Chapter 1

Introduction

A Personal Journey

When I first became interested in nuclear power in the mid-1970s, its fortunes were much brighter than they are today. Defenders of nuclear energy pointed to the market's apparent endorsement of the technology (over 200 plants ordered by 1974) as *prima facie* evidence of its economic viability and technological superiority. I was more skeptical about the desirability of nuclear power, and after participating in the protests against the Seabrook nuclear plant, was led to ponder how market organized technical change might promote "inappropriate" technologies. This question evolved into an economics Ph.D. dissertation on the political-economic history of nuclear power (1986), a year's research at Oak Ridge National Laboratory (1988–1989), a sabbatical year as a Visiting Research Associate in the Department of Nuclear Engineering at MIT (1992–1993) and, finally, this book.

Reinforcing my original skepticism about nuclear power was a general distrust of technological determinism. I was skeptical of theories of innovation that analogized technological evolution to the inevitable sequence of mathematical theorems so inexorably derived in high school geometry classes. I was also skeptical of Panglossian economic theories that tended to reduce market-governed technical choices to the optimal expression of technical rationality. My instinct was to look for how social contexts influenced technical decisions about nuclear power. My goal was to develop analytical techniques to illuminate these influences. The task proved a complex and engaging project. I hope that readers can share the fascination I've felt in unpacking the diverse ways that ideology, institutional structures, distributions of power, and other products of social contexts have influenced market responses to nuclear power.

The assertion that social contexts *infuse* what appear to be "technically driven" decisions does not deny that "nature" and engineering constraints play key roles in shaping technological evolution, nor does it imply that market-organized technical change is generally a bad idea. The claim does,

however, assert that market-structured technical change is laden with social *as well* as technical inputs, and it questions simple policy recommendations that counsel "leaving innovation to the the market." As will be demonstrated in the text, the issue is not *whether* socio-political-ideological phenomena influence technological evolution, but *how* and to what degree. When these forces are understood, the "leave it to the market" mantra of the Reagan and Bush administrations that promised "pure technological change" appears as naive as King Canute's legendary order to the tides to cease their advance.

How To Read This Book

This book is intended for two major audiences: those interested in the history and future of nuclear power, and those interested in social theory. I hope to convince members of the first group that attention to methodological and philosophical issues in social theory has very practical implications for understanding nuclear power history and forecasting its future. I wish to convince the second group that the nuclear power experience provides an excellent context for exploring important methodological and conceptual debates in social theory.

It is my hope that the book weaves together its concrete and theoretical foci in a way that maintains the interests of its two audiences. There will be sections, however, that go into more detail than some readers of each audience might find necessary for their purposes. I have tried to identify such passages with a brief note and to avoid including in them material necessary for understanding later sections.

In order to further guide readers to those notes most likely to be of interest to them, I have used a footnoting system designed to signal whether the note is a simple source citation, a more detailed elaboration of a concrete nuclear power issue, or a further exploration of a social science issue. Notes in square brackets (e.g., [1]) are reference citations. Notes in angled brackets (e.g., <1>) elaborate concrete issues related to nuclear power, while notes in squiggly brackets (e.g., {1}) pertain to social theory issues.

Nuclear Power Issues

For those readers primarily interested in the technical aspects of the nuclear power debate, the book offers a detailed analysis of the history and

future of nuclear power. Part I of the text analyzes the reasons for the rapid expansion of nuclear power during 1954–1974 (chapters 2–5) and its subsequent collapse from 1974–1995 (chapter 6). Part II (chapters 7–10) explores the key issues within the nuclear sector that will shape its future. The chapters focus on expected future nuclear power costs, likely government R&D, subsidy, and regulatory policy, and the debate between proponents of evolutionary light water and passively safe reactor designs over which is the most promising route to a second nuclear era.

Part III (chapters 11–13) analyzes the factors outside the nuclear sector that will most influence nuclear power's future. The chapters focus on the level of future energy demand, the expected economics of non-nuclear energy options, and the implications of greenhouse hazards. Part IV (chapter 14) summarizes the book's findings.

Nuclear Power and Social Theory

The book's theoretical framework emphasizes two aspects of technological evolution to highlight the way social contexts have influenced nuclear power's history and future. The first is the potential for path dependency in technological competition, and the second is the paradigmatic nature of technology assessment.

Path Dependency

The potential for positive feedback in technological development implies that the outcome of technological competition can be determined by early path choices. Technologies gaining a head start in economic development may be able to transform initial advantages into permanent market dominance if they are able to capture path dependent cost reductions, such as:

- standardization and mass production economies
- learning curve cost reductions
- reduced risk premiums in capital markets
- the fruits of system-wide efficiencies (such as payoffs from investments in complementary technologies)

- the benefits of bureaucratic momentum
- the benefits of institutional accommodation to the social needs of the technology

While a few authors have insightfully explored some of these phenomena (see, for example, Bupp and Derian 1981, Morone and Woodhouse 1989, and Cowan 1990), analysis has most frequently concentrated on the first two factors rather than the full socio-technical process. There has also been a tendency to neglect the implications of path dependency for the behavior of corporate, political, and other participants in technical change. Such oversights have deflected attention from some important implications of path dependency, such as the links between path dependency and the polarization of energy sector debates.

The "Planning Context" - "Official Technology" framework developed in chapter 2 is specifically designed to grapple with path dependency and the impact of social contexts on technological development. The analysis demonstrates how ideological beliefs, institutional biases, etc. can significantly shape technical evolution if linked to positive feedback. The findings parallel some of the conclusions of contemporary "chaos theory" concerning the sensitivity of system outcomes to small changes in initial conditions.

The Planning Context-Official Technology framework introduced in chapter 2 develops three related concepts for analyzing technological evolution: (1) a "Planning Context" (PC); (2) "Technological Aesthetics" (TA); and (3) an "Official Technology" (OT). A *Planning Context* is a decision making environment defined in four dimensions: by the identities and political-economic objectives of its participants, by the context's ideological milieu, by the context's institutional structures, and by the nature of existing technical information. A planning context functions like a scientific paradigm, in that it defines the conceptual framework that informs decision making. The PC concept goes beyond categories of discourse, however, to include the material circumstances shaping and shaped by the discourse.

The second concept, *Technological Aesthetics*, refers to engineering intuitions and other subjective judgments about technological trajectories that are generally untestable but still play important roles in technology assessment. These judgments often represent collective traditions (such as those of professional societies, protest movements, or corporate subcultures) rather than random individual beliefs and thus are intertwined with larger institutional and ideological histories.

The third related concept of an *Official Technology* refers to a technology that enjoys strong state support, the sponsorship of a significant repre-

sentative of private capital, the promoted aura of "the coming technology," and the capture of path dependent advantages. The book's analysis of nuclear power history demonstrates that the decision to choose one particular technology over another can be underdetermined by technical variables, due to the early presence of incomplete information and path dependent effects. Thus in the early stages of decision making, different technologies may be able to win enduring market dominance if they are able to capture OT status. By emphasizing the influence of non-technically determined planning context phenomena, such as technological aesthetics, on which of several competing technologies captures OT benefits, the analysis highlights how social contexts can influence market-organized technical evolution.

The PC-OT framework also illuminates the character of technological competition. The framework's image of technological change challenges conventional economic theory's "passive" image of the firm as a "technology-taker." The PC-OT approach replaces older images of companies methodically trying to *discover* a priori technically determined development paths, with a new image of companies racing to *create* or *capture* path dependent OT status for technologies in which they possess a competitive advantage. The victor's prize is a stream of surplus profits (quasi rents) on technologically-specific capital (such as staff technical expertise, long lived plant and equipment, marketing networks, mineral rights, etc.).

Put more generally, "PC-OT analysis" seeks to uncover the socio-political variables influencing technical change by tying official technologies to particular planning contexts and their sponsoring dynamics. The book's analysis of this process follows a three step strategy:

Step one identifies the four dimensions of the planning context that produces a technical change by specifying the context's political-economic participants, its ideological milieu, its institutional structure, and its available technical information.

Step two analyzes how advocates of different development paths attempt to achieve critical mass or OT status for their favored option and how various ideological and institutional factors influence the success of their efforts.

Step three calculates the impact of promotional support on the micro-economic competitiveness of the victorious "Official Technology."

Chapters 2–5 of this book use the PC-OT framework's three step logic to unravel the origins of nuclear expansion 1950–1974. Chapter 6 explores the sociological origins of the shifting character of the nuclear planning context after the mid-sixties and ties these changes to nuclear power's eventual loss of OT status and economic competitiveness. Later chapters employ many of the same concepts to explore the potential impact of social contexts and path dependent phenomena on future energy sector developments.

Sociology of Knowledge Concerns

The book's second focus vis-à-vis social theory involves the implications of sociology of knowledge concerns for technology assessment. The analysis shows why attention to epistemological issues is critical for an understanding of nuclear power debates. Using Thomas Kuhn's concept of paradigmatic discourse, the book explores:

(1) why nuclear power cost forecasting and hazard assessment debates persist and are unlikely to be resolved in the foreseeable future by appeal to empirical data or available theory;

(2) why nuclear power costs and safety hazards have been traditionally underestimated;

(3) the parallels between nuclear power and alternative energy technology assessment; and

(4) the "technological aesthetics" that differentiate nuclear optimists from nuclear pessimists.

Put in terms more familiar to economists, the analysis explores the implications of bounded rationality and unfalsifiable assumptions for technology assessment. The book also raises some broader epistemological issues not usually addressed by economists or engineers.

By noting the inevitable tendency for constrained realms of discourse to organize technology assessment, and further by linking these constraints to the impact of social contexts, the analysis adds another dimension to the avenues by which social contexts infuse technical decisions.

Because Kuhn's theory of scientific knowledge plays such a large role in my analysis of nuclear power, it may be helpful to review the major aspects of his work that are relevant to technology assessment.[1] Kuhn asserts that scientific inquiry is always conducted within a paradigm or conceptual framework. Paradigms are said to influence the data attended to, the abstractions used to organize data, the character of research agendas, the responses to anomalous findings, and the boundaries of legitimate questions. He writes:

> "What a man sees depends both upon what he looks at and also upon what his previous visual-conceptual experience has taught him to see. In the absence of such training there can only be, in William James's phrase, 'a bloomin' buzzin' confusion'" (p. 113).

> ". . . one of the things a scientific community acquires with a paradigm is a criterion for choosing problems that, while the paradigm is taken for granted, can be assumed to have solutions. To a great extent these are the only problems that the community will admit as scientific or encourage its members to undertake. Other problems, including many that had previously been standard, are rejected as metaphysical, as the concern of another discipline, or sometimes as just too problematic to be worth the time. A paradigm can, for that matter, even insulate the community from those socially important problems that are not reducible to the puzzle form, because they cannot be stated in terms of the conceptual and instrumental tools the paradigm supplies" (p. 37).

I shall return many times in the course of this book to the issue of how such paradigms have influenced the development of nuclear power. The discussion will link the character of particular planning contexts to the construction of specific paradigms for assessing nuclear power, and tie the reasoning style of particular paradigms to specific conclusions about nuclear energy, be it judgments about nuclear hazards, nuclear cost forecasting, or analyses of nuclear power's competition.

Kuhn argues that paradigms define themselves by establishing templates for generating analogies. One learns a paradigm by studying these templates which embody the paradigm's solutions to classical problems. The paradigm advances by extending these solutions (or shared exemplars) to new problems.

Key to Kuhn's epistemology is his claim that paradigms operate at the level of perception as well as interpretation. Like a pair of spectacles (and/or a specialized language), a paradigm conditions the way practitioners *see* (and/or conceptualize) the world. All observations and deductions conditioned within the paradigm are therefore theory laden.

Debate about Kuhn's claims has often centered on his discussion of the way paradigm changes or scientific revolutions occur. He argues that the timing and direction of these gestalt shifts is underdetermined by available data. He does not claim that paradigm choices are irrational, or undisciplined by judgments about a theory's relative simplicity, consistency, scope, etc. He does claim that after ensuring logical consistency, and competitive, rather than absolute consistency with available data, (as all theories will contain puzzling inconsistencies or anomalies), judgments can differ about the relative promise of competing gestalts. He writes,

> "Observation and experience can and must drastically restrict the range of admissible scientific belief, else there would be no science.

> But they cannot alone determine a particular body of such belief. An apparently arbitrary element, compounded of personal and historical accident, is always a formative ingredient of the beliefs espoused by a given scientific community at a given time" (p. 4).

It is such open-endedness and ambiguity that Kuhn's positivist critics have found the most troubling. In a famous postscript to *The Structure of Scientific Revolutions*, Kuhn adds,

> "Debates over theory-choice cannot be cast in a form that fully resembles logical or mathematical proof. . . . Nothing about that relatively familiar thesis implies either that there are no good reasons for being persuaded or . . . that the reasons for choice are different from those usually listed by philosophers of science: accuracy, simplicity, fruitfulness, and the like. What it should suggest, however, is that such reasons . . . [can] be differently applied. . . . There is no neutral algorithm for theory-choice, no systematic decision procedure which, properly applied, must lead each individual in the group to the same decision" (pp. 199–200).

I will return to these observations in later chapters, when analyzing the open-ended nature of energy sector debates between "soft" and "hard" path energy advocates and when discussing intra-nuclear sector debates between proponents of "evolutionary light water reactors" and those who favor "passive safety reactor" designs.

The ambiguity involved in technology assessment and cost forecasting for new energy technologies is analogous to the uncertainties Kuhn found to accompany judgments about the relative fertility of alternative research paradigms. While assessments are not made arbitrarily, the evaluation of a theory in terms of its scope, consistency, simplicity, or fecundity, necessarily involves a weighting and aggregation that defies a priori, deterministic rules. "What is simple?" and "What is fertile?" in scientific paradigms, and "What is promising?" in technological paradigms, are more ambiguous questions than "What is the freezing point of water?" Such judgments necessarily involve "technological aesthetics."

By "technological aesthetics" I mean judgments about aspects of a technology where measurement is qualitative rather than quantitative and subject to "tastes." Relatedly, Kuhn writes, ". . . there is also another sort of consideration that can lead scientists to reject an old paradigm in favor of a new. These are arguments, rarely made entirely explicit, that appeal to the individual's sense of the appropriate or the aesthetic—the new theory is said to be 'neater,' 'more suitable,' or 'simpler,' than the old" (Kuhn 1970, 155).

With respect to nuclear power this can be analogized to judgments about what is an "appropriate technology". Nuclear enthusiasts perceive the technology as the obvious next step in an energy heritage that has already progressed through wood, coal, and oil/natural gas. Indeed, from this perspective, nuclear power's energy intensity (BTU per pound of fuel) and fuel abundance (assuming reprocessing and breeder designs) make it one of the few appropriate technologies for continuing industrial civilization. Cost containing technical fixes are assumed to be available for all conceivable engineering problems. Critics, on the other hand, attack nuclear power as an "inappropriate technology" analogizing its use to "cutting butter with a chain saw." They expect the economic implications of increased efforts to minimize reactor accident probabilities and other hazards, such as nuclear weapons proliferation, to overwhelm any cost saving innovations. Neither side sees very much appealing or attractive in the metaphors and images constructed by the other.

We shall see similar instances of conflicting technological aesthetics in the discussion of different assessments of energy sector alternatives to nuclear power, found in chapter 12.

Extending Kuhn's observations concerning scientific revolutions, Clark (1987) suggests that technological paradigms very rarely collapse solely from internal contradiction. Instead, paradigm shifts require both internal anomalies and external alternatives. The recent attention to reactor designs without the thermal instability of light water reactors (and the accompanying hazard complications), may provide such an alternative inside the nuclear community. Significant leaders of nuclear opinion (Alvin Weinberg formerly at Oak Ridge National Laboratory and Lawrence Lidsky at MIT, for example) are currently taking a more critical view of the future of light water reactors than was prevalent before the expansion of alternative nuclear development paths.

Overview of the Book and Chapter Summaries

As the book is lengthy, it seems appropriate to provide a preview of upcoming chapters. These summaries offer a roadmap for situating individual chapters within the book's overall logic. Part I (chapters 2–6) analyzes the history of nuclear power 1950–present. Chapter 2 outlines the four dimensions of the planning context overseeing nuclear power decision making from 1950–1970 and details the promotional mechanisms used by nuclear power's private sector sponsors to seek OT status for the technology. The

chapter analyzes the historical conjuncture created by the period's ideological milieu, institutional structure, corporate growth strategies, national political dynamics, and available technical information. While many parts of the story have been told elsewhere, the analysis adds several new threads (such as greater elaboration of the early support of nuclear initiatives by segments of the utility industry than has been commonly noted) and weaves the history together in novel ways, designed to highlight the impact of path dependency, constrained realms of discourse, and social contexts on nuclear development. The implications of this history are used later in the text to recommend policy responses to current nuclear power choices.

Chapter 3 analyzes the mechanisms used by nuclear power's public sector sponsors to promote OT status for the technology. Particular attention is paid to the factors facilitating massive R&D spending for nuclear power 1954–1974. The analysis uses the PC-OT framework to develop a Kuhnian model of private sector energy research that divides R&D activities into periods of "normal" and "revolutionary" research. The analysis demonstrates how social contexts can condition the timing and direction of "revolutionary" departures. The second part of chapter 3 explores the long list of subsidies, cost deferments, and risk shifting measures given the nuclear industry by its state sponsors.

Chapter 4 uses insights from the sociology of knowledge to analyze the impact of the nuclear planning context on nuclear power hazard assessment and cost forecasting. In a detailed study of the extraordinary history of nuclear cost underestimation and briefer analyses of routine radiation release, thermal pollution, and reactor accident hazard assessment, this section explores how contextual factors imposed an optimistic bias on technical realms of discourse. The analysis demonstrates how the nuclear planning context conditioned the data available, the methodologies used to analyze the data, and the research attention given to anomalous information in the nuclear cost forecasting and hazard assessment fields. Much like direct subsidies, the results were extremely helpful to nuclear power in its competition with alternative energy options. The discussion also briefly illustrates how the gradual restructuring of the nuclear planning context from the mid-sixties forward (vis-à-vis participants, institutions, etc.) altered the technical frames of reference organizing nuclear power information.

Chapter 5 assesses the overall impact of nuclear promotionalism on nuclear power's market position from 1954 to 1974. The chapter analyzes the impact on nuclear power costs of direct nuclear power assistance (such as R&D spending), in-kind aid (such as accident liability protections), and the technology's induced capture of OT status and accompanying path dependent economies (such as the capture of mass production economies). The analysis also highlights the qualitative impact of the OT process as a whole,

noting how OT dynamics created the great bandwagon market of 1966–1967, triggered massive oil company investment in the nuclear fuel industry in the late-sixties, stunted European efforts to develop alternative nuclear technologies to U.S. light water reactor designs, and retarded coal based economic options in the U.S.

The chapter concludes by discussing the ability of the PC-OT framework to reinforce and operationalize Amory Lovins' dichotomy between hard and soft energy paths. Using the PC-OT framework, Lovins' mutual exclusivity assertion can be disaggregated into discrete testable claims, a task he never fully addresses. Lovins' "technical incompatibilities" are analogized to the economic level of the PC-OT framework and represent the extent to which phenomena like economies of scale, learning curve efficiencies, system-wide positive externalities, and interdependent risk premiums characterize the energy sector. Lovins' "social incompatibilities" are analogized to the PC-OT framework's attention to the social construction of constraining realms of discourse and planning context logics.

Chapter 6 uses the PC-OT framework to explain the collapse of the nuclear power industry from 1975 to 1995. The beginning of chapter 6 parallels chapter 2's analysis of the nuclear planning context from 1954–1974. The discussion specifies the changing character of the *participants* in nuclear planning, the *ideological beliefs* facilitating collective action, the *institutional structures* organizing nuclear decision making, and the *technical conditions* surrounding nuclear choices. The chapter stresses how the interactive logic of the above changes reconstituted the basis for nuclear planning in a manner equal to a paradigm shift. The chapter thus offers a "structuralist epistemology" that locates the origins of shifting judgments about nuclear hazards, costs, and competition in social structural changes.

Part II of the book shifts the focus into the present. Chapters 7–9 explore the issues within the nuclear sector that will shape nuclear power's future. Chapter 7 explains why there are large disagreements between nuclear industry and nuclear critics' cost projections for new nuclear plants. The chapter returns to the sociology of knowledge issues discussed in chapter 4's analysis of the history of nuclear cost forecasting. It demonstrates that the nuclear industry's current optimism rests on the same methodological assumptions that produced past forecasting errors.

Chapter 8 explores the cloudy future of nuclear energy R&D and the prospects for continued public subsidy of the technology. The chapter demonstrates that without OT status nuclear power's large scale and hazardous nature (requiring both expensive demonstration projects and careful regulatory review before deploying innovations) leave it disadvantaged in R&D competition with small scale technologies that have shorter turnaround times for technical experiments.

The analysis highlights the paradigmatic character of R&D assessment and demonstrates how technological aesthetics can influence judgments about potential R&D payoffs. The chapter contrasts the technological aesthetics governing current energy planning, which favor technologies offering planning flexibility, marginal rather than radical change, and environmental protection, with the OT period's technological aesthetics, which favored technologies with long run growth potentials, centralized administrative formats, and novel scientific bases.

Chapter 9 discusses the likely direction of future NRC regulatory policy and the implications of changing electric utility regulations for the future of nuclear power. Extending the Kuhnian approach to technology assessment highlighted earlier, the chapter's detailed analysis of current radiation hazard and reactor safety debates presents these controversies as paradigm debates over modes of safety analysis. While acknowledging that the data is inconclusive about the seriousness of nuclear hazards, the chapter supports safety skepticism and foresees little public support for relaxation of current safety regulations.

The discussion of utility sector issues foresees little chance of a return to the OT period's regulatory regime which appeared to promise automatic recovery of utility investments in new generating plants. The analysis projects an increasing role for independent power producers (IPPs) in the electricity generating market and expects regulatory changes, such as Integrated Resource Planning (which requires increased utility attention to energy demand management and alternative energy options) to make future utility nuclear plant purchases more difficult.

Chapter 10 explores the intra-nuclear industry debate between advocates of evolutionary light water and passively safe reactor designs over the most attractive technological development path for the nuclear industry. The chapter outlines the strengths and weaknesses of each approach with respect to reactor safety, plant economics, and miscellaneous factors (such as proliferation resistance) and demonstrates the paradigmatic character of judgments about the designs' relative merits. The chapter concludes that only passively safe reactors have a chance of recapturing public confidence in nuclear power, a prerequisite for any second nuclear era.

Part III of the book analyzes issues external to the nuclear sector that will influence nuclear energy's future. Chapter 11 addresses energy demand issues, especially the competition faced by nuclear power from increased energy efficiency investments. The chapter briefly reviews the history of energy demand forecasting and reemploys insights from the sociology of knowledge to understand past and current energy demand forecasting debates.

Chapter 12 analyzes the economics of fossil fuel and renewable energy

alternatives to nuclear power. Cheap natural gas and coal-fired electricity (~4.5–6 c/kwh) are expected until at least 2010, with large reductions in renewable energy costs anticipated by 2030. The economics of wind and biomass renewable energy sources seem especially promising and even now appear to underprice nuclear power at favorable sites. As a result nuclear energy is found to have to achieve costs of less than 6 c/kwh (versus my expectation of costs of 7.5–8.5 c/kwh) to regain market attention. The chapter highlights the impact of technological aesthetics on assessments of non-nuclear energy alternatives and the importance of path dependent cost reductions to many of the technologies' economic prospects.

Chapter 13 focuses on the problem of global warming as the future of nuclear power has been increasingly linked to possible "greenhouse" constraints on fossil fuel use. The chapter reviews the science of the greenhouse effect, current cost estimates of the damages potentially caused by climate change, and the projected costs of different abatement responses, including increased reliance on nuclear power. The analysis finds that large uncertainties surround estimates in all of these fields. The final part of the chapter adds political consideration to the mix, and speculates on likely policy responses to greenhouse concerns and their implications for future nuclear power development.

Chapter 14 summarizes the book's findings and discusses the implications of the book's PC-OT organized history of nuclear power for debates in economic and social theory.