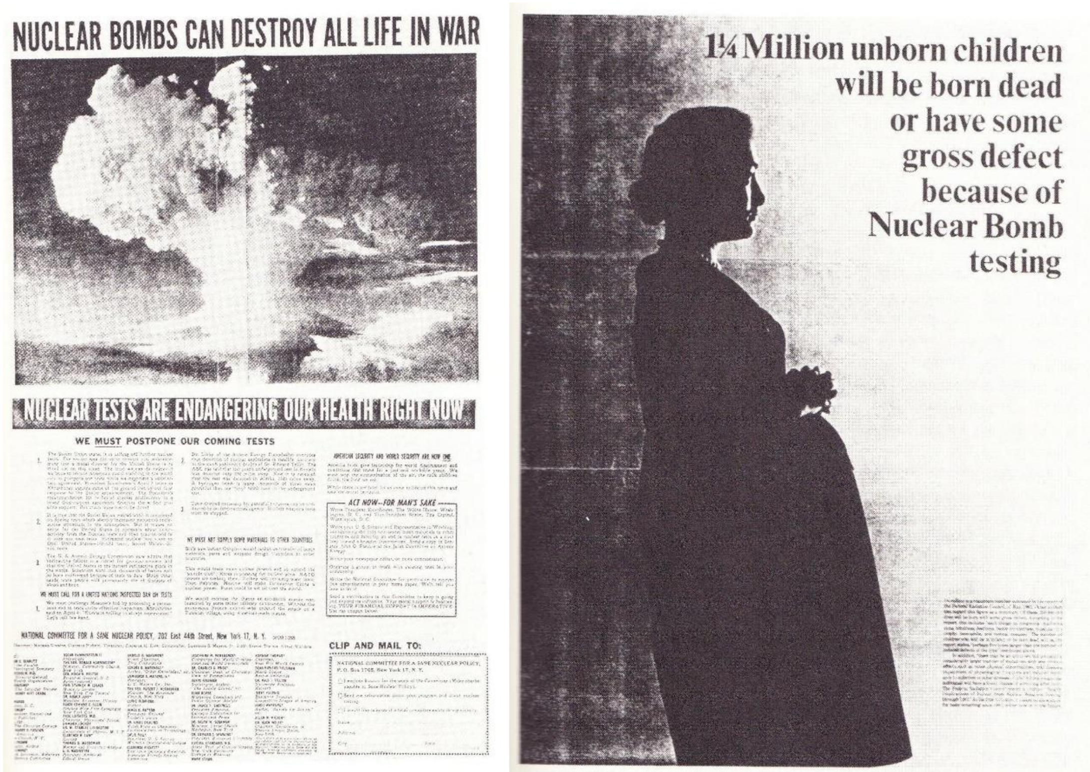

Figure 7-1 SANE Newspaper Advertisement and New York Subway Poster[627]

In addition to the newspaper and poster campaigns, SANE performed direct outreach to communicate its views. In the spring of 1959, SANE set up a pop-up information center in a Times Square storefront with a window display that included a Geiger counter, magazine articles on strontium-90 in the milk supply, and a loudspeaker repeating messages about strontium-90 in fallout.[628] In addition to distributing literature, SANE hosted lunchtime speakers at the storefront daily.[629] The outreach center ran for one month, and an estimated 40,000 people visited to take literature, sign a petition, fill out postcards and letters supporting SANE's objectives, and donate money.[630] The storefront also attracted media interest, with stories about it appearing in print media and on television.[631]

SANE organized meetings and rallies in New York City and Hollywood to further spread its *discourse* and broaden its support network.[632] SANE's work in Hollywood resulted in celebrities such as Marlon Brando, Gregory Peck, Kirk Douglas, and Henry Fonda signing onto their cause.[633] Their New York rallies and meetings featured Linus Pauling, who warned that there was no safe level of strontium-90 in the human body, and drew telegrams of support from U.S. Senators and Adlai Stevenson.[634] Particularly in its activism in New York City, SANE

[627] Katz, 33, 79.
[628] Katz, 38.
[629] Katz, 38.
[630] Katz, 38.
[631] Katz, 38.
[632] Katz, 38-43.
[633] Katz, 42-43.
[634] Katz, 38-46.

sought to engage the attention of world leaders and the United Nations to press for global disarmament.[635]

SANE made creative and effective use of the ordering instruments of co-production in its campaign against nuclear weapon testing. Its multimedia *discourse* centered on *making representations* of fallout as a grave health hazard, especially to children's health. SANE crafted its own public *identity* as a source of reliable scientific information by citing the FRC as the source of estimates of fallout's health impacts and by obtaining public statements of support from scientists, celebrities, and other well-known public figures. SANE's effective use of these ordering instruments reinforced the validity of the underlying model that no level of radiation exposure was safe and that the likelihood of harm was proportional to the magnitude of the radiation exposure.

7.2.3 Committee for Nuclear Information / Committee for Environmental Information

This citizen group was initially formed as the Greater St. Louis Citizens Committee for Nuclear Information in April 1958 with the objective of informing the public about "the scientific facts about fallout and other nuclear issues."[636] Unlike SANE, CNI did not take overt political positions but instead organized scientists not affiliated with the AEC (none of whom were nuclear physicists or radiation biologists) to provide information about nuclear safety in public talks and articles that would be comprehensible to members of the non-scientist public.[637] The articles began as a newsletter and evolved into a monthly magazine.[638] The citizen group's interests broadened over time, and it renamed itself the Committee for Environmental Information in 1967 to reflect its broader scope.[639]

CNI avoided advocacy because its founders believed that they would get a more favorable reception in St. Louis if they stuck to describing what was known and what was unknown instead of arguing for policies such as banning atomic testing or testing milk supplies for fallout.[640] Moreover, CNI formed at a time when the U.S. Congress' House Committee on Un-American Activities was working to expose communist sympathizers in the United States, and a Senate Subcommittee had driven SANE into instituting a formal policy excluding communists from joining their organization.[641] In that environment, CNI's "just the facts" approach helped it to survive challenges to its neutrality.[642] Moore's evaluation of this manner of *discourse* noted that, despite its claimed neutrality, it nonetheless *represented* the government's sharing of scientific information as inadequate, and "undermined the idea of the

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635 Katz, 36-46.
636 Virginia Warner Brodine, "The Day Before Yesterday: The Committees for Nuclear and Environmental Information," *New Solutions* 8:1 (1998), 17-25.
637 Moore, 98-99.; Brodine, 19.
638 Brodine, 19.
639 Moore, 126.
640 Moore, 118.
641 Moore, 120.
642 Moore, 120-122.

state as a neutral arbiter of the public good," because otherwise there would be no need for citizen-produced scientific reports.[643]

From the late 1950s to mid-1960s, CNI disseminated information on controversial topics related to nuclear safety, including: fallout from atmospheric testing of nuclear weapons; nuclear war and civil defense; Project Plowshare (the AEC's program for peaceful use of nuclear explosives); and siting of a proposed nuclear power station near the San Andreas fault in California.[644] One of the founders of CNI, John M. Fowler, produced the edited volume *Fallout: A study of superbombs, strontium 90, and survival* in 1960 to thoroughly explain the origins of fallout, its health effects, and what the aftermath of a nuclear war would look like. Cited earlier in this dissertation for its technical content, the book featured chapters by Fowler (an assistant professor of physics), James Crow (president of the Genetics Society of America and professor of genetics), a number of other scientists, and Chet Holifield (Congressional Representative from California and chairman of the House Subcommittee on Military Operations and Special Subcommittee on Radiation), with a foreword by Adlai Stevenson (former governor of Illinois and Democratic Party nominee for the 1952 and 1956 Presidential elections). In the book's introduction, Fowler notes that information about fallout was available from technical papers and the reports of the JCAE's hearings, but that they were written in a manner "largely incomprehensible to the layman."[645] Fowler wrote that the book was intended to provide the information in a more understandable form and "to inform, not to mold opinion."[646] It provided a thorough discussion of the uncertainty about whether or not there was a threshold for health effects from exposure to ionizing radiation and discussed effects including heritable genetic damage, cancer, and life-shortening (including the fact that geneticists were convinced there was no threshold for radiation-induced mutations).[647] While acknowledging the uncertainties, the book used a linear no-threshold model to calculate the potential number of cancers, the amount of life-shortening, and the number of genetic defects that could be expected due to exposure to radioactive fallout from nuclear weapon testing.[648] As such, the thoroughly scientific book served as another ordering instrument *making representations* of the validity of the linear no-threshold model.

After the FRC published its estimates of the public health impacts of fallout, CNI published an article titled "Fallout in Food" in 1963 that described the levels of radioactive materials that had been found in children's diets due to prior nuclear weapons testing and described the guidance levels published by the FRC and similar guidance published by the ICRP.[649] The CNI article quoted the FRC's estimates for the additional cases of leukemia and genetic defects to be expected from fallout and further noted that "What is generally accepted by

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[643] Moore, 196.
[644] Brodine, 21-23.
[645] John M. Fowler, "Introduction," in John M. Fowler, ed., *Fallout: A study of superbombs, strontium 90, and survival* (New York: Basic Books, Inc., 1960), 9.
[646] Fowler, 9-10.
[647] Walter R. Guild, "Biological Effects of Radiation," in John M. Fowler, ed., *Fallout: A study of superbombs, strontium 90, and survival* (New York: Basic Books, Inc., 1960), 71-85.; James F. Crow, "Radiation and Future Generations," in John M. Fowler, ed., *Fallout: A study of superbombs, strontium 90, and survival* (New York: Basic Books, Inc., 1960), 98-101.
[648] Guild, 88-91.; Crow, 101-105.
[649] Irving Michelson, "Fallout in Food," *Nuclear Information* 5:5 (1963), 3-7.

scientists is that in the absence of proof that a threshold exists, below which no damage is caused, the safest assumption to make is that any radiation entails some risk of harm."[650]

Similarly, CNI published in its magazine written testimony it had provided to the JCAE on local effects of fallout from nuclear weapon testing in Nevada.[651] CNI's testimony took issue with the AEC's position that the tests posed no discernable hazard to the downwind communities. CNI argued that AEC was overlooking the radiation exposures suffered by people, particularly children, who ingested locally produced milk that was likely to contain radioactive iodine from fallout.[652] The CNI testimony cited FRC guidance and analysis and applied calculations developed by researchers from the United Kingdom's Atomic Energy Authority using a linear dose-response relationship to estimate the risk of thyroid cancer among the exposed children in communities near the Nevada Test Site.[653] CNI's testimony further asserted that "The smallest dose capable of inducing cancer is not known, but it is generally assumed that the frequency of induced cancer may be proportional to dose, down to very low levels of exposure."[654] It again cited the U.K. AEA researchers as concluding that exposing one million infants to one rad of radiation to the thyroid could be expected to result in 35 cases of thyroid cancer.[655] CNI's approach of basing its analysis on the linear no-threshold model and citing entities such as the FRC and the U.K. AEA as the sources of such analysis was another important ordering instrument that drew from the authority of those institutions in *making representations* of the validity of the model.

Beyond its publications, CNI attracted attention to its work via a joint project with the Washington University in St. Louis to directly engage citizens in research on radiation exposures due to fallout. This effort took the form of the Baby Tooth Survey.[656] Inspired by an article by a Johns Hopkins University biochemist who previously served as a research fellow at the Washington University School of Medicine, CNI proposed collecting baby teeth shed by the children of St. Louis and analyzing them for radioactivity from fallout they had ingested.[657] CNI advertised the program by word-of-mouth through churches and dentists, distributed forms at elementary schools and local businesses, and received publicity in local media.[658] Tooth collection started in January 1959, and the survey collected about 61,000 teeth by the time it published its first journal article 2-1/2 years later.[659] The journal article, published in *Science* in

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[650] Michelson, 5-6.
[651] Committee for Nuclear Information, "Local Fallout: Hazard from Nevada Tests," *Nuclear Information* 5:9 (1963), 1-12.
[652] CNI (1963), 1-2.
[653] CNI (1963), 2-3.
[654] CNI (1963), 10-11.
[655] CNI (1963), 11.
[656] Washington University School of Dental Medicine, *St. Louis Baby Tooth Survey, 1959-1970*, http://beckerexhibits.wustl.edu/dental/articles/babytooth.html (accessed November 29, 2020).; Yvonne Logan, "The Story of the Baby Tooth Survey," *Scientist and Citizen* 6:9-10 (1964), 38-39.
[657] Washington University School of Dental Medicine.
[658] Washington University School of Dental Medicine.; Rosalind Early, "How to Stop a Nuclear Bomb: The St. Louis Baby Tooth Survey, 50 Years Later," *St. Louis Magazine* (September 13, 2013), https://www.stlmag.com/How-to-Stop-a-Nuclear-Bomb-The-St-Louis-Baby-Tooth-Survey-50-Years-Later/ (accessed November 30, 2020).; Louise Zibold Reiss, "Strontium-90 Absorption by Deciduous Teeth," *Science* 134:3491 (November 24, 1961), 1669.
[659] Reiss, 1669-1670.

1961, showed that baby teeth from children born in 1954 contained about four times the amount of strontium-90 found in teeth from children born in 1951.[660] Later testing found that children born in 1957 had accumulated nine times as much strontium-90 in their baby teeth as children born in 1951.[661] By 1964, CNI had collected nearly 160,000 baby teeth, and its study area extended up to 150 miles from St. Louis.[662] Several years after the United States and Russia agreed to ban atmospheric testing of nuclear weapons in 1963, the trend reversed, and the levels of strontium-90 in baby teeth began to decline.[663] The study ended in 1970, having collected about 320,000 teeth in total.[664]

Figure 7-2 Forms for the Baby Tooth Survey[665]

CNI's vivid demonstration that children's teeth had become radioactive because of nuclear fallout provided a strong contrast with the AEC's assurances that the risk was acceptably low. This helped bring attention to the CNI's message that no level of radiation exposure was safe. It also inspired citizen groups around the world to pursue similar studies to test radiation levels in their communities in the years following CNI's Baby Tooth Survey.[666] This sophisticated instance of citizen science served as a strong ordering instrument for *making representations* of America's children as tangibly impacted by fallout, based on actual numbers from laboratory testing. By comparison, the AEC's public report from 1956 on the results of Project Sunshine emphasized that strontium-90 levels in humans were very low, without saying what the levels were. Furthermore, the AEC's short 3-1/2 page article, ostensibly about the hazards of strontium-90 in fallout, was larded with unhelpful scientific commentary such as the following discussion of carbon-14:[667]

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660 Reiss, 1670.; Early.
661 Early.
662 Logan, 39.
663 Early.
664 Early.
665 Washington University School of Dental Medicine.
666 Early.
667 Libby, 657.

> The cosmic rays themselves make neutrons, which, of course, make radiocarbon. In fact, the earth has on its surface a total of 80 tons of radiocarbon from the cosmic radiation. Now, since each neutron forms one C14 atom of mass 14 times the neutron's mass, this corresponds to 5.2 tons of neutrons, and we see that this enormous number of neutrons would have to be produced and escape in order that nuclear weapons would just double the feeble natural radioactivity of living matter due to radiocarbon. Such an increase would have no significance from the standpoint of health.

Citizens who turned to the AEC article seeking to understand whether they should be worried about strontium-90 in the food supply therefore found themselves confronted by vaguely related verbiage about cosmic radiation that creates neutrons that in turn create carbon-14, the idea that one can have "tons" of neutrons, and the statement that living matter is radioactive, but only feebly so, which makes it safe for the AEC to double that amount of radiation. Since many citizens would be unable to digest such prose, the AEC article does little to inform the public but instead performs boundary work by discouraging non-scientists from seeking to understand the AEC's activities. It is unsurprising, therefore, that CNI found an audience for its publications.

CNI's network-building efforts and use of ordering instruments of co-production were distinctly different from those employed by SANE. CNI clearly sought to cultivate sentiment against nuclear weapon testing, but where SANE used scientific data to support overt political activism, CNI took a "just the facts" approach that presented the scientific data in a neutral manner and directly engaged the public in performing science via the Baby Tooth Survey. CNI's approach was calculated to gain an audience with people who might find SANE's "peacenik" proclamations off-putting, which is not surprising considering that CNI's location in St. Louis ("Gateway to the West") was far away both physically and culturally from SANE's power centers in New York City and Hollywood. CNI's use of the ordering instrument of *making discourses* served to advance both critical thinking about the safety of nuclear weapon testing and affirmation of the linear no-threshold model for radiation dose effects.

Science information groups began forming around the United States in the years following CNI's establishment. An umbrella group named the Scientists' Institute for Public Information formed in 1963 to coordinate the activities of CNI and similar science information groups that had emerged in other U.S. cities.[668] The umbrella group operated in the same spirit as CNI, with the objective "to provide information not only to voters in general, but also to citizen action groups, governmental agencies, labor unions, and businesses which are grappling directly with environmental problems."[669]

7.2.4 Federation of Atomic Scientists/Federation of American Scientists

Thirteen groups came together in Chicago in November 1945 to form the Federation of Atomic Scientists, an organization that opposed nuclear war and claimed to have the support of over 90 percent of the scientists from the Manhattan Project.[670] In early 1946, FAS changed its

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668 Novick, 201.; McGowan, 16-20.

669 McGowan, 17.

670 Katz, 5.; Federation of American Scientists, *About FAS*, https://fas.org/about-fas/ (November 15, 2020).

name to the Federation of American Scientists to expand its network of supporters, and it remains active today.[671] Since December 1945, the *Bulletin of the Atomic Scientists* has been the "official organ" of FAS.[672] Whereas CNI and SIPI sought to make nuclear information intelligible to a very broad range of people, groups, and institutions, the *Bulletin* has been characterized as "directed only to a narrow and elite audience in the policy and scientific communities, who were assumed already to be informed on the basic issues."[673] The *Bulletin* is known in contemporary society for a "Doomsday Clock" that it updates annually to alert the public to the degree of existential peril faced by humanity, in terms of how many minutes are left before the midnight hour strikes for humankind.[674] This dramatic proclamation is a far cry from the sober language favored by CNI.

Figure 7-3 The *Bulletin of the Atomic Scientists* Presents the 2020 Doomsday Clock[675]

FAS and the *Bulletin* have published a vast number of articles over the decades taking strong positions on issues such as nuclear weapons testing, nuclear proliferation, and nuclear energy. The *Bulletin* has featured articles that rely on the linear no-threshold model to calculate the number of cancers and other negative health impacts resulting from various radiation exposures, and moreover has published articles explicitly defending the linear no-threshold model as the most appropriate way to estimate the health effects of radiation exposure. The *Bulletin* also served as a forum for debate by publishing statements by the AEC and other official sources and then featuring debate about those statements in subsequent issues. Examples of

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671 Katz, 5.; Federation of American Scientists.

672 Katz, 5.

673 Charles Bazerman, "Nuclear Information: One Rhetorical Moment in the Construction of the Information Age," *Written Communication* 18:3 (July 2001), 268.

674 Gayle Spinazze, *Press Release —IT IS NOW 100 SECONDS TO MIDNIGHT*, *Bulletin of the Atomic Scientists*, https://thebulletin.org/2020/01/press-release-it-is-now-100-seconds-to-midnight (January 23, 2020).

675 Spinazze.

articles and commentary published in the *Bulletin* during the era of atmospheric testing of nuclear weapons include:

- "Strontium Hazards: British Atomic Scientists' Association"—This 1957 article reprinted a report by a British committee of scientists on the health effects of fallout from atomic weapons testing. It noted that despite inconclusive evidence, "On the whole the experiments seem in favor of a proportionality between the frequency of tumors produced in a given length of time and the amount of radioactive material in the body even at low dose levels." The article proceeded to use a linear no-threshold model to estimate cancers worldwide from a single hydrogen bomb test (1000 people with bone cancer per megaton of nuclear yield, in their estimation).[676]

- "A Criticism of the GAC Report" and "Fallout: Criticism of a Criticism"—The *Bulletin* published these opinion pieces in 1959 and 1960, respectively, following its publication of a statement publicly released in 1959 by the AEC's General Advisory Committee on the hazards of fallout. In the first of these opinion pieces, Ralph E. Lapp, a physicist who had worked in the Manhattan Project during World War II, noted that the so-called GAC report had been widely publicized in the press, including being printed in its entirety in the *New York Times* under the headline "AEC Study Belittles Fallout; Advisers Report Radiation Low." Lapp criticized the GAC report for basing its conclusion on "generalized assertion" supported by a "distressing lack of documentation or technical reference" in comparing the radiation exposures from radioactive fallout to certain naturally occurring sources of radiation exposure.[677] The second opinion piece, written by Eugene P. Wigner, professor of mathematical physics and advisor to the AEC GAC, rebutted Lapp's criticisms. Wigner criticized Lapp for not acknowledging that the GAC report had estimated that even if potential future additional nuclear bomb testing added to contemporary fallout levels, the resulting doses would still be less than five percent of the exposure rate from either natural background sources or medical exposures. In an assessment reflecting the assumption of a linear dose-response relationship, Wigner went on to describe the genetic effects of this five percent increase in radiation exposure as "an increase in tempo of this degeneration by 5 per cent." He further quoted the GAC report in providing bounding estimates for increases in bone cancer and leukemia that similarly appear to have been based on a linear dose-response model. Wigner closed his argument by citing the considerably larger annual homicide rate in the United States and questioning why then people were so focused on fallout.[678]

- "Human Exposure to Radiation"—This 1959 article by Karl Z. Morgan, the Manhattan Project veteran who founded the Health Physics Society (see section below), reviewed the current understanding of radiation's health effects. Morgan discussed the acute effects of large radiation exposures and the potential for genetic mutations, leukemia, and

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676 British Atomic Scientists' Association, "Strontium Hazards: British Atomic Scientists' Association," *Bulletin of the Atomic Scientists* 13:6 (June 1, 1957), 202-203.

677 Ralph E. Lapp, "A Criticism of the GAC Report," *Bulletin of the Atomic Scientists* 15:7 (September 1959), 311-312, 320.

678 Eugene P. Wigner, "Fallout: Criticism of a Criticism," *Bulletin of the Atomic Scientists* 16:3 (March 1960), 107-108.

life span shortening from smaller exposures. He noted that estimating the effects of smaller doses requires extrapolating from the health effects of doses two to three orders of magnitude larger. As a result, he concluded that, although evidence suggested that high dose rates could have greater effects per millirad of exposure than lower dose rates, it was "safe only to assume" that there was no threshold for health effects and that effects would increase linearly with exposure. He proceeded to discuss recent ICRP guidance on exposure limits for the general population, observing that radiation exposures from medical procedures were higher than necessary, particularly to fetuses, and represented a considerably greater health hazard than fallout. He advocated for medical practitioners to record the dose each patient received from undergoing medical procedures involving radiation exposure.[679]

- "Fetal Irradiation and Fallout"—This 1959 article reviewed research "performed at the Argonne National Laboratory under the auspices of the Atomic Energy Commission" that attempted to establish a correlation between fetal radiation exposures and childhood cancer deaths. The article stated that about 11 percent of pregnant women in the United States underwent x-ray pelvimetry in that era and reviewed work by other researchers who had sought to correlate such radiation exposure to the likelihood of the exposed child suffering a fatal malignancy before the age of ten. That research resulted in the conclusion that a prenatal exposure of 2 r (not specified in the article as roentgen, rad, or rem) could be expected to double the likelihood of such a fatality. The article used a linear no-threshold correlation to extrapolate from that result to the smaller *in utero* exposures attributable to radiation from fallout, thereby estimating that prenatal radiation exposures to fallout as small as 0.02 r (again, not specified as roentgen, rad, or rem) could result in a one percent increase in childhood cancer fatalities.[680]

According to the *Encyclopedia of Science, Technology, and Ethics*, FAS dwindled from about 30 local chapters in the 1950s to only 2 in 1970, with its annual budget falling to $7000 in 1969.[681] However, it subsequently rebounded, and its website (fas.org) shows that FAS currently engages in advocacy on a wide range of issues involving science, arms control, and government policy, occasionally publishing articles on the linear no-threshold dose-response model.

7.2.5 Health Physics Society

The Health Physics Society was founded in 1955 as an organization for radiation safety professionals, with (initially) no journal and an annual membership fee of two dollars.[682] Its first president, Karl Z. Morgan, has been mentioned previously in this dissertation and will continue to appear in subsequent sections because of his eventual dissent with the nuclear establishment in

[679] Karl Z. Morgan, "Human Exposure to Radiation," *Bulletin of the Atomic Scientists* 15:9 (November 1959), 384-389.
[680] Jack Schubert, "Fetal Irradiation and Fallout," *Bulletin of the Atomic Scientists* 15:6 (June 1959), 253-256.
[681] Adam Briggle, "Federation of American Scientists," in Carl Mitcham, ed., *Encyclopedia of Science, Technology, and Ethics, Vol. 2* (Detroit: Macmillan Reference USA, 2005), 757-759.
[682] Alex J. Boerner and Ronald L. Kathren, "The Health Physics Society: A 50-Year Chronology," *Health Physics* 88:6 (June 2005), 735.

the United States.[683] In a sign of the close relationship between the HPS and the NCRP, the second president of the HPS was none other than Lauriston Taylor.[684]

The HPS began publishing a journal entitled *Health Physics* in 1958, with Morgan as its first editor-in-chief, and it remains in publication today.[685] In later years (i.e., the 1980s and beyond), the HPS began to take positions on public issues related to radiation, including the validity of the linear no-threshold model, but prior to that the HPS focused mainly on cementing health physics as a *bona fide* profession, including certifying the qualifications of health physicists.[686] Today, the HPS website states its mission is "to support its members in the practice of their profession and to promote excellence in the science and practice of radiation safety" and notes that it is not affiliated with the government or industry.[687]

During the era of the fallout controversy, *Health Physics* mainly published articles on highly technical topics related to dosimetry and radiation protection. However, it also included articles communicating or illustrating positions on dose-effect relationships for radiation exposures. For example, the first issue of the journal included two essays by Taylor, one of which opined that, "we must still operate on the principle that no radiation taken by man unnecessarily is good for him" while at the same time asserting that, even for the obsolete occupational exposure limit of 100 rem/year used in the early years of x-ray applications, "at none of these levels has there ever been developed any positive evidence of damage to the individual."[688]

Other articles in *Health Physics* during the atmospheric weapon testing era similarly reflected the viewpoints of the government's nuclear enterprise. Given that numerous health physics practitioners worked in the government's nuclear enterprise, this affiliation is unsurprising. For example, the second issue of *Health Physics* included an article, authored by a member employed at Los Alamos, on the potential hazard of global strontium-90 fallout from nuclear weapon testing.[689] The article noted that it represented work done under the auspices of the AEC, and provided a very thorough analysis of the levels of strontium-90 that could be expected to build up in the human population from continuing atmospheric testing of nuclear weapons. In evaluating the resulting health consequences, the article asserted that "it is impossible to say" whether or not there is a safe threshold below which chronic radiation exposure would convey no risk of solid cancer or leukemia.[690] The article further stated that some participants in the 1957 JCAE hearing on fallout had questioned the validity of a linear model for dose-response and cited a conference presentation from 1955 that proposed a threshold relationship for tumor development.[691] It concluded by comparing the potential body burdens of

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683 Boerner and Kathren, 735.
684 Boerner and Kathren, 736.
685 Boerner and Kathren, 736.
686 Boerner and Kathren, 744.
687 Health Physics Society, *About the Health Physics Society*, http://hps.org/aboutthesociety/ (accessed January 14, 2021).
688 Taylor (1958), 65, 70.
689 Wright H. Langham, "Potential Hazard of World-Wide Sr^{90} Fallout from Nuclear Weapons Testing," *Health Physics* 1:2 (April 1958), 105-124.
690 Langham, 117.
691 Langham, 118.

strontium-90 to the maximum permissible levels recommended by NCRP and ICRP, stating that the then-present rate of atmospheric testing of nuclear weapons would result "in a few people approaching body burdens about 50 to 75 percent of the recommended maximum," with "little potential hazard."[692] The report's abstract added the additional note that "Whether weapons tests should or should not be stopped depends on the importance of maintenance of a balance in nuclear weapons in averting a nuclear war."[693]

Another example of the content of *Health Physics* from that time period was an article, written by a member working for the AEC's Division of Biology and Medicine, on radiation exposures from weapon tests in Nevada.[694] This article compiled the estimated cumulative gamma radiation exposure to residents of towns near the test site and also estimated doses from inhalation of fallout. In assessing the resulting potential for thyroid cancer, it cited reports that large doses delivered to the thyroid by medical procedures had "no observable detrimental effects," although it did acknowledge "some evidence" that infants were more sensitive, albeit at much larger doses than calculated for fallout from the test site.[695] The article closed with a pair of quotations to further support the lack of harm to the site's downwinders: Regarding radiation exposure to the bones, it quoted a passage from the NAS 1956 BEAR report stating that "visible changes in the skeleton have been reported only after hundreds of rep [obsolete unit similar to rad] were accumulated and tumors only after 1500 or more."[696] Regarding internal organs, it quoted a review article by a researcher from the Naval Medical Institute as stating that "It takes doses well over 1000 r [not specified as roentgen, rad, rem, or rep] to damage the gut permanently in most mammals studied, and it is capable of rapid dramatic recovery of anatomical and functional integrity with doses in the lethal range."[697] These quotations serve to downplay the potential health effects of exposure to fallout and clearly advance the notion of a safe threshold for radiation exposure.

Despite publishing such materials in its journal, the HPS was not reaching out to a broader audience during that time period. As such, its influence on the broader discourse regarding dose-effect relationships for radiation exposure was more a function of the work of the individual members of the HPS, as opposed to the organization's activities.

7.2.6 American Nuclear Society

The American Nuclear Society was founded in 1954, on the heels of President Eisenhower's "Atoms for Peace" speech, as noted in the ANS website's discussion of the origins of the society.[698] Its current mission statement is to "Advance, foster, and spur the development and application of nuclear science, engineering, and technology to benefit society." As such, its

[692] Langham, 122.
[693] Langham, 105.
[694] G. M. Dunning, "Radiation Exposures from Nuclear Tests at the Nevada Test Site," *Health Physics* 1:3 (July 1958), 255-267.
[695] Dunning, 264.
[696] Dunning, 266.
[697] Dunning, 266.
[698] American Nuclear Society, *A Brief History of the American Nuclear Society*, https://www.ans.org/about/history/ (January 16, 2021).

activities have focused more on nuclear engineering and applications of nuclear technologies, as opposed to the health effects of radiation exposure. A review of its journals and other publications from the 1950s and 1960s does not reveal advocacy of any particular dose-response relationship for radiation exposures. This contrasts with more recent activism by ANS to advocate for government and industry to reevaluate their implementation of ALARA principles, which ANS currently considers to be too risk averse; for a social science research program to "help promote science-informed perspectives regarding all risks and benefits of nuclear and radiological technologies;" and for government funding for research on the health effects of low levels of radiation exposure.[699]

ANS publications and conference proceedings from the era of atmospheric nuclear weapons testing further illustrated the interconnections between the various organizations involved in nuclear technologies. For example, the only discussion of dose-effect relationships in ANS journals during that period appeared in a 1956 article on the potential impacts on nuclear facilities resulting from revised ICRP recommendations for allowable body burdens of radionuclides, submitted by Karl Z. Morgan of the NCRP and HPS.[700] Likewise the AEC Director of Reactor Licensing, who was also a member of ANS, gave a presentation titled "Nuclear Risk in Perspective" at an ANS conference on nuclear criticality safety in 1966.[701] As is commonplace in such perspective pieces, the AEC official compared risks of radiation exposure to other natural and manmade hazards. What was not commonplace about his analysis was that he cited the work of a University of Nevada botanist which purported to show "that the fragrant pine, the pungent sage, and related trees emit 1000 percent more pollutants than all man's fires, factories, and vehicles" and rhetorically asked how to equate that hazard to radiation exposure limits.[702] He also displayed the plot of past and present radiation exposure limits reproduced in Figure 7-4 below and stated that applying a linear extrapolation to the historical trend would show that the permissible whole body dose would be reduced to zero before the year 2000.[703] This is an obvious critique of the linear extrapolation of data for the health consequences from large radiation exposures to predict the effects of small exposures.

He acknowledged those remarks as "somewhat facetious" but stated their purpose was to illustrate that "There is no single, simple criterion by which one may judge the qualitative or quantitative acceptance of radiation risk."[704] He suggested that "rational, well-informed people" would conclude the following: "Radiation exposures should always be maintained at the minimum practicable level. No exposure should be accepted without anticipation of benefit. On the other hand, for economic and other operational reasons, one should not set the level too low."[705] This is equivalent to the modern articulation of the ALARA principle.

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[699] American Nuclear Society, *Position Statement #41: Risks of Exposure to Low-Level Ionizing Radiation*, https://cdn.ans.org/policy/statements/docs/ps41.pdf (November 2020).
[700] Karl Z. Morgan, "Maximum Permissible Internal Dose of Radionuclides: Recent Changes in Values," *Nuclear Science and Engineering* 1:6 (1956), 477-500.
[701] Peter A. Morris, "Nuclear Risk in Perspective," *American Nuclear Society Proceedings: Nuclear Criticality Safety, National Topical Meeting, Las Vegas, Nevada, SC-DC-67-1305* (December 13-15, 1966), 29-36.
[702] Morris, 30.
[703] Morris, 31.
[704] Morris. 30.
[705] Morris, 32.

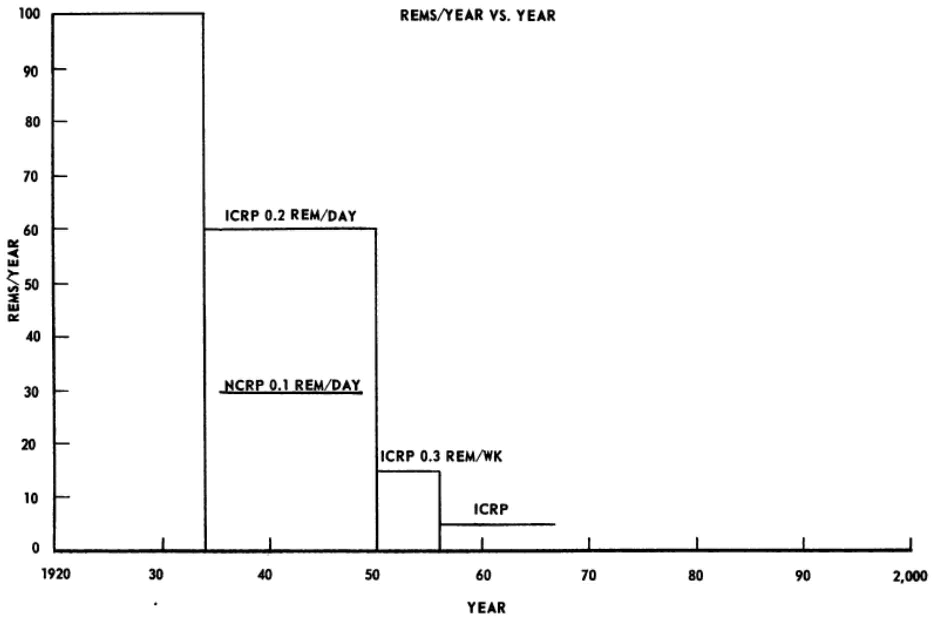

Figure 1. Permissible Whole-Body Doses for Occupational Exposures

Figure 7-4 Chart Displayed at 1966 ANS Conference[706]

7.2.7 Sociotechnical Imaginaries of Activist Organizations and Professional Societies

The manner in which the activist organizations discussed in the subsections above used the various ordering instruments of co-production provided rather predictable insights into the sociotechnical imaginaries that animate them. SANE, CNI, and FAS engaged in *discourse* and made *representations* of the hazards of nuclear weapon testing indicating that they considered nuclear arsenals to represent a grave danger by their very existence, suggesting that their imaginaries depict America finding another route to secure peaceful relations with other countries. Application of the linear no-threshold dose-response model was central to much of their *discourse*, reinforcing the *representation* that it is a valid model. Likewise, their imaginaries recognize, as described by Moore, that science can produce true information about nature but also that it is "fallible and shaped by politics." Accordingly, their imaginaries include a role for the input of citizens in sociotechnical questions, as opposed to leaving the course of science and technology in the hands of expert technocrats. Finally, it is clear that the activist social groups subscribe to imaginaries that view technological developments as subject to the precautionary principle, where the burden is on the purveyor of a new technology to prove it is safe.

In terms of pollution beliefs, the activist social groups view radioactive material in the environment and in the human body as literal pollution, even at small levels. Moreover, they appear to view technoscientific institutions' tendency for top-down decision-making and associated instinct to be less than forthcoming with laypersons as contradicting the democratic ideals of public involvement and transparency.

[706] Morris, 31.

The professional societies provided less evidence for characterizing their sociotechnical imaginaries and pollution concepts during the 1950s and 1960s. However, they are similar in many ways to the NCRP. Like the NCRP, the HPS engaged in institution-building efforts consistent with an imaginary that believes in society's institutions and sees them as instrumental in safely reconciling new technologies with society. Similarly, the emphasis by HPS on constructing health physics into a profession indicates an imaginary that believes in the importance of the technical expert in matters of radiation protection. The work by ANS to develop standards for applications of nuclear technologies indicates the view that radiation is a risk that can be safely managed even if the exact degree of risk is not understood. This suggests an imaginary that has faith in science and believes in technology as key to human progress.

Neither of the professional societies appeared to engage in vigorous boundary work of the type pursued by the NCRP, so there is no evidence that they share the NCRP leadership's pollution beliefs regarding nonscientific influences on risk discourse. Both the HPS and the ANS were built upon the premise that nuclear technologies were safe and beneficial to humanity, so neither of them would be expected to subscribe to imaginaries or pollution beliefs that treat radiation as fundamentally hazardous or unnatural.

7.3 Co-production of Science and Regulation Through the Era of Fallout

The preceding discussion shows that an extensive and diverse actor-network evolved in tandem with the development of the science and regulation of radiation safety. The actor-network started forming with the first realization that radiation could be harmful, and it continued to expand to include more and different actors as the decades passed and human-made radiation releases eventually came to affect the entire planet through global fallout from testing of hydrogen bombs. Individuals and groups participating in the actor-network included those developing and applying technologies involving radiation and radioactive materials, those engaged in research on the biological effects of radiation, and those subject to (or at least concerned about) radiation exposure from various sources.

The acceptance of the linear no-threshold dose-response model can be explained in terms of co-production of science and the social order. The science of radiation health effects evolved in parallel with the development of radiation-related technologies and the associated regulatory system. Particularly in light of the controversy over public exposure to radioactive fallout, the nuclear enterprise needed to support its position that occupational and public exposures were controlled to low levels that posed negligible health concerns. Despite the uncertainty over the actual shape of the dose-response relationship, laboratory experiments and epidemiology indicated that linear model appeared suitable as a "cautious assumption" (in the words of a landmark NCRP report from 1960.[707] Importantly, such a model proved useful to both the nuclear establishment and its detractors. In the hands of proponents of nuclear technologies, the model predicted that occupational exposures and exposures to the public represented small risks compared to naturally occurring levels of radiation and other risks that society deemed acceptable. Conversely, opponents of nuclear technologies were able to advance their causes by

[707] NCRP (1960), 485.

applying the model to predict that undesirable numbers of people would suffer radiation-related maladies if large populations received small radiation exposures from sources such as fallout from nuclear weapon testing.

The durability of the linear no-threshold model can be explained in terms of the ordering instruments of co-production deployed by members of the actor-network as they sought to influence how society used and controlled nuclear technologies, as discussed throughout the sub-sections above. In advocating for their causes, opponents of nuclear technologies engaged in *making discourses* about the potential consequences of nuclear technologies that included consistently *making representations* of the linear no-threshold model as scientifically valid. As adherents to the precautionary principle, they were not overly concerned that the linear no-threshold model was represented as a cautious assumption—their sociotechnical imaginaries accepted such caution as entirely appropriate.

Similarly, the AEC, NCRP, and FRC worked at *making institutions* to govern the development and application of nuclear technologies and applications of radiation, including issuing exposure standards (i.e., ordering instruments) that eventually came to be based on a linear no-threshold model. It is clear from the earlier ordering instruments propagated by the AEC and NCRP that they would have preferred a model with a clear threshold, but the proponents of a threshold model did not manage to enroll the actors needed to construct a successful counter-program to the no-threshold model. As a result, and notably with the 1962 issuance of FRC Report No. 3 on the health consequences of fallout—which for the first time provided government estimates for cases of leukemia, cancer, and genetic effects—the technocratic institutions turned their *discourse* towards acceptance and application of the linear no-threshold model, creating the enduring *representation* of the model as unproven but useful.

In terms of sociotechnical imaginaries, the linear no-threshold model was compatible with both of the dominant imaginaries involved in the actor-network. In the technocratic imaginary of institutions such as the AEC and NCRP, the model could be used by qualified experts to make risk-informed decisions about applications of nuclear technologies. In the socially progressive imaginary of the activist groups such as SANE, CNI, and FAS, the model empowered citizens to formulate arguments informed by science and rooted in the precautionary principle to challenge decisions and actions by the technocratic institutions.

This socially-driven choice of models shaped society, as it (1) bolstered social movements that contributed to the cessation of atmospheric testing of nuclear weapons and continued to sharply restrict other environmental releases of radioactive materials, and (2) worked in tandem with the ALARA principle to shape the regulatory system for radiation exposures as well as the day-to-day practice of radiation work of all kinds. Despite continuing challenges over the ensuing decades, including a pitched battle that began in 1979 (discussed later in this dissertation), this co-produced relationship between science and the social order has held firm, with the NCRP concluding again in 2017 that "there is no alternative dose-response relationship that is more pragmatic or prudent than the LNT hypothesis for radiation protection."[708]

[708] Boice, 1089.

Because of the practical need to accept some level of occupational radiation exposure, medical applications of radiation, and some *de minimis* exposure to the general public, the ALARA principle emerged as an important actant even before the linear no-threshold model had gained wide support. Although it was not possible to define an unequivocally safe threshold dose, all evidence indicated that very small doses resulted in very small risks to the health of exposed individuals. As a result, nuclear practitioners advanced the principle that, in addition to specifying quantified dose limits for exposures to workers and the public, all exposures should be kept as small as practical. This principle further argued that any exposure should result in sufficient benefit to justify accepting the risk of eventual health effects. The next chapter of this dissertation will detail how ALARA developed into a formal element of the regulatory system for radiation exposures. However, even before ALARA became the law, it had taken form as an actant that allowed the nuclear industry to rationalize its operations as representing acceptable levels of risk, even though it could not be proven that the established exposure limits truly precluded harm to the exposed individuals. As copiously quoted in the preceding chapters, the *discourse* from the technocratic institutions is replete with reinforcements of the *representation* of radiation exposure as always potentially harmful and always to be minimized.

One previously unmentioned ordering instrument that played a key role in the co-production process actor-network deserves mention here: radiation dosimetry. Ionizing radiation cannot be detected by human senses under most circumstances. (The most common exception is the perception of flashes of light when high energy particles travel through the eye, which is primarily a concern for astronauts exposed to cosmic radiation outside of the protection of the Earth’s atmosphere.[709]) However, while it cannot be seen, smelled, tasted, or felt like heat, cold, or chemicals can, radiation announces its presence to detection equipment in a manner that allows detecting minute quantities of radioactive materials and precisely measuring minute radiation exposures. As a result, occupational radiation exposures can be recorded accurately down to very low levels, and releases to the environment are readily apparent to anyone with the proper equipment. Thus, dosimetry is central to *making representations* of radiation.

Dosimetry for radiation workers includes self-reading dosimeters that provide real time measurement of exposure to ionizing radiation that the worker can use to track their exposure during a particular task, as well as record dosimeters that measure accumulated dose over longer periods. The technology of these devices has improved over the decades. Self-reading dosimeters have evolved from rudimentary pocket ionization chambers to devices with digital displays for dose and dose rate which can be set to alarm if some desired limit for either parameter is exceeded. Likewise, record dosimeters worn to measure the dose accumulated over longer periods of time have evolved from film badges that gradually fogged when exposed to ionizing radiation to highly precise technology based on thermoluminescent materials.[710]

[709] G.G.Fazio, J.V. Jelley, and W.N. Charman, “Generation of Cherenkov Light Flashes by Cosmic Radiation within the Eyes of the Apollo Astronauts,” *Nature* 228 (October 17, 1970), 260-264.

[710] R.H. Wilson, *Historical Review of Personnel Dosimetry Development and Its Use in Radiation Protection Programs at Hanford: 1944 to the 1980s*, PNP-6125 UC-41 (Pacific Northwest Laboratory: Richland, WA, February 1987).; U.S. Department of Health and Human Services, Radiation Emergency Medical Management, *8 Categories of Radiation Dosimeters for Dose and Exposure Monitoring and Worker Safety*, https://www.remm.nlm.gov/radiation-dosimeters-dose-monitoring-worker-safety.htm (accessed January 24, 2021).

A wide variety of surveying instruments are available for detecting radioactive contamination on people or in the environment. Such instruments enable precisely characterizing radiation fields in working environments, monitoring the air to detect any airborne radioactive material, and detecting any radioactive contamination on workers, on equipment, or in the environment.[711] As a result, even though ionizing radiation and radioactive contamination are invisible, their presence can be readily detected. This characteristic of radiation was used to great effect in CNI's Baby Tooth Survey to drive home the message that fallout was being incorporated into the bodies of the children of America. The ability to readily detect radioactivity fueled citizen concerns when cities and states reported fallout in milk supplies and took action to try to protect the public.

Radiation survey and dosimetry programs have been *institutionalized* as integral parts of radiation protection programs since the Manhattan Project and are specifically required by the Nuclear Regulatory Commission in 10 CFR Part 20, *Standards for Protection Against Radiation*.[712] Survey and dosimetry programs are essential in demonstrating that activities comply with the specified dose limits and maintain exposures as low as reasonably achievable. Moreover, they endow radiation with a tangible presence that powerfully reinforces dose minimization efforts and truly makes ALARA a way of life for radiation workers (described as "embodying the insensible danger" by Joy Parr, who studied the behavior of radiation workers in nuclear power stations).[713] Providing radiation workers with the expectations of an ALARA program together with the tools needed to monitor their radiation exposure enables the type of self-regulation envisioned by Foucault in his conception of government as "the conduct of conduct."

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711 W.P. Howell, J.L. Kenoyer, M.L. Kress, K.L. Swinth, C.D. Corbit, L.V. Zuerner, D.M. Fleming, and H.W. DeHaven, *A Historical Review of Portable Health Physics Instruments and Their Use in Radiation Protection Programs at Hanford, 1944 Through 1988*, PNL-6980 UC-41 (Pacific Northwest Laboratory: Richland, WA, September 1989).; Andrew R. McFarland, Carlos A. Ortiz, and John C. Rodgers, "Performance Evaluation of Continuous Air Monitor (CAM) Sampling Heads," *Health Physics* 58:3 (March 1990), 275-281.; U.S. Department of Health and Human Services, Radiation Emergency Medical Management, *8 Categories of Radiation Dosimeters for Dose and Exposure Monitoring and Worker Safety*, https://www.remm.nlm.gov/radiation-dosimeters-dose-monitoring-worker-safety.htm (accessed January 24, 2021).

712 R.H. Wilson.; W.P. Howell, *et al*.; *Standards for Protection Against Radiation*, 10 C.F.R. § 20 (September 30, 2015).

713 Joy Parr, "A Working Knowledge of the Insensible? Radiation Protection in Nuclear Generating Stations, 1962-1992," *Comparative Studies in Society and History* (48:4, October 2006), 850.

8 Licensing of Nuclear Power and Institutionalization of the ALARA Principle

In the latter part of the 1960s, the licensing of commercial nuclear power stations came to the forefront of the controversies related to radiation's health effects. This next round of discourse attracted organizations and people who had been active in the public discourse over fallout from atomic weapons testing but also prominently included contributions from individual scientists who had become particularly disaffected with the nuclear establishment after raising health and safety concerns. As a result of the controversy over the safety of radiation exposures to the public from nuclear power stations, one of the last major actions taken by the AEC before it dissolved into multiple successor agencies was to finally codify the practice of keeping both occupational exposures and exposures of the public as low as practically achievable.[714]

8.1 AEC Campaign to Promote Nuclear Power

Its assigned mission to promote nuclear power in the United States presented the AEC with a different playing field than it contended with in its defense of its nuclear weapon testing program. The siting, construction, and operation of nuclear power stations required consent and cooperation from non-federal entities and provided opportunities for citizen groups to intervene much more effectively than had been possible in the case of nuclear weapon testing.

The AEC pursued a public relations campaign for nuclear power that was similar in many ways to its approach to convincing citizens of the safety and necessity of the nuclear weapon testing program. For example, in a campaign beginning in March 1969, AEC representatives traveled to 39 public meetings on the environment, presented 22 speeches, and participated in 10 Congressional hearings (providing testimony amounting to over 300 pages) over the course of 18 months.[715] AEC staff published 66 articles on the environment and distributed over 140,000 copies of *Nuclear Power and the Environment*, a booklet arguing that America's future energy needs would be best met using nuclear power.[716] This campaign was undertaken with the aim to "confront the public with the facts"—again reflecting a deficit model of communicating scientific information.[717] The AEC approach is consistent with its sociotechnical imaginary, wherein the technocratic institutions make decisions and then tell the public why the decisions are correct. Under a different imaginary, the AEC might have pursued other options, such as gaining consensus by encouraging citizen involvement under a slogan along the lines of "involve the public in our decisions."

The booklet is much less informative on the subject of radiation health effects than the earlier booklets on nuclear weapon testing. It demonstrates much more concern with the thermal impacts of warm water discharges into natural bodies of water than with radiation exposure of

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[714] U.S. Atomic Energy Commission, "Control of Releases of Radioactivity to the Environment," *Federal Register* 35:234 (December 3, 1970), 18385-18388.

[715] Richard S. Lewis, *The Nuclear Power Rebellion* (New York: The Viking Press, 1972), 105.

[716] R.S. Lewis, 106.; U.S. Atomic Energy Commission, Division of Technical Information, *Nuclear Power and the Environment* (Washington, DC: U.S. Government Printing Office, 1969).

[717] R.S. Lewis, 105.

people and the environment. The booklet spends about 4-1/2 of its 30 numbered pages discussing radioactivity, whereas it devotes about 17 pages to discussing the thermal impacts of releasing warm water into natural aquatic environments. Thermal pollution is a very real impact of nuclear power, but the imbalance in coverage suggests that the booklet may have used it as a diversionary tactic. In terms of the ordering instruments of co-production, the AEC appears to have constructed its *discourse* to *make representations* of radiation hazards as being less important than thermal pollution. Additionally, since thermal pollution is common to both nuclear and fossil fuel power plants,[718] this *discourse* also works to *make representations* of nuclear power as posing the same sorts of hazards as fossil fuels.

The booklet does not identify any potential health effects of radiation exposure. It instead stresses the bureaucratic process for approving exposure limits and the participation of expert scientists in establishing the AEC limits. The booklet explains that Congress established the Federal Radiation Commission, and that the President approves the FRC's recommendations on guidance for radiation protection, which are then "published in the Federal Register for guidance of Federal agencies."[719] It further touts the fact that the FRC developed its recommendations with the assistance of "appropriate Federal agencies" as well as the National Academy of Sciences and the NCRP.[720] These appeals to authority and bureaucratic process did not prove particularly effective, as will be illustrated below. However, they do represent attempts to highlight the ordering instrument of *making institutions* as a means of reassuring the public that nuclear technologies are under appropriate technocratic control.

The only illustration from the Radioactivity section of the AEC booklet is reproduced below. It occupied one full page of the 4-1/2 pages allotted to the Radioactivity section:

[718] Edward A. Laws, *Aquatic Pollution: An Introductory Text, Fourth Edition* (Los Angeles: John Wiley & Sons, Ltd., 2018), 375-376.
[719] U.S. AEC (1969), 10.
[720] U.S. AEC (1969), 10.

A plankton trap is placed in a river as part of a long-range study of radionuclide uptake by aquatic organisms.

Figure 8-1 The Only Illustration from the Radioactivity Section of 1969 AEC Nuclear Power Booklet[721]

8.2 Dissenting AEC Scientists

By the late-1960s, the AEC had applied FRC and NCRP guidance to set the public exposure limit for emissions from nuclear power stations at 0.5 rem per year for any individual, with a broader goal to limit the average population exposure to 0.17 rem per year.[722] That limit was translated into restrictions on plant effluents that assumed that the exposed member of the public spent their entire year, day and night, at the site boundary.[723] This very conservative assumption resulted in actual public exposures being considerably less than 0.5 rem per year.

[721] U.S. AEC (1969), 8.
[722] R.S. Lewis, 112-113.
[723] R.S. Lewis 112-113.; Walker and Wellock, 41.

The AEC's approach to public safety came under attack in late-1969 by two scientists from the AEC's own Lawrence Livermore Laboratory.[724] These scientists, John W. Gofman and Arthur R. Tamplin, are almost certainly part of the "U.S. Six" dissenting scientists discussed earlier in this dissertation as the target of harsh criticism by Lauriston Taylor of the NCRP.

Gofman, a Livermore nuclear chemist with a medical degree, began studying radiation health effects at the request of the AEC in 1962 after concerns had been raised regarding *in utero* exposures of unborn children to medical irradiation.[725] Alice Stewart, the head of Oxford's Department of Preventive Medicine, had published studies in the 1950s linking medical x-rays of pregnant women to subsequent development of childhood cancers.[726] Her work concluded that prenatal exposures on the order of one rem could significantly increase the likelihood of a child developing cancer, but she was criticized for relying on mothers' recollections of the number and timing of x-rays they had received.[727] However, her work was subsequently supported by the Harvard School of Public Health using subjects who had hospital records to confirm their diagnostic x-ray history.[728]

Gofman's leadership of the AEC's investigation at Livermore set him and his associate Tamplin on a path that turned them into outspoken critics of the AEC during and after the late 1960s. In a case of good intentions gone wrong, Tamplin, a group leader in the Biomedical Division at Livermore with degrees in biochemistry and biophysics, took on a task to evaluate a dramatic paper—rejected by the journal *Science* but published in the *Bulletin of the Atomic Scientists* in 1969 and subsequently popularized in *Esquire*—that claimed that atomic fallout had killed 400,000 infants in the United States between 1951 and 1966.[729] The author, Ernest Sternglass, a physicist from the University of Pittsburgh, produced that estimate based on interpretation of nationwide trends in infant death rates before, during, and after the era of atmospheric testing of weapons, without attempting to correlate radiation exposures to deaths.[730] Tamplin investigated the issue for the AEC and determined that Sternglass had overlooked other social factors that affected infant mortality; taking those factors into account yielded a much lower estimate of 4000 infant deaths that could be attributed to exposure to fallout over that time period.[731] The AEC objected to Tamplin's interest in publishing his rebuttal in the *Bulletin* if it included the estimate that thousands of infant deaths may be attributable to fallout, but in the end Tamplin published it there anyway.[732]

Following the difficult interaction with the AEC on Tamplin's review of Sternglass' work, Gofman and Tamplin presented the results of their broader research effort into the health effects of radiation exposure at a conference held by the Institute of Electrical and Electronics

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[724] Walker and Wellock, 42.
[725] Caufield, 154.
[726] John W. Gofman and Arthur R. Tamplin, *Poisoned Power: The Case Against Nuclear Power Plants Before and After Three Mile Island* (Emmaus, PA: Rodale Press, 1979), 4.
[727] Caufield, 153.
[728] Caufield, 154.; Gofman and Tamplin (1979), 4.
[729] Caufield, 155.; Walker (2000), 37.; Gofman and Tamplin (1979), back cover.
[730] Caufield, 155.; Walker (2000), 37.
[731] Caufield, 155.; Walker (2000), 37.
[732] Caufield, 155-156.; Walker (2000), 38.

Engineers in October 1969 and published a summary of their work in 1970.[733] Their analysis considered the most recent results from studies of leukemia and solid cancers for the following five cohorts:[734]

- Atomic bomb survivors from Hiroshima and Nagasaki
- Patients treated with radiation for other diseases
- "Children who commonly received irradiation to the neck area in one unfortunate era of American Medicine" (based on the references cited in the article, this appears to refer to radiation treatment of juvenile thyroid conditions)
- Uranium miners
- Children of mothers who received diagnostic irradiation during pregnancy (the Stewart study and follow-up research at Harvard)

From this information, Gofman and Tamplin developed estimates of the "doubling dose" for a variety of cancers (the radiation exposure required to double the rate of cancers in the exposed cohort compared to the rate of cancers in the general population). They combined the estimates for different cancers to estimate an overall doubling dose for adult subjects of 100 rads, which they then articulated as a linear relationship with a one percent increase in the cancer rate per rad of exposure.[735] They developed similar estimates for exposures of children and pre-natal exposures, both of which indicated increased sensitivity compared to adults.[736] Applying these results to the FRC's allowable population-level dose to the public of 0.17 rads per year, they arrived at an estimate of 16,000 additional cancers across the population of the United States annually if each man, woman, and child received that level of exposure.[737] At the conference, Gofman and Tamplin asserted that the fatal cancer rate could reach 32,000 deaths per year.[738]

Based on this estimate, Gofman and Tamplin argued that the AEC limit should be reduced to one-tenth of its level at the time, and they later amplified their conclusion to recommend that nuclear power stations should not be allowed to release any radioactivity.[739] The AEC disagreed with applying the linear dose-response model to predict cancer fatalities resulting from population-level exposures (consistent with the NCRP's continuing objection to such calculations) and further disputed the realism of assuming that every person in the United States could receive the maximum allowable dose to the public from nuclear power station operations.[740] The AEC issued a formal rebuttal to Gofman and Tamplin's research in December 1969 and informally told journalists that they were "incompetent."[741]

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733 John W. Gofman and Arthur R. Tamplin, "Low Dose Radiation and Cancer," *IEEE Transactions on Nuclear Science* 17:1 (1970), 1-9.; Caufield, 156.
734 Gofman and Tamplin (1970), 2.
735 Gofman and Tamplin (1970), 4.
736 Gofman and Tamplin (1970), 4.
737 Gofman and Tamplin (1970), 5.
738 Caufield, 156.
739 Walker and Wellock, 42.; Gofman and Tamplin (1970), 5.
740 Walker and Wellock, 42-43.
741 Caufield, 156.

These interactions led to a very public falling out between the two scientists and the AEC. The scientists accused the AEC of harassing them and trying to censor and defund their work.[742] Gofman and Tamplin used congressional hearings and public meetings to continue to press for a reduction in allowable radiation exposures to the public, earning the support of senators and media coverage of their demands and complaints.[743] They also continued to publish documents to advocate their positions, such as the sensationally titled books *Poisoned Power: The Case Against Nuclear Power Plants* and *Population Control through Nuclear Pollution*.

The former official historian for the Nuclear Regulatory Commission, J. Samuel Walker, wrote that Gofman and Tamplin were particularly influential for several reasons:[744]

- They had excellent professional qualifications and enjoyed additional credibility because of their status as AEC insiders.
- They were "articulate, confident, and impressive" public speakers.
- Their arguments were easy to understand, "certain to arouse public interest," and hard to refute because they dealt with low-level radiation exposures whose effects were still "an open science question."
- The bases for NCRP and AEC standards for radiation exposure could not be explained in a simple manner.

Moreover, Walker argued that Gofman and Tamplin benefited from the "political atmosphere" of the late 1960s and early 1970s.[745] Walker noted that public concern about pollution and public health was high, and the credibility of federal agencies was declining.[746] In such an atmosphere, the appeals made in the AEC's booklet *Nuclear Power and the Environment* to trust the scientific authorities and to find reassurance in bureaucratic procedures would not be likely to counter Gofman and Tamplin's arguments effectively.

Other actors involved in the radiation health actor-network weighed in to disparage Gofman and Tamplin. The *HPS Newsletter* published a letter signed by 29 scientists in August 1970 claiming that federal radiation protection organizations completely disagreed with Gofman and Tamplin's work, and that there was no way to know if the current radiation limit was "deleterious, of no consequence, or even beneficial."[747] (This seems to be a remarkably noncommittal position for the nation's experts in radiation safety to take regarding the established safety limit for radiation exposure.) Gofman and Tamplin also seem to be the target of remarks by Lauriston Taylor published in *Health Physics* in 1971, where he complained that congressional committees offered "noisy platforms to a few people with axes to grind," and further characterized the complainers as individuals who "had not found acceptance among their professional colleagues for some of their ideas."[748] However, not all of the health physics

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[742] Ionna Semendeferi, "Legitimating a Nuclear Critic: John Gofman, Radiation Safety, and Cancer Risks," *Historical Studies in the Natural Sciences* 38:2 (Spring 2008), 273-278.
[743] Caufield, 157.; Walker (2000), 43.; Semendeferi, 276-277.
[744] Walker (2000), 64-65.
[745] Walker (2000), 65.
[746] Walker (2000), 65.
[747] Semendeferi, 288.
[748] Taylor (1971), 502-503.

community attacked Gofman and Tamplin: Karl Z. Morgan, the first president of the HPS, observed that they had raised issues that deserved attention.[749]

8.3 Three Landmark Events

The surge of debate started by Gofman and Tamplin led to watershed events in the study of the health effects of radiation and in regulation of radiation safety. Three parallel events playing out in 1969 through 1972, each of singular importance, were either directly caused by or strongly influenced by the controversy driven by Gofman and Tamplin: (1) the AEC undertook public rulemaking to revise its regulations for radiation protection to require keeping occupational and public radiation exposures as low as practicable; (2) citizen groups hotly contested the licensing of a proposed nuclear power station at a protracted public hearing in which Tamplin spoke on behalf of the citizens opposed to the power station; and (3) the National Research Council performed a comprehensive study of the health consequences of radiation exposure at the FRC's request. Each of these events is discussed in detail below.

8.3.1 Regulation of Nuclear Power Stations – Adoption of ALARA as a Regulatory Requirement

On April 1, 1970, the AEC published a Notice of Proposed Rulemaking in the *Federal Register* that would finally make the philosophy of dose minimization a regulatory requirement.[750] The AEC introduced its proposal with the following "Statement of Considerations":[751]

> The Atomic Energy Commission has under consideration amendments to its regulation, 10 CFR Part 20, "Standards for Protection Against Radiation", to improve the framework for assuring that reasonable efforts are made by all Commission licensees to continue to keep exposures to radiation and releases of radioactivity in effluents as low as practicable and amendments to 10 CFR Part 50, "Licensing of Production and Utilization Facilities", to specify design and operating requirements to minimize quantities of radioactivity released in gaseous and liquid effluents from light-water-cooled nuclear power reactors.

The proposed rulemaking stated that the FRC guidance on radiation exposure limits recommended that "every effort should be made to encourage the maintenance of radiation doses as far below this guide as practicable" and noted that the NCRP and ICRP provided similar statements in their exposure guidance.[752] The proposal professed that "The Commission has always subscribed to the general principle that, within radiation protection guides, radiation exposures to the public should be kept as low as practicable."[753] It further stated that the AEC's licensees had generally kept radiation exposures and releases of radioactivity in effluent to levels

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[749] Semendeferi, 292.
[750] U.S. Atomic Energy Commission, "Control of Releases of Radioactivity to the Environment: Notice of Proposed Rule Making," *Federal Register* 30:63 (April 1, 1970), 5414-5416.
[751] U.S. AEC (April 1970), 5414.
[752] U.S. AEC (April 1970), 5414.
[753] U.S. AEC (April 1970), 5414.

well below the 10 CFR 20 limits, and that continuing technological advancement could lead to further reductions.[754]

The revision to the AEC regulations would add the following paragraph to 10 CFR 20 (with similar wording also being added to 10 CFR 50 regarding minimizing the amount of radioactive material released in plant effluents):[755]

> In accordance with recommendations of the Federal Radiation Council, approved by the President, persons engaged in activities under licenses issued by the Atomic Energy Commission pursuant to the Atomic Energy Act of 1954, as amended, should, in addition to complying with the requirements set forth in this part, make every reasonable effort to maintain radiation exposures and releases of radioactive materials in effluents to unrestricted areas as far below the limits specified in this part as practicable.

The proposed changes were well-received. The public and representatives of various nuclear businesses submitted 80 comments to the AEC, with most of them supporting the rulemaking.[756] The AEC received a "substantial" number of comments regarding how to interpret subjective language such as "every reasonable effort" and "as low as practicable."[757] In response, the AEC added clarifying language to the revisions to 10 CFR 20 and 10 CFR 50. The specific additional language added to the proposed change to 10 CFR 20 read as follows (with similar language added to 10 CFR 50): "The term 'as far below the limits specified in this part as practicable' means as low as is practicably achievable taking into account the state of technology, and the economics of improvements in relation to benefits to the public health and safety and in relation to the utilization of atomic energy in the public interest."[758] These changes became effective on December 3, 1970.[759]

It is noteworthy that the AEC enacted these changes after its controversies with Gofman and Tamplin had begun but before the BEIR I committee finished its work. This is an indication of the pressure being applied by the disaffected scientists and other citizen groups, but it also reflects the degree to which the ALARA approach was already ingrained in nuclear designs and practices.

These requirements have been refined over the decades since 1970 but convey the same basic intent. The current text of 10 CFR 20 states the following: "The licensee shall use, to the extent practical, procedures and engineering controls based upon sound radiation protection principles to achieve occupational doses and doses to members of the public that are as low as is reasonably achievable (ALARA)."[760] 10 CFR 20 and 10 CFR 50 also provide requirements and

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[754] U.S. AEC (April 1970), 5414.
[755] U.S. AEC (April 1970), 5415.
[756] Walker (2000), 44.
[757] U.S. AEC (December 3, 1970), 18386.
[758] U.S. AEC (December 3, 1970), 18387.
[759] U.S. AEC (December 3, 1970), 18386.; Joyce P. Davis, "Taming the Technological Tyger: The Regulation of the Environmental Effects of Nuclear Power Plants – A Survey of Some Controversial Issues -- Part Two," *Fordham Urban Law Journal* 1:2 (1972), 160.
[760] "Radiation protection programs," 10 C.F.R. § 20.1101 (July 23, 1998).

guidance on implementation of the ALARA principle for emissions of radioactive material to the environment.

Adding the "as low as practicable" objective to the regulations does not seem to have prompted extensive public discourse. However, the rulemaking did attract 25 comments (19 of which came from nuclear utilities and vendors) asking the AEC to provide quantitative limits for radioactivity levels in plant effluents that would eliminate ambiguity in enforcing the "as low as practicable" language.[761] As a result, the AEC decided to hold public hearings beginning in January 1972 to obtain feedback on the quantification of the "as low as practicable" goals for reactor effluents that the AEC had added to 10 CFR 50.[762] The AEC hoped that the hearing would serve as a national forum to settle debate on this issue, so that it could avoid re-arguing the question at the individual licensing hearings for each future nuclear power station.[763]

This follow-up rulemaking attracted great interest from citizens and industry. A "Consolidated Utilities Group" that included 24 utilities participated, as well as "Consolidated National Intervenors" with representatives from more than 50 citizen groups.[764] Several architect-engineer firms also participated, as did one vendor of heavy plant equipment.[765] As an indication of the degree to which the concept of "as low as practicable" had become noncontroversial, the hearing was described as proceeding with "relative peace and quiet, good manners and dispatch."[766] The hearing began in January 1972 and was suspended in May 1972, after a total of 17 hearing days, because the AEC determined that it needed to complete an environmental impact statement for the rulemaking under the newly implemented National Environmental Policy Act.[767] The hearing resumed 18 months later and was completed in December 1973.[768]

The AEC proposed to establish design objectives for "as low as practicable" that would limit the total exposure of a person at the facility fence line to five millirem per year, a value so low that it would not be measurable above background radiation and would exist as a calculated parameter.[769] The main points of debate were whether the new rules for radiation levels, identified as "design objectives" as opposed to operational limits, would be too flexible if circumstances arose such that actual operations produced effluents exceeding the design objectives (the concern of the National Intervenors) or not flexible enough if such circumstances occasionally occurred (the concern of the industry representatives).[770] By the end of the hearing, the AEC staff decided that the design objectives should be raised to 15 millirem annually for skin

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761 Walker (2000), 44.
762 Walker (2000), 52.
763 George C. Freeman, Jr., "The AEC's Recent Experiment in 'Evidentiary' Rule Making," *The Business Lawyer* 28:2 (January 1973), 666-667.
764 Freeman, 669, 671.
765 Freeman, 671.
766 Freeman, 671.
767 Freeman, 671.
768 Walker (2000), 56.
769 Walker (2000), 52-53.
770 Walker (2000), 52.

and thyroid doses as a practical matter and made some adjustments to details such as how long operations could exceed the design objectives before being ruled as noncompliant.[771]

The AEC's commissioners had a number of concerns with the proposed rule the AEC staff had developed. The main concerns involved the balance between costs and benefits for the proposed requirements, how utilities would be expected to determine theoretical radioactive iodine doses to infants drinking milk from cows grazing near nuclear plants, and how the numeric design objectives would apply to sites with multiple nuclear reactors.[772] In the end, the debate outlived the AEC, which decided at the end of 1974 to hand the issue over to its successor, the Nuclear Regulatory Commission.[773] The NRC finally issued the revised regulations in May 1975, with design objectives for annual public exposure that were slightly more restrictive and slightly more complicated, somewhat offset by the decision that the objectives would apply to each reactor, not to the aggregate performance for sites with multiple reactors.[774]

It is notable that the concept of managing the potential public exposures far below the defined limits was generally uncontested during these rulemakings. This observation further supports the conclusion that by this time the linear no-threshold dose-response model for radiation health effects and the accompanying social practice of the ALARA principle had been firmly established in the American nuclear industry through the ordering instruments of co-production. In particular, the *representation* of radiation as posing some hazard even at low levels had been reinforced through decades of *discourse* in the form of continual reminders in handbooks and other communications by the NCRP and its predecessor committees that exposures should always be kept as small as possible because of the uncertain dose-response relationship. Likewise, the AEC had often repeated its public *discourse* affirming that it always kept exposures as small as possible as a common-sense precaution. This history of discourse and representations cleared the path for an uncontentious rulemaking to formally institutionalize the practice as a regulatory requirement.

8.3.2 Citizen Concerns About Nuclear Power Plants

At the same time that the AEC was contending with criticism from nuclear insiders, citizen groups arose to oppose the construction of nuclear power stations. Like the arguments advanced by Gofman and Tamplin, the concerned citizens based a substantial part of their objections on a linear no-threshold model for the health effects of ionizing radiation. The public hearings held by the AEC during 1970-1971 on licensing a proposed nuclear power station at Shoreham on New York's Long Island prominently illustrated the types of arguments advanced by citizen groups expressing concerns about the public health impacts of nuclear power.

The Long Island Lighting Company, the utility seeking approval to construct the Shoreham facility, had also planned a nuclear power station at Lloyd Harbor, another community

[771] Walker (2000), 57-58.
[772] Walker (2000), 58-59.
[773] Walker (2000), 60.
[774] Walker (2000), 61-62.

on Long Island about 25 miles west of Shoreham.[775] Residents concerned about the proposed Lloyd Harbor plant organized as the Lloyd Harbor Study Group and issued a report opposing it in November 1969.[776] The utility abandoned its proposal for the Lloyd Harbor plant but continued to pursue the Shoreham plant, which was strongly supported by employees at the AEC's Brookhaven National Laboratory, situated just a few miles from Shoreham.[777] Supporters of the Shoreham plant (mostly Brookhaven employees) organized as the Suffolk County Scientists for Cleaner Power and a Safer Environment.[778]

The Lloyd Harbor Study Group objected to the Shoreham plant and recruited scientists to argue on their behalf.[779] Their chief attorney declared that the group intended to "encourage the nation's scientific community to come in and testify and make this a landmark case."[780] The same attorney submitted a paper to the American Bar Association on the Study Group's strategy of making the hearing a "dramatic and suspenseful event" with "lively" statements "which will read or sound well when recorded in the next day's press or radio account."[781]

The selection of scientists lived up to the Study Group's ambitious objectives. James D. Watson, director of a laboratory on Long Island and the co-discoverer of the structure of deoxyribonucleic acid (DNA), spoke critically of the AEC's 0.17 rem allowable annual dose to populations and argued that "we must assume a linear connection between dose and probability of causation" for cancer.[782] Oxford's Stewart also appeared as a witness and testified that her research on the effects of prenatal radiation exposure had shown "absence of the safety threshold" and that "at these very low doses there seems to be this linear relationship that no doubt you have heard a great deal about."[783] The Study Group also arranged an appearance by Tamplin, who testified on the potential for 32,000 additional annual cancer fatalities in the United States if the whole population received radiation exposures up to the AEC's dose limits (calculated using the linear no-threshold model) and attested to his position that AEC's standards for radiation emissions were too high by a factor of ten.[784] Gofman was also scheduled to testify but had to cancel after continuing cross-examination of prior witnesses claimed his time slot.[785] Apart from complaining that Watson's remarks were "philosophical and general in nature and did not include any data to support his conclusions," it does not appear that those in favor of the Shoreham reactor contested the application of the linear no-threshold model by these witnesses.[786] In fact, in an attempt to answer the critics, the Long Island Lighting Company

[775] David P. McCaffrey, *The Politics of Nuclear Power: A History of the Shoreham Nuclear Power Plant* (Springer-Science+Business Media, B.V.: DOI 10.1007/978-94-011-3332-6, 1991), 48.
[776] McCaffrey, 48.
[777] McCaffrey, 47-49.
[778] R.S. Lewis, 116.
[779] R.S. Lewis, 116.
[780] McCaffrey, 53.
[781] McCaffrey, 53-54.
[782] R.S. Lewis 116-117.
[783] R.S. Lewis, 117.
[784] McCaffrey, 54.; Ann Carl, "The Lloyd Harbor Study Group Intervention—A Response," *Bulletin of the Atomic Scientists* 28:6 (June 1, 1972), 34.
[785] Carl, 33.
[786] McCaffrey, 58.

stated in the licensing hearings that it would be agreeable to limiting radioactive effluents from the Shoreham plant to one percent of the AEC's limits.[787]

The Study Group also featured Sternglass, who presented studies that sought to show a correlation between local increases in the infant mortality rate and the operations of nearby nuclear power stations in Pennsylvania, Michigan, Illinois, and New York, as well as operations of the West Valley nuclear fuel reprocessing center and an experimental nuclear reactor at Brookhaven National Laboratory.[788] His testimony was contested much more sharply than Watson or Stewart's testimony, with cross-examination by members of the Suffolk County Scientists, including scientists from Brookhaven.[789] It was reported at the time that Sternglass was "questioned for several days" regarding flaws in his statistical analysis, and that his reply (as quoted in an article by a sympathetic witness) was to point out that the kinds of questions he was researching simply were not being considered by the proponents of nuclear power: "As a matter of fact, this kind of study needs to be done much more accurately than I was able to do it. And it has not been done; that's what I'm saying."[790] In effect, Sternglass was arguing that the AEC and the utility had been content to not know whether or not available data on health trends could be used to gain insights into population-level effects of low-level radiation exposures.

The AEC eventually granted a construction permit for the Shoreham plant in April 1972.[791] However, as described above, the AEC had by that point revised its regulations to require that its licensees control radiation exposures and releases of radioactive effluents "as low as practicable" below its prescribed limits. Furthermore, because of the public furor over radiation hazards from nuclear power, vendors of nuclear steam systems and architect-engineers began to introduce new equipment that would reduce or even eliminate routine releases of radioactivity during reactor operations, with one vendor adopting a "zero release" slogan.[792] These initiatives by industry and the AEC's "as low as practicable" rulemaking were mutually reinforcing, as it was clear that it was eminently "practicable" to control radiation exposures and radioactive effluent releases well below the AEC's limits.

8.3.3 National Research Council Committee on the Biological Effects of Ionizing Radiations

In January 1970, the Chairman of the Federal Radiation Council recommended that the FRC reevaluate the scientific evidence that had become available since it had established its exposure guidelines in 1960, in order to assess whether the guidelines were still acceptable.[793] This led to the formation of a National Academy of Sciences – National Research Council committee to study the problem and make recommendations to the FRC.[794] This successor to the BEAR committees was named the BEIR committee (for Biological Effects of Ionizing Radiations).

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[787] Freeman, 664.
[788] R.S. Lewis, 118.
[789] McCaffrey, 55.
[790] Carl, 34.
[791] McCaffrey, 56.
[792] Freeman, 664.
[793] Semendeferi, 293.; Walker (2000), 43-44.
[794] Semendeferi, 293-294.; Walker (2000), 44.

The BEIR committee included the following subcommittees:[795]

- Advisory Committee on the Biological Effects of Ionizing Radiations
- Subcommittee on Environmental Effects
- Subcommittee on Genetic Effects
- Subcommittee on Effects on Growth and Development
- Subcommittee on Somatic Effects
- Advisory Committee on the Biological Effects of Ionizing Radiations Ad Hoc Committee

Committee members included many representatives from universities and the National Institutes of Health, several representatives from national laboratories, and assorted other scientists.[796] The committee's report (now known as the BEIR I report since further reports followed in later years) identified the motivations for the study as follows:[797]

> (1) a naturally developing sequence of the Advisory Committee's concern that there had been no detailed overall review since the BEAR reports;
>
> (2) new factors that might need to be considered, such as optional methods of producing electrical energy and types of environmental contamination different from those previously encountered; and
>
> (3) a growing number of allegations made in the public media and before Congressional committees that the existing radiation protection guides were inadequate and could lead to serious hazard to the health of the general population.

The third source of motivation appears to reference the controversy created by Gofman and Tamplin. In fact, the BEIR I report cites numerous works by Gofman and Tamplin. The BEIR I report disagrees with details in a number of the calculations advanced by Gofman and Tamplin and states that some of the Gofman/Tamplin results overestimate the cancer risks of various radiation exposures.[798] However, the BEIR I report followed Gofman and Tamplin's approach in applying the linear no-threshold model to estimate the health consequences if the entire U.S. population received annual radiation doses at the FRC limit for population-level exposure. The results indicated that 3000 to 15,000 annual cancer deaths could result, depending on assumptions, with a most likely estimate of 6000 additional annual cancer deaths, which would represent about a two percent increase in the national cancer death rate.[799] Given the large uncertainties in such estimates, this result is entirely compatible with the Gofman/Tamplin estimate that had been disparaged by the AEC and the health physics community.

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[795] NAS-NRC (1972), v-vii.
[796] NAS-NRC (1972), v-vii.
[797] NAS-NRC (1972), 6.
[798] NAS-NRC (1972), 185, 188.
[799] NAS-NRC (1972), 2.

The BEIR I report further observed that the existing radiation exposure guidelines had been based on an effort to balance societal needs for nuclear technologies against the perceived genetic hazards of radiation exposure, and that it had become apparent that the exposure guideline was "unnecessarily high" because society's needs could be met with far lower somatic and genetic risks.[800] BEIR I did not suggest specific exposure limits but provided the following fundamental recommendations for radiation protection of the public:[801]

- "No exposure to ionizing radiation should be permitted without the expectation of a commensurate benefit."

- Protection of the public from radiation should not result in "substitution of a worse hazard for the radiation avoided," and "reduction of small risks even further" should not come "at the cost of large sums of money" that would clearly produce greater benefit if spent otherwise.

- The upper limit for non-medical radiation exposure to individual members of the general population should ensure that the risk of somatic effects is very small compared to other normally accepted risks, and the limit for population-level exposure should be considerably lower than that.

- Guidance for the nuclear power industry should be based on cost-benefit analysis and should encourage quantifying the "as low as practicable" concept.

Regarding what it termed the "linear hypothesis," the BEIR I report elaborated that "in a situation that calls for a careful weighing of costs and benefits it has seemed prudent to present numerical risk estimates for man on the basis of exclusively human data with linear interpolation into the region of low dose, merely indicating at which points the experimental data, or further human observations, might modify such estimates in the future."[802] The report then used the linear hypothesis to calculate that exposing the citizens of the United States to 0.1 rem annually (which the report considered approximately equivalent to doubling the radiation exposure from background sources) could be expected to ultimately lead to 1350 to 3300 deaths annually.[803] Interestingly, 0.1 rem per year is the present-day regulatory limit for exposure of individual members of the public resulting from an activity licensed by the NRC, codified in 10 CFR Part 20.1301, *Dose Limits for Individual Members of the Public*.

This episode again demonstrated that the ordering instruments of co-production instituted by the participants in the actor-network had organized science and society in a manner that provided a great deal of durability to the linear no-threshold dose-response model. Despite the opposition of the NCRP, HPS, and AEC to applying the linear model to estimate cancer fatalities, the BEIR committee accepted the model as a valid approach to such calculations.

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[800] NAS-NRC (1972), 2.
[801] NAS-NRC (1972), 2-3.
[802] NAS-NRC (1972), 89.
[803] NAS-NRC (1972), 89.

Most remarkable of all, Lauriston Taylor, who had directly attacked the credibility of Gofman and Tamplin, lauded the BEIR I report as “a whale of a job and highly objective.”[804]

[804] Walker (2000), 50.

9 Interactions of Actors in the Courts

The prior discussions in this dissertation examined the strategies and tactics of the various actors as they deployed a host of ordering instruments of co-production in venues ranging from congressional committee hearings, AEC rulemakings, public meetings, publications, media campaigns and other direct outreach to the public, and even a live televised debate. ALARA had become a regulatory requirement, and the linear no-threshold model was firmly in place at the intersection of science and social order thanks to the ordering instruments of co-production and the sociotechnical imaginaries that guided their application. Citizens sought to apply this state of knowledge to obtain redress for harms they believed had resulted from past failures to protect them from harmful radiation exposure. Three prominent lawsuits that played out in the 1970s and 1980s were filed by radiation workers and members of the public who blamed illnesses and deaths on past radiation exposures and sought relief from the courts.

The plaintiffs and defendants brought in experts (whose names will be familiar from the prior sections of this dissertation) to argue whether or not plaintiffs' claims were supported by the current understanding of the dose-response model for radiation exposure. The testimonies, the judges' rulings, and the post-judicial outcomes provide insight into how the judiciary's sociotechnical imaginaries deal with cases in which claims and defenses are based on a model that cannot be proven. Jasanoff suggested that there is a risk that the court will try to press the evidence "to produce levels of proof that it cannot."[805] As noted much earlier in this dissertation, Weinberg observed that outside of science circles, scientists are judged on their credibility, not their competence, so when faced with unsettled science, the court may well rely on which side's expert witnesses convey the most credibility.[806] The three court cases of interest examined below are:

1. Silkwood versus Kerr-McGee Corporation[807]—An employee at a nuclear fuel fabrication facility became contaminated with plutonium in 1974 and soon afterwards died in an automobile accident. Both Gofman and Morgan testified on the hazards of plutonium. This case had many perplexing attributes and was made into a movie in 1983 starring Meryl Streep, Kurt Russell, and Cher.[808]

2. Allen versus United States[809]—This 1982 case involved 1,192 named plaintiffs claiming damages for solid cancers and leukemia illnesses suffered after exposure to fallout from atmospheric nuclear weapons testing in Nevada. Gofman, Tamplin, Morgan, Knapp (who had analyzed thyroid doses from fallout for the AEC in the 1960s), and Edward P.

[805] Sheila Jasanoff, "Acceptable Evidence in a Pluralistic Society," in Deborah G. Mayo and Rachelle D. Hollander, eds., *Acceptable Evidence: Science and Values in Risk Management* (New York: Oxford University Press, 1991), 45.
[806] Weinberg, 216.
[807] *Silkwood v. Kerr-McGee*, 485 F. Supp. W. D. Okla. 566 (1979), aff'd in part, rev'd in part, 667 F.2d 908 (10th Cir.), verdict restored, 464 U.S. 238 (1984).
[808] Internet Movie Database, *Silkwood (1983)*, https://www.imdb.com/title/tt0086312/ (accessed January 20, 2021).
[809] *Allen v. United States*, 588 F. Supp. 247 (D. Utah 1984), rev'd, 816 F.2d 1417 (10th Cir. 1987).

Radford (the Chairman of the BEIR III committee) testified on the health effects of radiation.

3. Johnston versus United States[810]—This case involved the claim that four employees of Aircraft Instrument and Development, Inc., had suffered cancer after exposure to radiation from radium in luminous dials and instrument parts sent to the plant as surplus equipment by the United States government. Expert witnesses on the health effects of radiation included Gofman and Morgan testifying on behalf of the plaintiffs, and Taylor and Jacob Fabrikant (a panelist on the NAS-NRC BEIR III committee) testifying on behalf of the defense. The judge's decision also cites BEIR III, the 1980 update of the BEIR committee's report.

9.1 Silkwood versus Kerr-McGee Corporation

This ten-week jury trial in 1979 stemmed from a lawsuit filed by the father of Karen Silkwood, a laboratory analyst employed by Kerr-McGee at a facility in Oklahoma that made uranium and mixed uranium/plutonium fuel elements for nuclear reactors, alleging an inadequate health and safety program.[811] Silkwood was reportedly gathering information to support claims that Kerr-McGee was negligent in maintaining safety and was driving to meet with a *New York Times* reporter in November 1974 when she died in a one-vehicle accident.[812] The case garnered media attention across the nation.

Earlier in November, plutonium contamination had been detected on and removed from her clothing and skin at the plant on two consecutive days, and when she turned in a bioassay kit with urine and fecal samples the following morning, the health physics office at the plant found plutonium contamination in the bioassay samples, in her nostrils, and on her upper body, hands, and one ear.[813] After removing the contamination from her skin and clothing, she returned to her apartment (which she shared with another plant employee) with Kerr-McGee health physicists who found plutonium contamination throughout the apartment, with the highest concentrations in the bathroom and kitchen, including on packages of bologna and cheese, as well as two areas of low-level contamination on her roommate.[814] Silkwood suggested that the spread of concentrated contamination occurred because she spilled urine in the bathroom while filling her bioassay kit and had later brought the bologna into the bathroom.[815]

Kerr-McGee sent Silkwood along with her boyfriend and her roommate to Los Alamos for more extensive testing.[816] After a variety of tests, the Los Alamos Laboratory Health

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[810] *Johnston v. United States*, 597 F. Supp. 377 (D.C. Kan. 1984).
[811] U.S. Nuclear Regulatory Commission, *Cimarron (Kerr-McGee)*, https://www.nrc.gov/info-finder/decommissioning/complex/kerr-mcgee-cimarron-corporation-former-fuel-fabrication-facility.html (accessed January 31, 2021).; George J. Annas, "The Case of Karen Silkwood," *American Journal of Public Health* 74:5 (May 1984), 516.
[812] Annas, 516.
[813] Los Alamos National Laboratory, "The Karen Silkwood Story," *Los Alamos Science* 23 (1995), 253.
[814] Los Alamos (1995), 253.
[815] Los Alamos (1995), 253.
[816] Los Alamos (1995), 253.

Division determined that Silkwood's roommate and boyfriend had negligible radioactive material absorbed in their bodies but that Silkwood was approaching half of the permissible occupational lung burden for plutonium.[817] The director of the Laboratory Health Division reassured her that this presented little risk of any health effects.[818]

Silkwood returned to work on November 13, where she was restricted from radiation work, then attended a union meeting after work, and subsequently was found deceased about 7 miles from the meeting location in an apparent one-vehicle accident.[819] Los Alamos participated in the autopsy and performed extensive analysis on samples of tissues from throughout her body, concluding that her plutonium exposure had occurred within 30 days of her death and that she had plutonium in her lungs and in her gastrointestinal tract, indicating that she had ingested plutonium contamination as well as inhaling it.[820] Controversy over the circumstances of her death and the source of the plutonium contamination remain unresolved.[821]

Because Silkwood never developed any adverse medical conditions from her exposure to plutonium, testimony at the trial focused on the potential hazards of plutonium, as opposed to trying to prove that some health condition could attributed to plutonium exposure. The Los Alamos Laboratory Health Division Director who had led the work to test Silkwood after her exposure to plutonium testified that "there were no health effects from the exposure." However, he did acknowledge that his opinion was based on federal radiation protection standards and that he did not know how much plutonium radiation would cause cancer.[822]

Gofman provided expert witness testimony for the plaintiffs, highlighting the damaging nature of alpha particles emitted by radioactive decay of plutonium, and stating that in his experience, the quantity of plutonium measured in Silkwood's lungs would "guarantee a fatal lung cancer."[823] He also discussed the potential for genetic damage and birth defects to children of people with body burdens of plutonium.[824] He further opined that when a new substance is introduced, the first question from industry is "how much can we allow people to have," and that he believed that for both radiation and chemicals, "the safe standards are set on nothing but thin air and guesswork."[825]

Morgan was also called as an expert witness for the plaintiffs. He was challenged by the defense to identify any case "which has been established to a medical certainty to have been induced by exposure to plutonium."[826] He replied that no one can say with absolute certainty that plutonium caused a particular cancer, but that it is possible to establish a probability that plutonium caused a particular cancer.[827]

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[817] Los Alamos (1995), 254.
[818] Los Alamos (1995), 254.
[819] Los Alamos (1995), 254.
[820] Los Alamos (1995), 254-255.
[821] Annas, 516.
[822] Paul Wenske, "Defense Rests in Silkwood Contamination Lawsuit," *The Washington Post*, May 10, 1979.
[823] Morgan and Peterson, 140-141.
[824] Morgan and Peterson, 140-141.
[825] Morgan and Peterson, 141.
[826] Morgan and Peterson, 143.
[827] Morgan and Peterson, 143.

After the jury found in favor of the plaintiff and awarded damages, Kerr-McGee submitted post-trial motions seeking to overturn the result on several grounds, including that since Silkwood's exposure was within occupational limits, the jury could not find any injury, nor could the jury award punitive damages.[828] The court dismissed this position, stating, "Had this Court instructed the jury that substantial compliance with governmental regulations would bar an award of actual damages in the area of nuclear power, the Court would have paved a new road in jurisprudence that heretofore has not existed in any other comparable area of the law," drawing an analogy with a crash of a defectively designed aircraft whose design the Federal Aviation Administration had certified as airworthy.[829]

The court then specifically addressed AEC's regulations for radiation safety, demonstrating great insight into their origins and intent. The court noted that "the AEC itself acknowledges that these regulations are not static or final standards for reasonable care upon which the industry might absolutely rely without additional safety precautions."[830] The court continued by stating that the AEC exposure regulations originated from NCRP and ICRP "guides for good radiation practices rather than strict levels of safety" and that both the AEC and EPA maintained that those levels are not "a 'safe' or threshold level below which injury does not become a possibility."[831] The court then observed that "the standards represent a balancing of social benefit against estimated cost … where scientific knowledge of low level radiation exposure effects is insufficient to determine the precise risk" and that the ALARA approach arose from "acknowledgment of the limitations of the regulations."[832] This judge avoided the trap identified by Jasanoff of demanding precision that the evidence could not support and did not try to demand a precise risk assessment.

In 1979, the jury awarded punitive damages of $10 million for Kerr-McGee's conduct in allowing the release of plutonium, $500,000 in personal injury damages for Silkwood's exposure to plutonium, and $5000 for property damage to her possessions contaminated by plutonium.[833] After twice being appealed all the way to the U.S. Supreme Court, during which the personal injury damages were invalidated on the grounds that they should be addressed as a worker's compensation claim, the Supreme Court finally decided in 1985 that the punitive damages were disproportionate to the property damage and authorized a new trial for the issue of Kerr-McGee's conduct.[834] Rather than undergo another trial, the parties settled for $1.38 million in 1986.[835]

[828] *Silkwood v. Kerr-McGee Corp.,* 485 F. Supp. 566 (W.D. Okla. 1979), 571.
[829] *Silkwood v. Kerr-McGee* (1979), 577-578.
[830] *Silkwood v. Kerr-McGee* (1979), 579-580.
[831] *Silkwood v. Kerr-McGee* (1979), 580-581.
[832] *Silkwood v. Kerr-McGee* (1979), 581.
[833] Myrna Oliver, "Firm to Settle Silkwood Case: Kerr-McGee Will Pay $1.38 Million to Estate," *Los Angeles Times*, August 23, 1986.
[834] Oliver.
[835] Oliver.

9.2 Allen versus United States

Allen v. United States was filed on August 30, 1979, by 24 plaintiffs claiming injury and wrongful death from radioactive fallout from nuclear weapon testing at the Nevada Test Site.[836] The 24 plaintiffs represented a test case for a total of 1192 people with injury claims.[837] The plaintiffs had first sought administrative settlement in 1978 with the Department of Energy (the present-day successor to the AEC responsible for America's nuclear weapon program), but they were unsuccessful.[838] In response, the U.S. government claimed that the court had no jurisdiction due to exemptions for discretionary function and misrepresentation enjoyed by the government, but it also claimed that its actions in the testing program were not negligent and that "there is no competent scientific evidence" showing that fallout had caused any adverse health effects among the plaintiffs.[839] Pretrial discovery commenced that fall and continued through the spring of 1982.[840]

The government's attorneys focused strongly on arguing that the government had absolute immunity from tort liability.[841] For example, when asked during discovery whether the government acknowledged the responsibility of warning citizens of hazards from testing, the government's attorneys replied that the government had no such legal responsibility and that warning or not warning citizens of hazards was "properly the subject of executive discretion."[842] In response, the plaintiffs argued that under the Federal Tort Claims Act, negligence had occurred at the operational level and was therefore not exempt, and furthermore, since this was a civil case, they need only show that radiation exposure was a cause of the cancers and leukemias among the plaintiffs, not the only cause.[843] The judge sided with the plaintiffs on the need for a full trial, noting that any ruling was likely to be appealed and that he wanted to establish a complete record for the benefit of higher courts.[844]

The trial ran from September 20 through December 17, 1982.[845] Since the only defendant was the U.S. government, the trial had no jury, only a judge.[846] The trial included testimony from 98 witnesses and more than 1600 documentary exhibits.[847] The plaintiffs presented evidence from experts including medical researchers and former government employees to establish that radiation from fallout was a cause of the plaintiffs' health impacts. A medical epidemiologist from the University of Utah testified that child deaths from leukemia had increased by 40 percent in Utah in the early 1960s, with the largest increases in southern Utah, peaking in the five counties nearest the Nevada Test Site with a fatality rate 3.4 times that in

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[836] Howard Ball, *Justice Downwind: America's Atomic Testing Program in the 1950s* (New York: Oxford University Press, 1986), 146.
[837] Morgan, 145.
[838] Ball, 146.
[839] Ball, 146-147.
[840] Ball, 147.
[841] Ball, 149.
[842] Ball, 149.
[843] Ball, 151.
[844] Ball, 151.
[845] Ball, 152.
[846] Morgan, 145.
[847] *Allen v. United States*, 588 F. Supp. 247 (D. Utah 1984), 258.

other parts of the state.[848] He estimated that there was a 71 percent probability that fallout had caused cancer and leukemia among children near the test site.[849] A former Public Health Service employee who monitored fallout in St. George, Utah during nuclear tests testified for the plaintiffs, asserting that the AEC had underreported dose rates and had inaccurately claimed that schoolchildren were indoors when fallout from the HARRY test passed over the town in 1953, when the children had actually been outdoors.[850]

Morgan and Gofman testified as expert witnesses for the plaintiffs. Morgan described the physical effects of various types of ionizing radiation in human tissues, emphasizing the particularly damaging nature of alpha particles from inhaled or ingested radioactive materials, and described how a damaged cell can become cancerous.[851] He described "our misconceptions" regarding a threshold or tolerance dose early in the nuclear age and how scientists had moved on to accepting the linear no-threshold model and "that all radiation is harmful."[852] He asserted that many scientists had already accepted a linear model for dose effects before the testing at Nevada in the early 1950s, and that hundreds of documents had been published during that period on animal experiments showing adverse effects of relatively low radiation exposure.[853] Morgan went beyond this statement, however, and asserted that he had "good evidence" to support a "super linear hypothesis" indicating that at very low doses, the risk of cancer per rem is actually larger than the linear model would predict.[854]

Morgan further described how the sensitivity to radiation varies from person to person, and that children are more sensitive than adults.[855] Morgan additionally offered the opinion that a responsible health physicist would have established a bioassay program that included the offsite public to assess whether people were suffering intakes of radioactive material from fallout from the nuclear weapon tests.[856] He stated that the physical ailments such as mouth lesions, loss of wool and hair, sores, etc., observed in livestock near the test site indicated local doses on the order of thousands of rads.[857]

On cross examination, the government's attorney challenged the certainty of Morgan's testimony, asking "All the answers aren't in, is that correct?"[858] Morgan acknowledged that science did not have all the answers, but that such a situation was just the nature of existence, and "that every door we open we see a dozen more that we would like to enter."[859]

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848 Ball, 152.
849 Ball, 152.
850 Ball, 152-153.
851 Morgan, 146.
852 Morgan, 148.
853 Morgan, 149.
854 Morgan, 148.
855 Morgan, 147.
856 Morgan, 147.
857 Morgan, 148.
858 Morgan, 149.
859 Morgan, 149.

Gofman testified that the nuclear weapon tests had released fallout emitting alpha, beta, and gamma radiation across the region outside the test site.[860] Regarding the safety of low doses of radiation, he stated that "There has never been in the history of science any evidence that there's a safe dose of radiation" and therefore there was no threshold for dose effects.[861] He concurred with the University of Utah epidemiologist's report of significantly elevated rates of leukemia in counties near the test site.[862]

Gofman also testified that in 1963 the director of the AEC Biology and Medicine Department had summoned him to a meeting in Washington, DC to discuss Knapp's analyses of radiation doses to the thyroid near the test site.[863] Gofman claimed that the AEC asked him and five other attendees to try to persuade Knapp not to publish his results, because if he did, the public would know that the AEC had not been telling the truth about exposures around the test site.[864] Gofman testified that he and his colleagues declined the request.[865]

Gofman, Knapp, and Tamplin provided estimates for radiation doses for the citizens exposed to fallout.[866] Gofman retrospectively estimated (i.e., "back-calculated") exposures based on a survey performed by another witness to assess the excess incidence of cancers in Mormon families in Utah.[867] Using a linear dose-response model, Gofman arrived at dose estimates substantially larger than the estimates provided by Tamplin and larger still than the estimates that would be presented by the government.[868]

In response, the government produced its own expert witnesses. They testified that the AEC's exposure guidelines were not established in a negligent manner and that fallout had not caused cancer.[869] The government also provided sampling results for the present levels of fallout residues near the Nevada Test Site and estimates of the internal and external radiation doses for citizens in the region based on limited past monitoring and theoretical models.[870] The government urged the court to treat its estimates as the probable upper limit for radiation exposure.[871] In his decision, the judge considered all of the various dose estimates to try to make sense of the fallout exposure of each of the 24 individuals in the case. He dryly noted that the government's estimate of the ovarian dose for one of the men in the group of plaintiffs suffered from the problem that the man in question, "like almost all men, had neither ovaries nor a uterus."[872]

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[860] Morgan, 150.
[861] Morgan, 150.
[862] Morgan, 150.
[863] Morgan, 150-151.
[864] Morgan, 151.
[865] Morgan, 151.
[866] *Allen v. United States* (1984), 426.
[867] *Allen v. United States* (1984), 427.; Carl J. Johnson, "Cancer Incidence in an Area of Radioactive Fallout Downwind from the Nevada Test Site," *Journal of the American Medical Association* 251:2 (January 13, 1984), 230-236.
[868] *Allen v. United States* (1984), 427-428.
[869] Ball, 154.
[870] *Allen v. United States* (1984), 426.
[871] *Allen v. United States* (1984), 427.
[872] *Allen v. United States* (1984), 436-437.

The judge deliberated for 17 months after the trial adjourned, studying nuclear physics, biochemistry, statistics, and epidemiology.[873] He set the stage for his May 10, 1984, ruling by opening with the statement that "This case is concerned with atoms, with government, with people, with legal relationships, and with social values."[874] In a statement sharply at odds with the principles later espoused by a different judge in the case of *Johnston v. United States* discussed below, he asserted that "Dispute resolution demands rational decision, not perfect knowledge."[875] He found that that the government had behaved negligently and that fallout was more likely than not (the applicable standard for a civil suit) to have caused 10 of the 24 plaintiffs' health problems.[876] As discussed below, he had studied the science of the case extensively, but, like the judge in the Silkwood case, he avoided demanding evidence to provide a degree of certainty that it could not support.

The judge's written decision devoted the first 50 pages to the science applicable to the case, including the biological effects of radiation and the relationship between low-level radiation and cancer.[877] He pointed out the important distinction between whole body radiation exposure and exposure to individual organs, noting for example that an exposure that is limited to particular organs such as the thyroid, bone marrow, lung, or skin can signify significantly less damage to other organs and tissues.[878] He discussed the nature and distribution of fallout from weapon testing, particularly noting the highly variable levels of fallout from place to place and the appearance of hot spots with several thousand times more radioactivity than adjacent locations.[879] He also reviewed other manmade and natural sources of radiation.[880] Regarding a safe threshold dose, the judge wrote:[881]

> Although some scientists and commentators have at times suggested the presence of a "threshold" dose, the predominant philosophical approaches to radiation protection have eschewed such a view, and the overwhelming weight of currently available scientific evidence supports the view that at *any* exposure level, ionizing radiation causes *some* degree of biological damage and creates *some* long-term risk of cancer and leukemia in those persons who are exposed.

In discussing exposure guidelines, the judge's decision noted that scientists long ago had recognized the lack of a threshold dose. He quoted Lauriston Taylor's history of the NCRP as having documented that as far back as 1946, the NCRP had emphasized that its "permissible limits" were maximum values and that "every effort should be made to maintain the actual exposures considerably below these limits."[882] He further reasoned even in relying on NCRP

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[873] Ball, 154-155.
[874] Ball, 155.
[875] *Allen v. United States* (1984), 260.
[876] Ball, 155.
[877] Ball, 156.
[878] *Allen v. United States* (1984), 327.
[879] *Allen v. United States* (1984), 305.
[880] *Allen v. United States* (1984), 327-328.
[881] Morgan, 151.; *Allen v. United States* (1984), 419.
[882] *Allen v. United States* (1984), 359.

recommended standards for radiation exposure, the AEC was "bound to give some credence to the warning that compliance was no guarantee of 'no injury.'"[883] He concluded overall that "The reasonable man would not, therefore, conclude if radiation dosage is kept at or near the 'maximum permissible' limits suggested by the NCRP, the ICRP or others, there is no increased risk of injury."[884] (I am deliberately overemphasizing these points to provide contrast with a different judge's standard of evidence in *Johnston v. United States*, detailed later in this chapter.)

The judge wrote that the Atomic Energy Act required the AEC to protect health and safety, and that the government had done that at other AEC sites but not at the Nevada Test Site.[885] He particularly noted that the government had made no concerted effort to measure internal contamination in people who had been exposed to fallout in the towns near the test site.[886] He scathingly noted, "The negligence reflected in the monitoring program is highlighted by the fact that even now we have more direct data concerning the amount of strontium-90 deposited in the bones of the people of Nepal, Norway or Australia than we have concerning residents of St. George, Cedar City or Fredonia."[887]

His ruling also pointed out that because the AEC had not informed the public that any amount of exposure posed some risk, the public did not take available measures that could have provided some protection from fallout.[888] He also pointed out that the law would "impose a stringent duty of care … upon a private individual releasing megacuries of radioactivity into the air."[889] He particularly noted the important distinctions between a radiation worker who accepts the risk of radiation exposure as part of their voluntary employment and the AEC's actions which subjected entire communities, including children, to ionizing radiation without consent.[890]

The judge's decision evaluated AEC pamphlets distributed to communities near the test site during the atmospheric weapon testing era. Among other flaws, a 1955 pamphlet reassured the citizens that the 31 test explosions to date had not hurt anyone and asserted that "The important fact about radiation is that it takes quite a bit of overexposure to cause illness. Only when overexposures are very heavy is recovery problematical."[891] The pamphlet made no mention of the potential for cancer or leukemia.[892]

A 1957 pamphlet went even farther in advancing a line of reasoning that could be described as inverse-ALARA: "It should also be emphasized that the 3.9 roentgens is not a safety limit. Should a single exposure exceed this figure, it would not necessarily mean that the individuals concerned had been injured."[893] The judge contrasted that advice offered to the public with the radiological safety training manual provided to workers at the Nevada Test Site

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[883] *Allen v. United States* (1984), 361.
[884] *Allen v. United States* (1984), 362.
[885] Ball, 157.
[886] Ball, 158.
[887] *Allen v. United States* (1984), 377.
[888] Ball, 158.
[889] *Allen v. United States* (1984), 357.
[890] *Allen v. United States* (1984), 363.
[891] *Allen v. United States* (1984), 395.
[892] *Allen v. United States* (1984), 395.
[893] *Allen v. United States* (1984), 397.

in 1957, which warned, “Since there is no proof that living tissue is actually tolerant of ionizing radiation, even at background levels, the aim should always be to keep radiation exposures as small as possible.”[894]

In a 39-page section of his decision entitled “The Problem of Causation,” the judge considered the issues associated with demonstration of causation in this case. He acknowledged that the causation was indeterminate, i.e., instead of “A shoots B, who dies,” this case involved “A irradiates B, who develops cancer 22 year later.”[895] However, he determined that sufficient information was available to reach a verdict. Among other precedents, the judge cited the case of a firefighter who had developed lung cancer after decades of fighting fires and smoking cigarettes. In that case, the court ruled that “we cannot say whether it was the employment or the cigarettes which ‘actually’ caused the disease; we can only recognize that both contributed substantially to the likelihood of his contracting lung cancer” and that it was sufficient that the firefighter’s employment had been a contributing cause of his disease.[896] Taking this complication into account, the judge in *Allen v. United States* concluded that each plaintiff needed to show each of the following causal factors had been met:[897]

(1) the decedent or living plaintiff having cancer was probably exposed to fallout radiation significantly in excess of “background” radiation rates;

(2) the injury is of a type consistent with those known to be caused by ionizing radiation; and

(3) the person injured had resided in geographical proximity to the Nevada Test Site for some if not all of the years of atmospheric testing between 1951 and 1962.

A subsection of the judge’s discussion of causation evaluated the “Problem of the Dose-Response Relationship.” Based on studying the current body of literature on the health effects of radiation, including among other sources a book by Gofman, the most recent NAS-NRC BEIR report (BEIR III, issued in 1980), and a 1977 report by the United Nations Scientific Committee on the Effects of Atomic Radiation, the judge concluded that “While there remains considerable uncertainty and controversy surrounding the precise quantitative mathematical description of the dose-response relationship for various radiations and cancers, none of the recent studies offer any direct evidentiary support for a threshold dose below which exposure is ‘safe,’ harmless and without additional risk.”[898]

The judge’s ruling discussed the BEIR III report’s statements about dose-response models in a manner that suggested he did not view its conclusions to be as definitive as one would assume of a report by the National Academy of Sciences. He noted that BEIR III stated that a majority of their committee generally agreed that “the dose response relationship for low

[894] *Allen v. United States* (1984), 398.
[895] Ball, 159.; *Allen v. United States* (1984), 405-406.
[896] *Allen v. United States* (1984), 408.
[897] *Allen v. United States* (1994), 429.
[898] *Allen v. United States* (1984), 419.

to intermediate doses of low-LET [linear energy transfer] radiation [i.e., gamma rays and x-rays] is best described by a linear-quadratic function of dose"[899] However, he added that "Where compelled by experimental or epidemiological data, the Committee conceded that the dose-response relationships for high-LET radiation [i.e., neutrons and alpha particles] and human breast cancer, for example, are probably linear if not supralinear" and that "in the linear quadratic model, the linear component is dominant at low doses."[900] The judge further explained that separate analyses by Edward P. Radford, the Chairman of the BEIR III Committee and Chairman of the BEIR III Subcommittee on Somatic Effects, and Gofman (among others), "argue persuasively for a linear relationship, if not a supra-linear relationship, between radiation dose and increased risk of cancer at low doses."[901] He further noted that data for atomic bomb survivors that the BEIR III committee had relied on had recently been updated to support a linear dose-response model (or at least a linear-quadratic model with a significant linear term).[902]

The situation in which the Chairman of the BEIR III committee appeared to disagree with the BEIR III report, and the significance of this controversy, are discussed below following this analysis of the *Allen v. United States* trial. It does appear to have led the judge in this trial to finalize his view on the dose-response relationship. He closes that section of his ruling by quoting Radford as articulating a concept that he considered to deserve great credence: "[O]ne may conclude that in human studies where a small excess of cancer is found at a particular dose of radiation but is borderline in statistical significance, it is prudent to consider the effect may be real rather than to dismiss the study as negative."[903]

The judge applied the three criteria he had developed and determined that 10 of the 24 plaintiffs had more likely than not suffered cancers and leukemia because of exposure to fallout. Three of the plaintiffs failed the second criterion, in that their maladies were not considered among those potentially caused by radiation.[904] The other 11 plaintiffs that he judged not to meet the criteria typically failed because of a lack of elevated rates for their particular illness in the vicinity of the test site.[905] He awarded damages ranging from $100,000 to $625,000 to the families of the 10 plaintiffs whose cancers he judged sufficiently linked to fallout.[906]

The government appealed the judge's decision and successfully overturned it in the Tenth Circuit Court of Appeals.[907] The successful appeal was unrelated to the science of radiation health effects. The appeals court found that the government's actions at the Nevada Test Site fell under the discretionary function exemption of the Federal Tort Claims Act and therefore the government was exempt from liability claims.[908] However, the judge in the appeals court wrote that the plight of "the cancer victims who have borne alone the costs of the AEC's choices" was

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[899] *Allen v. United States* (1984), 424.
[900] *Allen v. United States* (1984), 424.
[901] *Allen v. United States* (1984), 424.
[902] *Allen v. United States* (1984), 424.
[903] *Allen v. United States* (1984), 425.
[904] *Allen v. United States* (1984), 428-430.
[905] *Allen v. United States* (1984), 430-443.
[906] *Allen v. United States* (1984), 446.
[907] Morgan, 152.
[908] Morgan, 152.

a matter for Congress, and that Congress alone had the power to decide whether those costs will "continue to be unfairly apportioned."[909]

Congress indeed did act, with the result that President George H. W. Bush signed the Radiation Exposure Compensation Act into law in 1990. The law provides for downwinders who contracted specific diseases after living in specific places during specific times to receive $50,000 in compensation without needing to prove that their health conditions were caused by exposure to fallout.[910] The act was subsequently expanded to include other groups of people exposed to radiation due to past activities of the U.S. government. The program now provides the following categories of compensation (which notably include the "atomic veterans" who were brought onto the Nevada Test Site to witness atomic blasts firsthand):[911]

- Uranium miners, millers, and ore transporters may be eligible for one-time, lump sum compensation of $100,000.
- "Onsite Participants" (military personnel and civilians) at atmospheric nuclear weapon tests may be eligible for one-time, lump sum compensation of up to $75,000.
- Individuals who lived downwind of the Nevada Test Site ("downwinders") may be eligible for one-time, lump sum compensation of $50,000.

In order to be eligible as a downwinder, a person must show they were physically present in one of the defined downwinder areas for at least two years between January 21, 1951, and October 31, 1958, or for the entirety of June 30-July 31, 1962, and must have been diagnosed with leukemia, multiple myeloma, non-Hodgkin's lymphoma, or primary cancer of one or more of 16 different organs.[912] As of February 5, 2021, RECA had approved 37,804 compensation claims totaling more than $2.4 billion, with nearly $1.2 billion of that amount awarded to 23,959 downwinders.[913]

9.3 An Aside on BEIR III

An aside is necessary before examining *Johnston v. United States*, because the National Academy of Science – National Research Council's BEIR III report and one of its primary authors, Jacob I. Fabrikant, are featured in the trial, as is John Auxier, an Oak Ridge AEC researcher whose work featured prominently in BEIR III. As noted in the discussion of *Allen v. United States* above, BEIR III was a controversial report that the BEIR III committee chairman did not support. The National Academy of Sciences initially released the BEIR III report in May 1979, updating the information and recommendations on assessing the effects of low-level

[909] Morgan, 152-153.
[910] DOE (1995), 30-31.
[911] U.S. Department of Justice, *Radiation Exposure Compensation Act*, https://www.justice.gov/civil/common/reca (accessed February 6, 2021).
[912] U.S. DOJ, *Radiation Exposure Compensation Act*.
[913] U.S. Department of Justice, *Awards to Date*, https://www.justice.gov/civil/awards-date-02052021 (accessed February 6, 2021).

radiation exposures to populations.[914] BEIR III continued to support the linear no-threshold model for radiation's health effects.[915] However, the National Academy of Sciences quickly withdrew the report on the grounds that a minority statement signed by two of the 22 committee members (one of the dissenters being Harald Rossi, a physicist and professor of radiology at the Columbia University College of Physicians and Surgeons) and endorsed by three more committee members indicated that the somatic effects chapter "did not adequately reflect the full range of committee opinion."[916] The head of the National Academy of Sciences designated seven members from the original BEIR III committee to revise the report, with Jacob I. Fabrikant (of the Department of Radiology at the University of California School of Medicine and the Donner Lab of the University of California Berkeley) leading the group.[917] The result of their work was a revised BEIR III report that reached the following conclusion regarding somatic effects:[918]

> Whenever possible, in estimating the cancer risk from low doses of low-LET [low linear energy transfer, i.e., gamma ray and x-ray] radiation, the Committee has used a linear-quadratic dose-response model that is felt to be consistent with epidemiologic and radiobiologic data, in preference to more extreme dose-response models, such as the linear and pure quadratic. The Committee recognizes that some experimental and human data, as well as theoretical considerations, suggest that, for exposure to low-LET radiation at low doses, the linear model probably leads to overestimates of the risk of most cancers, but can be used to define upper limits of risk. Similarly, the Committee believes that the quadratic model may be used to define the lower limits of risk from such radiation. For exposure to high-LET radiation, linear risk estimates for low doses are less likely to overestimate risk and may, in fact, underestimate risk.

This major change significantly reduced the predicted likelihood of cancer from exposure to low doses of gamma rays and x-rays (i.e., the types of radiation most often applied in medical diagnostic and treatment) compared to BEIR I. The BEIR III report also stated that "The Committee does not know whether dose rates of gamma or x rays of about 100 mrads/yr are detrimental to man," as opposed to suggesting that there was no known safe threshold dose.[919] The rewriting effort did not modify the chapter on genetic damage. That chapter continued to use a linear model for the dose-effect relationship for genetic damage and does not suggest a threshold below which the model should not be applied.[920]

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[914] National Academy of Sciences – National Research Council Committee on the Biological Effects of Ionizing Radiations, *The Effects on Populations of Exposure to Low Levels of Ionizing Radiation: 1980* (Washington, DC: National Academy Press, 1980), iii.
[915] Joseph Rotblat, "Hazards of low-level radiation—less agreement, more confusion," *Bulletin of the Atomic Scientists* 37:6 (June/July 1981), 32.
[916] Rotblat, 31.
[917] Rotblat, 32.; Jacob I. Fabrikant, "The BEIR-III Report: Origin of the Controversy," *American Journal of Roentgenology* 136:1 (January 1981), 209.
[918] NAS-NRC (1980), 2.
[919] NAS-NRC (1980), 3.
[920] NAS-NRC (1980), 82.

The changes did not resolve the objection of Rossi (the Columbia University radiology professor) to BEIR III. The final version of BEIR III included another dissenting opinion from Rossi in which he objected to the fact that the report still included risk estimates based on the "linear hypothesis," which led to the risk that standards-setting bodies might adopt them "for the sake of prudence."[921] He also objected that data indicating risk factors smaller than the lowest provided in the report were not explicitly presented in the report and suggested that overestimating the hazard of gamma rays and x-rays could lead to underestimating the hazard of neutrons.[922]

The final version of BEIR III included a 27-page dissent by the Chairman of the BEIR III committee, Edward P. Radford (Professor of Environmental Epidemiology at the University of Pittsburgh Graduate School of Public Health).[923] Radford criticized the process used to produce the revised report, particularly the fact that instead of obtaining positive agreement or disagreement from each committee member, the 15 members who were not part of the revision effort were simply given the opportunity to submit comments by mail; few of them responded.[924] Radford also provided a lengthy argument as to why the linear model was the most appropriate means for estimating cancer risks from exposure to ionizing radiation.

Interviewed in 1984, Lauriston Taylor stated, "Radford is not part of the radiation protection community."[925] This appears to be a literally true statement, given that Radford was a professor of environmental epidemiology. However, considering the importance of epidemiology in establishing the dose-response relationship for low-level exposure to ionizing radiation, Taylor's statement is a fairly dismissive example of boundary work.

The National Academy of Sciences – National Research Council produced a successor document, BEIR V, in 1990. BEIR V states that "The need for replacement of the BEIR III report became obvious when it was determined that the long standing estimates of the radiation exposures received by the A-bomb survivors, that had been utilized by the BEIR III Committee, required extensive revision."[926] The judge in *Allen v. United States* made a similar remark in his written decision, as noted above. Research reveals that those comments understated the situation. The dose estimates for the people exposed to radiation from the bombing of Hiroshima and Nagasaki had been generated in 1965 by John Auxier, an AEC physicist at Oak Ridge.[927] Auxier analyzed measurements taken during and after the explosions, interviews with the bomber crews, and experiments at Los Alamos and the Nevada Test Site to produce his estimates, but he never described his methods in detail, and parts of his work were classified.[928] His modeling concluded that the Hiroshima bomb had emitted more than five times the neutron radiation of the Nagasaki bomb.[929] This incongruity was an important factor in the retraction and

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[921] NAS-NRC (1980), 255.
[922] NAS-NRC (1980), 255.
[923] NAS-NRC (1980), 227-253.
[924] NAS-NRC (1980), 228.
[925] Caufield, 171.
[926] NAS-NRC (1990), v.
[927] Eliot Marshall, "New A-Bomb Studies Alter Radiation Estimates," *Science* 212:4497 (May 22, 1981), 901-902.
[928] Marshall, 902.; W.H. Ellett, "Neutrons at Hiroshima: How Their Disappearance Affected Risk Estimates," *Radiation Research* 128:1, Supplement (October 1991), S148.
[929] Ellett, S148.

rewrite of BEIR III, as the group performing the rewrite had relied on the data from Hiroshima to argue that neutrons were responsible for many of the cancers among survivors, and that gamma rays and x-rays followed a different, less harmful dose-response relationship.[930]

The NCRP had questioned Auxier's work in the 1970s, prior to the BEIR III effort. After months of work, Auxier could not reproduce his results and informed the NCRP that he had accidentally destroyed the required data when he moved to a new office in 1972.[931] Independent work ensued, and in 1980 (the same year that BEIR III was reissued) researchers at Lawrence Livermore Laboratory presented preliminary conclusions indicating that Auxier had overstated the neutron dose at Hiroshima by a factor of 6 to 20, underestimated the gamma ray dose at Hiroshima, and overestimated the gamma ray dose at Nagasaki.[932] In the end, new official estimates found that Auxier had overstated the neutron dose at Hiroshima by a factor of 8.3, understated the gamma ray dose at Hiroshima by a factor of 1.5, and overstated the neutron and gamma ray doses at Nagasaki by factors of 2.6 and 1.1, respectively.[933] The changes rendered the survivor cancer data from the two cities similar enough to allow them to be treated as a single data set, analysis of which clearly favored a linear relationship for solid cancers and a linear-quadratic relationship for leukemia, as well as increasing the estimated likelihood of cancer for any given dose compared to the estimates in BEIR III and, to a lesser extent, BEIR I.[934]

The BEIR V report included the summary statement that, "In spite of evidence that the molecular lesions which give rise to somatic and genetic damage can be repaired to a considerable degree, the new data do not contradict the hypothesis, at least with respect to cancer induction and hereditary genetic effects, that the frequency of such effects increases with low-level radiation as a linear, nonthreshold function of the dose."[935] BEIR V further stated, "The cancer risk estimates derived with the preferred models used in this report are about 3 times larger for solid cancers (relative risk projection) and about 4 times larger for leukemia than the risk estimates presented in the BEIR III report."[936]

9.4 Johnston versus United States

The temporarily successful attempt led by radiologists to overturn the linear no-threshold dose-response model for gamma rays and x-rays, in BEIR III if not in regulations, is an important aspect of the setting for *Johnston v. United States*. Moreover, where the judge in *Allen v. United States* had considered a broad range of information sources in order to put BEIR III in proper context, the judge in *Johnston v. United States* took BEIR III at face value, as discussed below. Together with the government's experience in the long-running *Allen v. United States* case, this appears to have driven resolve in the government's defense team to strenuously fight back against allegations of harm from radiation exposure.

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930 Rotblat, 36.; Marshall, 900.
931 Marshall, 902.
932 Rotblat, 36.
933 Ellett, S148.
934 Ellett, S150, S152.
935 NAS-NRC (1990), 4.
936 NAS-NRC (1990), 6.

In the Johnston trial, four plaintiffs claimed health impacts from occupational radiation exposure. The plaintiffs were the estate of Earl E. Johnston, who died from leukemia; the estate of Don C. Vessels, who died from lung cancer; Barbara J. Womack, suffering from thyroid cancer; and Lila M. Mewhinney, suffering from colon cancer.[937] All four had worked at Aircraft Instrument and Development, Inc. (AID), which purchased surplus aircraft components, including instruments with luminous radium dials, for refurbishing, and their complaint claimed the cancers were caused by radiation from the radium-bearing items.[938]

Like the *Allen v. United States* case, *Johnston v. the United States* was not a jury trial. Originally, 23 companies that had been the initial source of the instruments were included as defendants.[939] However, all the companies settled rather than go to trial, paying a total of $400,000 to each plaintiff.[940] This left only the United States as a defendant, and as a result, there was no jury. Gofman later recollected that he had advised the plaintiffs to end the litigation after the private firms settled, because "anytime you go to court with a judge and no jury, you're taking an awful big chance."[941]

The judge ruled in favor of the defense in a rambling 61-page decision dated November 15, 1984. Before discussing the arguments presented in the ruling, it is worth noting that the court's conclusion appears correct, because of a combination of factors dispersed throughout the judge's ruling. The circumstances differ somewhat for each of the plaintiffs, but on the whole it appears that their likely level of radiation exposure and length of employment prior to exhibiting cancer symptoms make it unlikely that their cancers were associated with their employment at the plant, given the latency between exposure and cancer. However, in light of the apparent spread of radium contamination in the plant and the lack of any labeling or radiological controls, it is not surprising that the plaintiffs and their expert witnesses felt that working there had placed the employees at unnecessary risk.

The details of the court ruling reveal many problematic statements by the judge, who insulted the experts engaged by the plaintiffs repeatedly and at great length. For example, regarding Karl Z. Morgan, founder of the Health Physics Society, the judge wrote in his decision, "He is, in the Court's view, a pathetic figure who can better serve the field by simply 'going home.'"[942] Other insults and ridicule, directed exclusively at the plaintiffs and their experts, are pervasive in the judge's ruling. A lawyer from England who read a summary of the judge's remarks commented that such conduct would be "unthinkable" in his country and that if such a case were appealed, "the judge would be severely criticized, the judgment would be set aside, and a new trial would be ordered before another judge."[943] The judge articulated the motivations for both the United States' approach to the trial and for his attacks on the plaintiffs' experts as follows: "The paramount and obvious overriding interest has been to 'put to rest, once

[937] *Johnston v. United States*, 375-376.
[938] *Johnston v. United States*, 375.
[939] Rosalie Bertell, "Scientific information suppressed," *Index on Censorship* 14:3 (October 1, 1985), 61.
[940] Bertell, 61.
[941] U.S. Department of Energy Office of Human Radiation Experiments, DOE/EH-0457, "Oral History of Dr. John W. Gofman, M.D., Ph.D.," *Human Radiation Studies, Remembering the Early Years* (June 1995), 58.
[942] *Johnston v. United States*, 410.
[943] Bertell, 61.

and for all, the likes of Drs. Gofman, Morgan and Johnson.' If there has been any other reason to detail the Court's findings on these witnesses, it is in part to now support the United States' concerns."[944] (Johnson was a medical doctor on the plaintiffs' team and the architect of the survey of cancers in Mormon families presented in the *Allen v. United States* trial.) The proximity in time to the issuance of the revised BEIR III report, and the involvement of Fabrikant and Auxier on the defense team, suggest that there was also an element of "putting to rest" support or recognition for the linear no-threshold dose-response model.

The judge was effusive in his praise for the experts retained by the government for its defense. He announced Taylor as "Perhaps the most eminent person to testify at trial." Similarly, he described Fabrikant (who led the faulty rewrite of BEIR III, with its weak review and approval process based on the approach that "silence equals consent") as "probably the United States' most eminent witness."[945] Ironically, the judge's decision also summarized a discussion by Fabrikant on how parameters in cancer risk assessments could be manipulated to achieve a desired result, which the judge referenced in order to direct accusations of such conduct at Morgan.[946] The judge described Auxier (who, as detailed above, had generated incorrect estimates for the doses received by Japanese atomic bomb survivors and could not reproduce his own results) as follows: "Dr. John Auxier is an eminent health physicist who has specialized in matters of radiation dosimetry."[947]

Morgan appeared as a witness for the plaintiffs, presenting more than 500 pages of testimony on radiation health issues.[948] Morgan argued that the primary radiation exposure to the workers came from inhaling radon emitted by the decay of radium in the luminous paint on the instruments handled at the plant.[949] Morgan also described how ionizing radiation damages cells and can lead to malignancies.[950] Morgan went on to evaluate the buildup of radon in the plant, based on assumptions about the ventilation system and the number of radium-dial instruments inside, concluding that workers would be exposed to 14 millirem per hour on average, which over time would provide sufficient dose to cause the plaintiffs' cancers.[951] Simple math indicates that sustaining such an exposure rate over a 2000 hour work year would result in an annual dose of 28 rem, far exceeding regulatory limits. According to the judge's decision, Morgan provided the estimate that the plaintiff's cancers had likelihoods ranging from 76.2% to 99.7% of having been caused by the radiation exposure they experienced at the plant.[952]

Gofman also testified for the plaintiffs and endorsed Morgan's conclusions.[953] In introducing Gofman, the judge's decision noted that "he is an alarmist, truly, obsessed with the righteousness of his long espoused concerns regarding exposure to radiation in any setting," and that "it is clear from the outset that this man enjoys the 'limelight' … and is no stranger to the

[944] *Johnston v. United States*, 415.
[945] *Johnston v. United States*, 392.
[946] *Johnston v. United States*, 412-413.
[947] *Johnston v. United States*, 418.
[948] *Johnston v. United States*, 378-379.
[949] *Johnston v. United States*, 379-380.
[950] *Johnston v. United States*, 379-380.
[951] *Johnston v. United States*, 380.
[952] *Johnston v. United States*, 394.
[953] *Johnston v. United States*, 380.

courtroom."[954] Gofman testified that there is no safe threshold for exposure to ionizing radiation, described how ionizing radiation can induce cancer by damaging chromosomes in irradiated tissue, and described how alpha particles from radon decay are more damaging to tissue than gamma rays—the judge captured this concept as "Alpha particles rage through tissue, destroying as they go."[955] Based on factors similar to those considered by Morgan, Gofman concluded that 15 millirem per hour was a "very reasonable" estimate for the average exposure for workers in the plant.[956] Gofman then reviewed the medical aspects of the plaintiffs' cancers (except for plaintiff Vessels) and concluded they were all causally related to their employment at the plant.[957]

The judge's decision next provided a lengthy summary of the health effects of radiation, drawn from the BEIR III report, and a discussion of the hazards of radium and radon, correctly identifying the routes by which an employee working with or near radium-dial instruments could be exposed to radiation.[958] The judge further identified that while no dosimetry was in use at the plant, whole body radiation counts had established that there was no detectible radium deposited in the plaintiffs' bodies.[959] Commentary from a third party after the trial disagreed with that statement and claimed that the evidence submitted included whole body counts of the plaintiffs showing radiation above normal levels by factors ranging between 132 and 330.[960]

The judge devoted many words to drawing equivalencies between the radiation sources in the facility and naturally occurring radiation. Based on such equivalencies, the judge opined that if the court were to decide that any amount of radium or radon were hazardous (i.e., that there was no safe threshold dose), then he would have to label the Earth's environment "ultra-hazardous," because, for example, 200,000 gallons of drinking water or five pickup truck loads of Kansas dirt contained enough radium to make a radium-dial instrument.[961] He then proceeded to quote from NCRP reports on naturally occurring sources of radium and consumer products that produce radiation (making the odd choice of including airport x-ray machines, even though he presumably understood that air travelers do not lie down on the conveyer belt and pass through the beam of airport x-ray machines.[962] He also quoted the BEIR III report as stating that "natural background radiation remains the greatest contributor to the radiation exposure of the U.S. population today."[963]

The judge continued by extolling the "knowledgeable and most eminent scientists" of the NCRP and ICRP who set radiation limits and stating that the court is "ill-equipped to second

[954] *Johnston v. United States*, 380.
[955] *Johnston v. United States*, 381.
[956] *Johnston v. United States*, 382.
[957] *Johnston v. United States*, 382.
[958] *Johnston v. United States*, 383-387.
[959] *Johnston v. United States*, 387-388.
[960] Bertell, 62.
[961] *Johnston v. United States*, 388.
[962] NCRP Report No. 77, *Exposures from the Uranium Series with Emphasis on Radon and Its Daughters* (Washington, DC: National Council on Radiation Protection and Measurements, 1984).; NCRP Report No. 56, *Radiation Exposure from Consumer Products and Miscellaneous Sources* (Washington, DC: National Council on Radiation Protection and Measurements, 1977).; *Johnston v. United States*, 388-389.
[963] *Johnston v. United States*, 389.

guess those scientists by setting different standards of safety in tort suits."[964] He quoted Taylor as testifying that the original standards for x-ray and gamma ray exposure allowed 36 rem per year in the U.S. and 72 rem in Europe "without evidence of harmful effect" and that the originally recommended maximum permissible body burden of radium established for NCRP and ICRP by none other than Morgan in the 1950s would have produced a lifetime dose of 20,000 rem.[965] He further quoted Taylor as testifying that the current dose limit of 5 rem was selected "arbitrarily" based on "an unfounded concern for genetic effects" and on the reality that technological advancement had already reduced worker exposures below 5 rem anyway.[966]

Based on the foregoing reasoning, the judge determined that the only pertinent standards were the existing regulatory limits of 5 rem per year occupational exposure, 0.5 rem per year for individual members of the public, and a maximum permissible body burden of 0.1 microcuries of radium.[967] The judge did not acknowledge the cautions in the NCRP Handbooks warning that exposures and intakes should be kept well below the limits. This stood in stark contrast to the ruling in *Allen v. United States*, where as detailed above, the judge after much study concluded that "While there remains considerable uncertainty and controversy surrounding the precise quantitative mathematical description of the dose-response relationship for various radiations and cancers, none of the recent studies offer any direct evidentiary support for a threshold dose below which exposure is 'safe,' harmless and without additional risk."

The judge in *Johnston v. United States* next reviewed the history of radium safety in the U.S., ending with a summary of a safety inspection performed by the Public Health Service in 1966 to 1967 of the AID plant and 14 similar companies in the region that concluded there was little chance of worker exposures exceeding 500 millirem per year from beta or gamma radiation or breathing air that exceeded permissible levels of radon.[968] The inspectors did note extensive radium contamination on surfaces and noted that the facilities had been unwilling to clean up and control the contamination.[969]

The judge criticized Gofman and Morgan's cancer likelihood estimates based on their failure to use the analytical parameters recommended in BEIR III (which as noted earlier, was later to be refuted decisively by BEIR V) and for using erroneous assumptions about conditions in the plant, such as the number of radium-dial instruments in the plant at any given time, air flow in the plant, ambient radiation levels, etc.[970] The latter criticism appears well-founded—based on the record, it seems that they used secondhand information, recollections of the plaintiffs, and various assumptions in their estimates, whereas the experts for the defense seemed to have firm and accurate inputs for their assessments.

[964] *Johnston v. United States*, 391.
[965] *Johnston v. United States*, 391.
[966] *Johnston v. United States*, 392.
[967] *Johnston v. United States*, 392.
[968] *Johnston v. United States*, 397-398.
[969] *Johnston v. United States*, 398-399.
[970] *Johnston v. United States*, 408-416.

The judge ultimately articulated the position that a court could never attribute harm to a low occupational dose of radiation. After quoting at great length from NCRP Handbook 59 (which had been issued in 1954), he reasoned as follows:[971]

> We can see that in matters of determining the cancer risk from low occupational doses of radiation, scientists do not deal with what exists in fact and can be measured or experimentally proven. Rather, they deal with theory, hypothesis and assumption. While such an approach is a valid way to set general safety standards, it cannot be used to establish legal cause through mathematical calculations. A theory of hypothesis or assumption which yields a number like 97.6% or 8% is not yielding a real number.

This judge's simplistic view of the need for certainty in causation is far different than the reasoning in the approach taken by the judge in the *Allen v. United States* trial. Where the judge in *Johnston v. United States* demanded that causation be measured or experimentally proven, the judge in *Allen v. United States* acknowledged that the causation was indeterminate but determined that sufficient information was available to reach a verdict and cited several precedents to support his position. The judge in *Johnston v. United States* evaluated the evidence in precisely the manner that Jasanoff warned against, demanding a level of precision that was not obtainable. It is also amply clear from the judge's commentary that he viewed the defense's expert witnesses as far more credible than those of the plaintiffs. That judgment appears to be the underlying reason for his ruling, particularly in light of the extravagant praise he gave the defense witnesses and the intense criticism he directed at the plaintiffs' witnesses.

An article critical of the judge's conduct in the *Johnston v. United States* trial noted that the judge failed to quote or append any prior court rulings involving claimed exposures to ionizing radiation, including three recent cases in which government experts were unable to convince the courts that low-level radiation exposures were harmless.[972] The analysis further observed that publications such as *Nuclear News* and the Health Physics Society *Newsletter* reported summaries of the judge's decision, with the HPS *Newsletter* including an editorial stating that the judge "has declared that he believes in us, in our standards, and in our integrity,"[973] without acknowledging the judge's statements accepting Taylor's assertion that exposures of up to 72 rem per year were safe, or the judge's incorrect claim that there were no epidemiological studies supporting the occurrence of cancer below 50 rad.[974] The analysis also noted that the nuclear industry publications did not report numerous misstatements in the judge's decision, including having "referred to autoradiographs as audiographs; called the inverse square law the immense square law; thought MeV was a unit of power whereas it is a unit of energy; described alpha rays as bombarding tissues in millicuries per second; and said that electrons gave off daughter products."[975] The analysis quoted an environmental activist as observing, "the nuclear industry wrote that decision."[976]

[971] *Johnston v. United States*, 426.
[972] Bertell, 61.
[973] Bertell, 61-62.
[974] Bertell, 62-63.
[975] Bertell, 63.
[976] Bertell, 63.

9.5 Implications of the Court Cases for the Linear No-Threshold Model

These three court cases provide further insight into how dose-response models are viewed by and used by different actors and how the imaginaries animating America's judiciary contend with the science and regulation of radiation health. Actors pursuing radiation injury claims consistently applied the linear no-threshold model to support their cases. In fact, they used it both to estimate the likelihood of cancer from particular exposure levels and also to estimate unmonitored exposure levels from claimed cancer rates. In some instances, plaintiffs even suggested that the response for low-level exposures may be supralinear, with the likelihood of cancer incidence per unit of exposure higher than a linear relationship would predict for low-level exposures.

On the other side of the courtroom, actors opposing radiation injury claims tended to avoid supporting any dose-response model for low-level exposures, instead asserting that established exposure guidelines were adequate to ensure safety and citing anecdotal evidence to support them. Examples of such argumentation included Taylor's assertions that no health problems ever resulted from prior exposure limits as high at 72 rem per year, and that a body burden of 0.1 microcuries of radium was safe because decades ago no known health impacts had been identified for body burdens ten times larger. Other examples include the government's experts in *Johnston v. United States* supplying the judge with false equivalencies such as the idea that a workplace contaminated with radium contains no special hazards because radium is present in trace quantities in water and dirt, and additionally pointing the judge toward lists of consumer products (such as "airport x-ray machines") that emit radiation.

The different approaches taken by the judges, and the resulting wide variance in outcomes, are also worth discussion. The judges in *Allen v. United States* and *Silkwood v. Kerr-McGee* engaged with the actor-network for radiation health in their deliberations. Rather than pronounce one party "eminent" to justify discarding other information, those two judges considered information from across the actor-network in order to reach a conclusion that they considered to be supported by the preponderance of the evidence. Conversely, the judge in *Johnston v. United States* repeatedly praised the "eminence" of the government's witnesses while repeatedly insulting the witnesses for the plaintiffs, to a degree that crossed over into unprofessional behavior on his part.

The judges also expressed widely varying views on causation and scientific knowledge. The judge in *Allen v. United States* wrote many pages on the problem of establishing causation in a case involving latent cancers attributed to past radiation exposures. Emblematic of his reasoning was his observation, "But, we remain uncertain still of our scientific certainties."[977] This understanding underpinned his perception of the need to understand risks and probabilities in order to reach an informed judgment. Similarly, the judge in *Silkwood v. Kerr-McGee* stated that the AEC exposure regulations originated from NCRP and ICRP "guides for good radiation practices rather than strict levels of safety" and that both the AEC and EPA maintained that those

[977] *Allen v. United States* (1984), 259.

levels are not “a ‘safe’ or threshold level below which injury does not become a possibility.”[978] He went on to state that “the standards represent a balancing of social benefit against estimated cost … where scientific knowledge of low level radiation exposure effects is insufficient to determine the precise risk” and that the ALARA approach arose from “acknowledgment of the limitations of the regulations.”[979]

The judge in *Johnston v. United States* adopted a completely different stance, opining that scientists “deal with theory, hypothesis and assumption. While such an approach is a valid way to set general safety standards, it cannot be used to establish legal cause through mathematical calculations.”[980] The judge then applied the NCRP guidelines as rigid limits below which no harm could be expected. He judged applications of science that acknowledged uncertainty, such as risk estimates, to be unreliable and unsuitable to serve as evidence in his court.

The judges’ approaches to the cases diverged to such a degree that it is not possible to describe them as animated by a common imaginary. The judges in *Silkwood v. Kerr-McGee* and *Allen v. United States* both seem to subscribe to an imaginary that accepts some degree of uncertainty as part of the human condition and views the judicial system’s role as coming to a reasoned decision using the best available information. The judge in *Johnston v. United States* appeared to be animated by an imaginary that only had room for clear-cut statements of fact, with no allowance for reaching a verdict blaming the defendants for causing or contributing to harm based on anything less than certainty. He appeared to view the plaintiffs’ experts as pollution in the court system, fueling his determination to put an end to them through his vicious treatment of them in his ruling.

The court cases and the BEIR III controversy suggest a divergence among various professions within the actor-network. The BEIR III controversy originated in a dissenting opinion published by a radiologist (Rossi) who objected to findings in a section of the report chaired by an epidemiologist (Radford). The ensuing revision of the somatic section of the report was led by a radiologist (Fabrikant) who overturned the conclusion that the linear no-threshold model best described the dose-response relationship for low-level exposures to x-rays and gamma rays. The revision also characterized the dose-response relationship at very low dose levels in a manner that neither committed to nor disavowed a threshold dose for cancer incidence. The epidemiologist responded by publishing a dissent arguing that the revisions were incorrect. The original dissenting radiologist continued to dissent and argued that the predicted cancer incidence should be reduced to still smaller levels. Physicist Taylor’s remark that the epidemiologist leading the BEIR III committee was “not part of the radiation protection community” underscores the division between epidemiology and physics/radiology. History shows that the epidemiologist (and possibly science) won out in the end, as BEIR V reversed the changes and presented a linear no-threshold model that predicted a higher risk of cancer for low-level x-ray and gamma ray exposures.

[978] *Silkwood v. Kerr-McGee* (1979).
[979] *Silkwood v. Kerr-McGee* (1979).
[980] *Johnston v. United States,* 426.

Similar divisions existed between experts for the plaintiffs and the experts for the defense in the court cases reviewed above. Taylor (a physicist), Fabrikant (a radiologist), and Auxier (a physicist) provided testimony for the government in *Johnston v. United States* that the judge employed in deciding to treat NCRP guidelines as dose thresholds and in ignoring the existence of decades of admonitions to minimize radiation exposures to people. While Morgan stands out as an exception as a physicist recruited into what would become the field of health physics in the Manhattan Project, the other prominent plaintiffs' witnesses included Gofman (a nuclear chemist with a medical degree), Tamplin (from the Livermore biomedical division, with degrees in biochemistry and biophysics), and Johnson (a doctor). Knapp had no medical or biological credentials, but as a mathematician, he stood apart from the physicists and radiologists.

This completes the analysis of the actor-network. Chapters 5 through 9 applied actor-network theory, the idiom of co-production, and the concept of sociotechnical imaginaries to analyze the actors involved in the identification, application, and contestation of the dose-response model for human health effects of radiation and limits for radiation exposure. Chapter 10 concludes this dissertation by synthesizing insights from those chapters to draw conclusions regarding the co-production of science and social order in the regulation of radiation safety in the United States.

"That radiation protection standards are socially constructed and politically, rather than scientifically, decided may be the most pervasively misunderstood point in the entire public controversy." – Barton Hacker in *Elements of Controversy*

10 Conclusions

10.1 Summary of Research

10.1.1 Risk in Society

This research investigated the social processes at work in the development and stabilization of the approach taken in the United States for regulating the hazard posed by human exposure to ionizing radiation. It began with a review of the literature on social studies of risk in order to identify a theoretical framework for studying the social processes involved in establishing safety regulations for exposure to ionizing radiation. This review established that the "technoscientific" view which holds that risk is a measurable, calculable quantity overlooks the social processes through which social groups identify risks and prioritize them for action.[981] The technoscientific view often leads authorities to incorrectly believe that disagreements about risk result from the public's lack of knowledge about the risk and can therefore be resolved by providing the public with the information that it lacked. This "deficit model" of risk communication fails to recognize or respond to the social factors at the root of many disagreements about risk.[982]

Constructionist interpretations of risk include Beck's risk society, the cultural theory of risk pioneered by Douglas and Wildavsky, and Foucault's governmentality. Beck postulated that modern society faces pervasive risks that are indeterminate but potentially catastrophic, and that in this "risk society," the fundamental challenge is to resolve democratically the disputes over risks that science cannot settle.[983] Cultural theory proposed that people and social groups select and prioritize risks based on the values and beliefs that sustain their particular forms of social relations, as opposed to a value-neutral ranking scheme.[984] Governmentality describes how risks are constructed and managed through processes of social regulation and control.[985] Elements of each of these constructivist approaches bear upon the social construction of the risks of radiation exposure and how American society regulates those risks.

As described by Porter and Moore *et al*, modern regulatory systems are "scientized," relying on ostensibly impartial, scientific standards to regulate risks such as radiation exposure.[986] This approach tends to deter explicit consideration of social factors and to limit democratic participation in formulating regulations despite uncertainty in the underlying science and the negotiated nature of standards and regulations.[987] Ottinger observed that such standards

[981] Lupton, 17-18.
[982] Gross, 6.
[983] Beck, 29; Beck, Bonss, and Lau, 21.
[984] Wildavsky and Dake, 41-60.
[985] Dean, 134.
[986] Moore *et al*, 514; Porter.
[987] Moore *et al*, 517.

serve a boundary-keeping function by establishing the circular logic that experts are reliable because they cite authoritative standards, and that the standards are authoritative because experts support them.[988] As a result, standards can become a locus for challenges to official risk narratives, with citizens sometimes challenging standards as inadequate but in other instances relying on standards to gain credibility for their own risk discourses.[989]

10.1.2 Theoretical Framework for Investigation

The development of the scientific understanding of radiation health effects and its application in safety regulations provide excellent targets for two frameworks that apply the social construction of science: Co-production and actor-network theory. Jasanoff described co-production as providing an analytical position between the extremes of technoscientific determinism (in which science and technology inevitably progress in a particular direction, and society evolves to accommodate them) and social determinism (i.e., social construction, which in its extreme assigns causation to the societal aspects of a technoscientific situation).[990] Jasanoff identified four "ordering instruments" that lie at the heart of co-production, stabilizing "what we know and how we know it."[991] These instruments—making identities, making institutions, making discourses, and making representations—are how the mutual shaping of science and society takes place.[992] Jasanoff further proposed "sociotechnical imaginaries" as a means for explaining why different societies and different segments of society make such different choices and have such different views on issues involving science and technology.[993] Investigating the shared understandings and visions of the imaginaries that animate different social groups can provide great insight into the reasons for their choices and the origins of their views on sociotechnical issues.

The combination of these approaches proved to be highly effective both in conducting the research for this dissertation and in interpreting the research results. In simple terms, actor-network theory, co-production, and sociotechnical imaginaries came together to provide both theory and method for establishing the "who, what, how, and why" of the development of the science and regulation of radiation health effects. Actor-network theory provided both a theoretical framework and a structured methodology for researching the actors (the <u>who</u> and <u>what</u>). Jasanoff's development of co-production included not only the theoretical underpinnings for the interrelationships between science and society but also a practical approach for investigating <u>how</u> the actors advanced their agendas through their use of the ordering instruments that Jasanoff identified. Lastly, the concept of sociotechnical imaginaries proved to be central in establishing what animated various categories of actors in their engagements with the science and regulation of radiation health (the critically important <u>why</u>).

In order to apply this research framework, I began by establishing the space available for contestation. The nature of radiation and its interactions with matter are well-established and

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988 Ottinger, 251.
989 Ottinger, 246, 249.
990 Jasanoff (2006), 19-20.
991 Jasanoff (2006), 39.
992 Jasanoff (2006), 40-41.
993 Jasanoff (2015), 3-4.

have not been subject to contestation in recent decades. Furthermore, large doses of ionizing radiation consistently produce deterministic effects such as erythema, radiation sickness, cataracts, and birth defects, with the severity of the effect increasing with the radiation dose. However, lower doses result in stochastic effects—primarily various forms of cancer—that involve random aspects of damage and repair at the molecular level. Increasing the radiation dose will increase the likelihood of a stochastic health effect, but the severity of the effect (i.e., initiation of cancer) will remain more or less the same.

These relationships between dose and effect have resulted in general consensus on the dose-response model for relatively large radiation exposures. The prevailing dose-response models accepted for decades by authoritative entities such as the U.S. National Research Council rely on epidemiological studies to define the relationship between dose and response—linear for solid tumor cancers and linear-quadratic for leukemia.[994] Based on the observed data and the underlying theory for how radiation exposures lead to cancer, the prevailing models do not recognize any threshold below which there would be no added risk of cancer; nor do they recognize any potential for a beneficial effect of low doses of ionizing radiation ("radiation hormesis"). However, small radiation exposures (100 mSv or less) result in a small likelihood of cancer relative to the background fatal cancer risk from all other causes, which is estimated to be on the order of 20–25 percent.[995] Even epidemiological studies have been unable to statistically quantify the dose-response relationship for low-level radiation exposures. As a result, socially significant controversy has resulted when the models for radiation dose-response have been applied by regulatory authorities setting limits on radiation exposure and release of radioactive materials and by social groups using them to critique national policy on nuclear weapons, nuclear power, and other activities involving radiation exposure.

10.1.3 Identification of Actors

I heeded Latour's advice to follow the actors and observe their interactions by conducting a broad literature survey to identify venues and forums dealing with regulation of radiation health and cataloguing the various actors drawn to the debates, as well as others cited by those actors. The records of conferences, workshops, public hearings, court cases, and rulemakings pertaining to the science and regulation of radiation health and safety feature a broad range of actors ranging from individual concerned citizens to major scientific, academic, and governmental institutions and provide a wealth of insight into the process of *making discourses* as American society sought to accommodate nuclear weapons, nuclear energy, and technological applications of radiation into its social order, while at the same time shaping those technologies to conform with American ideals, which themselves vary among social groups and institutions.

Analysis of this actor-network commenced by considering the formation, growth, and institutionalization of the NCRP, which began in 1929 as an industry committee and eventually earned a congressional charter in 1964 to affirm its identity as America's leading authority on standards for radiation protection. NCRP's standards served as an ordering instrument by *making representations* about radiation, conveying the idea that exposures below their officially

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[994] NAS-NRC (2006), 16.
[995] Wakeford, 161.

endorsed limits were safe, even when they were essentially based on anecdotal observations and expert opinion. Its standards first were premised on the existence of a safe threshold for ionizing radiation exposure but by the 1950s specified "permissible" doses, with recommendations to keep exposures well below the limits. The NCRP documented its agreement that a linear model was appropriate as a "cautious assumption" in 1960 and since then has continued to treat it as conservative and useful but at the same time unproven and at risk of being misapplied.[996] The NCRP particularly discourages applying the model to estimate cancer fatalities for large populations exposed to small doses of radiation.[997]

The NCRP has gone beyond simply offering up a scientific consensus for industry and regulators to apply. It has offered guidance on balancing the risks of radiation exposure with the benefits of technologies that result in radiation exposure, particularly in the low-dose regime where risks are not well-characterized. Additionally, its leadership's decades-long campaign of *making discourses* through editorializing in various venues and testimony at administrative and legislative hearings, as well as expert testimony in the courts, has served as boundary work to affirm its position as the authoritative voice on radiation protection in the United States.

The NCRP's use of the ordering instruments of co-production in *making institutions*, *making identities*, *making discourses*, and *making representations* paints a clear picture of the sociotechnical imaginary that animates the NCRP. NCRP's handbooks and other discourse emphasize the technical expert and reinforce the expert's stature and authority in applying judgment in matters of radiation protection. In the NCRP's imaginary, standards are important, but the judgment of the technical expert is the deciding factor in managing radiation hazards. NCRP's handbooks and other discourse also represent radiation exposures as a necessary consequence of progress and as a risk that can be safely managed even if the exact degree of risk is not understood. This suggests an imaginary that has faith in science and believes in technology as key to human progress. Lastly, the NCRP's institution-building efforts indicate an imaginary that believes in society's institutions and sees them as instrumental in safely reconciling new technologies with society.

In analyzing the actor-network, I continued by considering the Federal government's activities as it developed, applied, regulated, and promoted nuclear technologies. The U.S. Atomic Energy Commission and Congress' Joint Committee on Atomic Energy were created together by the Atomic Energy Act of 1946. This act was a direct use of the ordering instrument of *making institutions* to give the government a repository of knowledge and power for shaping the development and implementation of nuclear technologies. The AEC played a crucial role in *making discourses* about the safety of nuclear technologies and the health effects of ionizing radiation, *making representations* about the nature of radiation and radiation's place among the risks confronting America, and *creating identities* related to nuclear technologies and radiation (including identities that were unintended by-products of its activities).

The AEC's human radiation experiments, conducted from the 1940s through the early 1970s, indicate that it accepted a *representation* of ionizing radiation as a tool that could be safely wielded to advance scientific knowledge and reflected a self-*identification* as experts

[996] NCRP (1960), 485.
[997] Boice, 1099.

exempt from external scrutiny and empowered to accept risks on behalf of others. Despite the NCRP's move away from the concept of a safe threshold for radiation exposure in the early 1950s, many of the AEC's experiments were conducted in a manner that suggested the researchers believed in a threshold. The AEC's atmospheric nuclear weapon testing program, conducted until America signed the Limited Test Ban Treaty in 1963, similarly involved *making representations* of radiation as controllable and of fallout as presenting a risk far smaller than the risk of not testing nuclear weapons. It similarly reflected the AEC's self-*identification* as experts empowered to accept risks on behalf of others. Unlike the secrecy of the human radiation experiments, the AEC engaged in a vigorous public relations campaign to advance its views on the risks and benefits of the nuclear weapon testing program, including widely distributing literature and films. This public relations campaign reinforced the institutional authority of the AEC by emphasizing the support for the program by the military and the Public Health Service and *represented* persons concerned with fallout as being ignorant of the facts or simply opposed to nuclear weapons. The later versions of these materials did use language consistent with a non-threshold dose-response model but always characterized the risks to the public as very small and justified by the national security benefits of the testing program.

The AEC's evolving public discourse on fallout reflected the influence of the National Academy of Sciences' report on the Biological Effects of Atomic Radiation, issued in 1956 and updated in 1960. This report articulated a linear no-threshold dose-response relationship for genetic effects of ionizing radiation. However, it also included the findings of a pathology panel led by a former AEC executive, which found the notion of a universal human body burden of radioactive strontium from fallout to be acceptable if limited to about the same radiation levels as natural background radiation.

Congress' Joint Committee on Atomic Energy held numerous public hearings during its decades of oversight of the AEC; I found hearings held in 1955 and 1957 on the health effects of fallout to be of particular interest to this dissertation. The JCAE held the 1955 hearing to calm public agitation after the 1954 CASTLE BRAVO thermonuclear test in the Pacific Ocean spread dangerous levels of fallout over the task force conducting the test, islanders evacuated for the test, and a Japanese fishing vessel outside of the established safety zone. In the hearing, the AEC and affiliated experts testified that it was AEC's policy to keep radiation exposures to a minimum but then proceeded to *make representations* of radiation from fallout as a small and imminently manageable risk and further sought to *represent* a body burden of radioactive material as a normal condition for humans. Consistent with much of the AEC's *discourse* on fallout, the AEC's emphasis on naturally occurring sources of radiation sought to *make representations* of artificially produced radioactive materials as not-so-unnatural.

The JCAE held its 1957 hearing on fallout in response to media uproar over the 1956 BEAR report, with its emphasis on the potential genetic effects of radiation. The 1957 hearing included testimony (written or in-person) from about 50 expert witnesses, including not only the AEC and its affiliates but also numerous other scientists and medical professionals. In this hearing, AEC officials again engaged in boundary work, *making representations* of the AEC as the source of scientific truth and representing its critics as biased. The AEC representatives generally acknowledged the lack of a threshold for genetic effects but continued to advance the potential for a threshold exposure level for somatic health effects. Several hearing participants not affiliated with the AEC argued that evidence supported a linear no-threshold dose-response model and that basing policy on such a model would be prudent. I found it noteworthy that the JCAE's summary of the hearing concluded that the question of whether or not to allow population-level radiation exposures was not going to be settled based on science alone but would depend on national policy and moral considerations, a conclusion that still holds true more than 60 years later.

In an effort to bolster public confidence in the safety of America's nuclear endeavors, President Eisenhower created the Federal Radiation Council in 1959. Unlike the AEC, the FRC was not responsible for both mission execution and regulation, and unlike the NCRP, the FRC was a *bona fide* Federal entity. However, the FRC included the Secretary of Defense and the AEC Chairman, and it only provided guidance (not requirements) to Federal entities such as the AEC. Overall, the FRC appears to have been held firmly in alignment with the AEC, and its publications largely followed existing radiation protection guidance from the NCRP, the NAS, and the ICRP. However, its 1962 report on fallout from nuclear weapon testing departed from other government and government-affiliated actors by applying the linear no-threshold model to estimate the number of people potentially suffering health effects from low-level radiation exposures to large populations. The *institutional discourse* would prove to be a powerful ordering instrument in *making representations* of radioactive fallout as potentially harmful, despite other government discourse to the contrary, and *making representations* of the linear no-threshold model as a valid dose-response model. This would figure prominently in the arguments advanced by actors voicing concerns about atmospheric testing of nuclear weapons and, later, nuclear power stations.

Non-governmental actors active during the years of the fallout controversy included a wide range of individuals and social groups. Debate during the 1956 Presidential campaign well illustrated the contrast in sociotechnical imaginaries of people like Adlai Stevenson who viewed nuclear weapon testing as a risk and believed the world would be safer with fewer nuclear weapons, versus those like Dwight D. Eisenhower who viewed testing as a risk worth taking because they believed it was needed to fend off a greater risk (global thermonuclear war). This contrast in imaginaries was similarly dramatized in a televised debate held two years later, in which famous hydrogen bomb designer Edward Teller echoed Eisenhower's opinions and additionally espoused technological advancement as the solution to problems. Opposing Teller in the debate, Nobel Laureate and peace activist Linus Pauling conveyed an imaginary that regarded technology as something to be handled with caution unless shown to be safe.

Activist citizen groups that made the most notable contributions to the public discourse on the health effects of fallout from nuclear weapon testing included the National Committee for a Sane Nuclear Policy and the Committee for Nuclear Information/Committee for Environmental Information. SANE made creative and effective use of the ordering instruments of co-production in its campaign against nuclear weapon testing. Its multimedia *discourse* centered on *making representations* of fallout as a grave health hazard, especially to children. SANE crafted its own public identity as a source of reliable scientific information by citing the FRC as the source of estimates of fallout's health impacts and by obtaining public statements of support from scientists, celebrities, and other well-known public figures. SANE's effective use of these ordering instruments reinforced the validity of the underlying model that no level of radiation exposure was safe and that the likelihood of harm was proportional to the magnitude of the radiation exposure. CNI also sought to cultivate sentiment against nuclear weapon testing, but where SANE used scientific data to support overt political activism, CNI took a "just the facts" approach that presented the scientific data in a neutral manner and directly engaged the public in performing science via its Baby Tooth Survey. CNI's approach was calculated to gain an audience with people who might find SANE's "peacenik" proclamations off-putting, which is not surprising considering that CNI's location in St. Louis was far away both physically and culturally from SANE's power centers in New York City and Hollywood. CNI's use of the ordering instrument of *making discourses* served to advance both critical thinking about the safety of nuclear weapons testing and affirmation of the linear no-threshold model for radiation dose effects.

The sociotechnical imaginaries of the activist groups recognize, as described by Moore, that science can produce true information about nature but also that it is "fallible and shaped by politics."[998] Accordingly, their imaginaries include a role for the input of citizens in sociotechnical questions, as opposed to leaving the course of science and technology in the hands of expert technocrats, and view technological developments as subject to the precautionary principle, where the burden is on the purveyor of a new technology to prove it is safe.

In the latter part of the 1960s, the licensing of commercial nuclear power stations came to the forefront of the controversies related to radiation's health effects. The AEC pursued a public relations campaign for nuclear power that resembled its approach to marketing nuclear weapon testing, including holding public meetings, making speeches, testifying at congressional hearings, and distributing materials arguing that America's future energy needs would be best met using nuclear power. This campaign aimed to "confront the public with the facts"—again reflecting a deficit model of communicating scientific information.[999] The AEC approach remained consistent with the sociotechnical imaginary that animated it during the era of atmospheric testing of nuclear weapons, wherein the technocratic institutions make decisions and then tell the public why the decisions are correct.

AEC scientists-turned-dissidents, John Gofman and Arthur Tamplin, publicly challenged AEC's regulatory limits for radiation exposures to the public from nuclear power stations based on calculations using the linear no-threshold dose-response model, first arguing for a tenfold reduction in exposure limits and later urging that nuclear power stations should not be allowed to release any radioactivity. The AEC issued a formal rebuttal to Gofman and Tamplin's research in December 1969 and informally told journalists that they were "incompetent." In response, Gofman and Tamplin testified at congressional hearings and public meetings to press the AEC to reduce exposure limits for the public, earning the support of senators and media coverage of their demands and complaints, and published sensationally titled books and other materials to continue to advance their *discourse*.

The surge of debate started by Gofman and Tamplin led, directly or indirectly, to three watershed events, each of singular importance, that played out in 1969-1972: (1) the AEC

[998] Moore, 214.
[999] R.S. Lewis, 105.

undertook public rulemaking to revise its regulations to require keeping occupational and public radiation exposures as low as practicable; (2) citizen groups contested the licensing of a proposed nuclear power station at a protracted public hearing that featured testimony by Tamplin; and (3) the National Research Council performed a landmark study of the health consequences of radiation exposure at the FRC's request.

The AEC rulemaking professed that it had always been AEC policy to minimize radiation exposure to the public. The proposed changes applied to both public and occupational radiation exposures and included minimizing radioactive material released in plant effluents. The proposed changes were well-received, with most comments from the public and industry supporting the rulemaking. The main concerns expressed in the comments involved how to interpret subjective language such as "every reasonable effort" and "as low as practicable" and whether the AEC could quantify such goals. The AEC clarified the words in the regulation it issued in 1970, but efforts to develop quantitative targets outlasted the AEC and were finally completed in 1975 by its successor, the Nuclear Regulatory Commission. The fact that the concept of managing radiation exposures far below the defined limits was generally uncontested during the rulemaking strongly indicates that by 1970 the linear no-threshold dose-response model for radiation health effects and the accompanying social practice of the ALARA principle had been firmly established in the American nuclear industry through the ordering instruments of co-production.

Coincident with the AEC rulemaking, public hearings held by the AEC during 1970-1971 on licensing a proposed nuclear power station at Shoreham on New York's Long Island prominently illustrated the types of arguments advanced by citizen groups expressing concerns about the public health impacts of nuclear power. Local citizens recruited scientists to support their campaign against the planned nuclear plant, including Tamplin who provided alarming estimates of the potential public health impacts based on the linear no-threshold dose-response model. By the time the AEC eventually granted a construction permit for the Shoreham plant in April 1972, it had revised its regulations to require controlling radiation exposures and releases of radioactive effluents "as low as practicable" below its prescribed limits. Furthermore, because of the public furor over radiation hazards from nuclear power, vendors of nuclear steam systems and architect-engineers began to introduce new equipment that would reduce or even eliminate routine releases of radioactivity. These industry initiatives and the AEC's "as low as practicable" rulemaking were mutually reinforcing, as it was clear that it was eminently "practicable" for industry to maintain exposures and releases well below AEC limits.

Finally, in parallel with the two events above, the FRC instigated a National Research Council evaluation of the FRC's radiation exposure guidelines in 1970. The resulting report of the Committee on the Biological Effects of Ionizing Radiations found that the FRC's radiation guidelines were unnecessarily high, that a linear model was appropriate for estimating the health effects of low-level radiation exposure, and that ionizing radiation exposures should only be allowed if commensurate benefits were expected.[1000] Together, the rulemaking, reactor licensing activities, and the BEIR report constituted powerful *ordering instruments* that cemented the linear no-threshold dose-response model in place as the basis for regulation of radiation safety.

[1000] NAS-NRC (1972), 2-3.

10.1.4 Science in the Courts

Study of several court cases involving alleged harm due to radiation exposure found that U.S courts are capable of rendering thoughtful decisions on problems that expose the social content of science. *Silkwood v. Kerr-McGee* and *Allen v. United States* involved presiding judges who made a sincere attempt to understand the linear no-threshold model, the rationale behind ALARA, and the problems in attempting to show causation when the alleged harm is cancer that develops years after exposure to radiation. Although the defendants in both cases successfully appealed the verdicts on procedural grounds after the plaintiffs had initially prevailed, plaintiffs in both ended up receiving compensation. *Silkwood v. Kerr-McGee* reached a settlement, and *Allen v. United States* eventually gave rise to congressional action in the form of the mammoth Radiation Exposure Compensation Act. Conversely, the judge in *Johnston v. United States* was not interested in the social content of science, asserting that "theory, hypothesis, and assumption … cannot be used to establish legal cause" in a court case.[1001] The plaintiffs in his case had already reached settlements with all of the defendants except the U.S. government, so it appears they were satisfied with what they had and did not appeal.

10.2 Conclusions: Co-production of Science and Social Order

This dissertation began by establishing the space available for contestation in the study of the effects of ionizing radiation on human health. This range of radiation exposures, from zero to 100 mSv, happens to encompass the entire range of occupational exposures allowed by regulations in the United States, as well as the allowed range of non-medical radiation exposures of members of the public. As a result, the model that serves as the basis for regulation of such radiation exposures has been a source of controversy for decades. This dissertation traced the evolution of the science and regulation of radiation health effects since the early 1900s in an effort to apply actor-network theory and the concept of co-production of science and social order by identifying the ordering instruments that operated at the nexus of the social and the natural in *making institutions, identities, discourses, and representations*. This process of co-production culminated in a regulatory system centered on the linear no-threshold dose-response model and the As Low As Reasonably Achievable philosophy. Two dominant sociotechnical imaginaries that diverge in important respects but have a common appreciation for the utility of the linear no-threshold dose-response model have animated the key participants in the actor-network.

The actor-network began with experimenters exploring applications for x-ray tubes and naturally occurring radioactive materials such as radium. After learning painful and sometimes fatal lessons, professional practitioners organized into industry groups and began establishing safety standards. Early on in this evolving field, the principle of using the least amount of radiation exposure needed to achieve the desired effect became accepted as a prudent measure given the immature understanding of radiation's health effects. Accordingly, a rudimentary form of the ALARA principle existed long before there was a linear no-threshold dose-response model, established as a social convention to help avoid inadvertent harm.

[1001] Johnston v. United States, 426.

This small community of practice exploded into a mammoth government-controlled industrial complex with the World War II Manhattan Project. The Manhattan Project unleashed a Pandora's box of new radioactive materials and vastly expanded the scope of radiation work across the United States, simultaneously creating new problems while also advancing scientific understanding of radiation health effects. However, basic questions on the nature of the dose-response relationship and the potential existence of a safe threshold level of exposure remained unsettled.

The science of radiation health effects evolved in parallel with the development of radiation-related technologies and the associated regulatory system. Particularly in light of the controversy over public exposure to radioactive fallout, the nuclear enterprise needed to support its position that occupational and public exposures were controlled to low levels that posed negligible health concerns. Despite the uncertainty over the actual shape of the dose-response relationship, laboratory experiments and epidemiology indicated that a linear model appeared suitable as a "cautious assumption" (in the words of a landmark NCRP report from 1960).[1002] Importantly, such a model proved useful to both the nuclear establishment and its detractors. In the hands of proponents of nuclear technologies, the model predicted that occupational exposures and exposures to the public represented small risks compared to naturally occurring levels of radiation and other risks that society deemed acceptable. Conversely, opponents of nuclear technologies were able to advance their causes by applying the model to predict that undesirable numbers of people would suffer radiation-related maladies if large populations received small radiation exposures from sources such as fallout from nuclear weapon testing.

The durability of the linear no-threshold model can be explained in terms of the ordering instruments of co-production deployed by members of the actor-network as they sought to influence how society used and controlled nuclear technologies, as discussed throughout the body of this dissertation. In advocating for their causes, opponents of nuclear technologies engaged in *making discourses* about the potential consequences of nuclear technologies that included consistently *making representations* of the linear no-threshold model as scientifically valid. As adherents to the precautionary principle, they were not overly concerned that the linear no-threshold model was represented as a cautious assumption—their sociotechnical imaginaries accepted such caution as entirely appropriate.

Similarly, the AEC, NCRP, and FRC worked at *making institutions* to govern the development and application of nuclear technologies and applications of radiation, including issuing exposure standards (i.e., ordering instruments) that eventually came to be based on a linear no-threshold model. It is clear from the early ordering instruments propagated by the AEC and NCRP that they would have preferred a model with a clear threshold, but the proponents of a threshold model did not manage to enroll the actors needed to construct a successful counter-program to the no-threshold model. As a result, and notably with the 1962 issuance of FRC Report No. 3 on the health consequences of fallout—which for the first time provided government-endorsed estimates for cases of leukemia, cancer, and genetic effects—the technocratic institutions turned their *discourse* towards acceptance and application of the linear no-threshold model, creating the enduring *representation* of the model as <u>unproven but useful</u>.

[1002] NCRP (1960), 485.

In terms of sociotechnical imaginaries, the linear no-threshold model was compatible with both of the dominant imaginaries involved in the actor-network. In the technocratic imaginary of institutions such as the AEC and NCRP, the model could be used by qualified experts to make risk-informed decisions about applications of nuclear technologies. In the socially progressive imaginary of the activist groups such as SANE, CNI, and FAS, the model empowered citizens to formulate arguments informed by science and rooted in the precautionary principle to challenge decisions and actions by the technocratic institutions.

Because of the practical need to accept some level of occupational radiation exposure, medical applications of radiation, and some *de minimis* exposure to the general public, the ALARA principle emerged as an important ordering instrument even before the linear no-threshold model had gained wide support. Although it was not possible to define an unequivocally safe threshold dose, all evidence indicated that very small doses resulted in very small risks to the health of exposed individuals. As a result, nuclear practitioners advanced the principle that, in addition to specifying quantified dose limits for exposures to workers and the public, all exposures should be kept as small as practical. This principle further argued that any exposure should result in sufficient benefit to justify accepting the risk of eventual health effects. Even before ALARA became the law, it had taken hold in a manner that allowed the nuclear industry to rationalize its operations as representing acceptable levels of risk, even though it could not be proven that the established exposure limits truly precluded harm to the exposed individuals.

The strident activism by Gofman and Tamplin in the late 1960s and early 1970s was built around reliance on the linear no-threshold model to calculate predicted cancer fatalities due to projected population-level exposures. Their relentless *discourse* on the need to reduce the allowable radiation exposures to the public, delivered in written documents and in testimony in various venues, played a significant role in leading the AEC to hold a rulemaking to institutionalize the practice of keeping exposures well below limits. It is notable that the concept of managing the potential public exposures far below the defined limits was generally uncontested during the rulemaking. This observation further supports the conclusion that by this time the linear no-threshold dose-response model for radiation health effects and the accompanying social practice of the ALARA principle had been firmly established in the American nuclear industry through the ordering instruments of co-production. In particular, the *representation* of radiation as posing some hazard even at low levels had been reinforced through decades of *discourse* in the form of continual reminders in handbooks and other communications by the NCRP and its predecessor committees that exposures should always be kept as small as possible because of the uncertain dose-response relationship. Likewise, the AEC had often repeated its public *discourse* affirming that it always kept exposures as small as possible as a common-sense precaution. This philosophy had even become physically manifested in the design of reactor equipment that reduced potential exposures well below the AEC's limits, facilitating industry's ready acceptance of ALARA as a regulatory requirement. All of these elements contributed to the clearing the path for an uncontentious rulemaking to formally institutionalize the practice as a regulatory requirement.

The prolific *discourse* spread by Gofman and Tamplin played a significant role in the FRC's decision to request the National Academy of Sciences to reevaluate the state of understanding of radiation's health effects. The fact that the resulting BEIR I report supported the linear no-threshold model for both somatic and genetic effects should have come as no surprise, since that result was consistent with a model that was already agreeable to the dominant sociotechnical imaginaries and supported by many *representations* and a wide variety of *discourses*.

The BEIR III controversy in 1979-1980 demonstrated the durability of the linear no-threshold model. To begin with, the radiologists leading the effort to renounce the linear no-threshold model were only able to substitute a linear quadratic model, not a fully quadratic model that would have produced still lower estimates of health effects. Furthermore, they were only able to accomplish that partial success for x-rays and gamma rays, not alpha particle or neutron radiation, and even then only for somatic, not genetic, effects. Most importantly, the changes the radiologists succeeded in making to BEIR III were not propagated into new regulatory guidance or requirements. In essence, the BEIR III revision amounted to little more than a change to a committee report that was recognized as aberrant and corrected in the next revision.

10.3 Areas for Future Study

There are a host of avenues for further study in this research area. Some of the more compelling research opportunities are summarized below:

- International influences. This research was limited to radiation protection regulation in the United States. Other nations have their own scientific institutions similarly engaged in research and regulation of radiation safety. There are also international organizations, such as the ICRP, the United Nations Scientific Committee on the Effects of Atomic Radiation, and the International Atomic Energy Agency. Comparative study of the United States versus other nations and the international organizations would be informative regarding how the U.S. regulatory system achieved its present state and what other outcomes are possible.

- Inner workings of the Atomic Energy Commission. The AEC was a vast bureaucracy with inherent conflicts in its mission, including being both the safety regulator and the entity responsible for carrying out a host of hazardous nuclear activities. Instead of treating the AEC as a monolithic entity that suffered from a few dissident staff, it would be informative to study each of the different divisions of the AEC to compare their actions and discourse regarding radiation safety. It would also be useful to study how the various elements of the AEC interacted and how policies and decisions were established.

- Inner workings of the BEIR committees. The BEIR III controversy illustrated that the outcome of the BEIR committees was a product of negotiation and possibly shaped by power struggles or political influence. Performing the Latourian exercise of "following scientists around" either virtually through the records of a prior BEIR study (if records exist to support such a review) or directly through observation of the next BEIR committee as it negotiates the content of the next set of BEIR recommendations would be very informative.

- Studying the importance of a scientist's professional alignment in determining their views on radiation protection. This dissertation found indications that professions that use radiation as a tool, such as radiologists and nuclear medicine providers, tend to favor models that downplay the hazards of radiation and suggest a threshold dose or even hormesis. Similarly, biologists, chemists, doctors, and mathematicians appeared in roles challenging claims of radiation safety and agitating for more cautious exposure limits. A more thorough exploration of the various disciplines taking part in this discourse may be able to reach definitive conclusions about the factors behind the BEIR III controversy and the recalculated exposure estimates for the survivors of the World War II atomic bombings that were important in determining the appropriate dose-response relationship for low-dose radiation exposure.

- Later years. Except for the three court cases selected for study, this research did not consider the last 40-plus years of history in any detail. That void omitted important historical events including the Three Mile Island accident, the dissolution of the AEC, and the rise of additional interest groups, including advocates of radiation hormesis who did not appear to play a significant role during the time period analyzed.

- Comparative study of ionizing radiation and COVID-19. While performing this research, I was struck by continual parallels between society's response to ionizing radiation and its response to COVID-19. A comparative study could reveal some basic characteristics of American society, such as the sociotechnical imaginaries held by different social groups and how they respond to hazards such as radiation and pandemic disease.

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