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FINANCIAL AND ENVIRONMENTAL BEHAVIOR OF THE REGULATED FIRM: A CASE STUDY OF THE U.S. NUCLEAR POWER INDUSTRY, 1974-1984

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF CHARTS

ABSTRACT

FINANCIAL AND ENVIRONMENTAL BEHAVIOR OF THE REGULATED FIRM: A CASE STUDY OF THE U.S. NUCLEAR POWER INDUSTRY, 1974-1984

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This dissertation is a study of the U.S. commercial nuclear power industry from 1974-1984 covering the operations of 87 power plants. It seeks to help explain the actions of a regulated firm faced with environmental constraints from the Nuclear Regulatory Commission and financial constraints from State regulatory bodies. Theoretical and applied conceptions of the regulated monopoly are reviewed in a historical and integrated format using both the neoclassical and institutional positions. For the neoclassical approach, I've attempted to find empirical support for the Averch-Johnson hypothesis by including profit maximizing and environmental constraints in my econometric model. For the institutionalist approach, I have tried to look into the institutional reasons for the behavior exhibited by the firms. The seminal hypothesis for this project was that because of the unique plant-specific characteristics of the U.S. nuclear industry that emissions were a function of specific plant characteristics, operational data, financial results and regulatory requirements.

A data base which consists of financial, radioactive emissions, and technical operations information has been compiled in order to allow testing of various hypotheses drawn from theoretical and applied sources. For this longitudinal data base, a semi-log, fixed-effect model with a lagged dependent variable was estimated. The estimation requires the use of a two-stage least squares procedure which results in consistent estimates.

The results of my analysis support five very clear conclusions. First, nuclear power plant emissions have dramatically trended downward since 1978/1979 across most of the elements examined. Second, there is little indication that variability in emissions is affected by variability in the firm's financial results. Third, the statistics reveal the very clear individual nature of the nuclear power plants in the U.S. Fourth, in spite of these dramatic declines in emissions releases, evidence was presented that the environmental inventories of some isotopes have been increasing. Fifth, for this one example of environmental behavior by one group of regulated monopoly firms, the increased vigilance by the regulatory officials within the Nuclear Regulatory Commission and the Environmental Protection Agency has indeed had its intended effects.

INTRODUCTION

This essay will attempt to integrate the historical development of both the theoretical and applied conceptions of the regulated monopoly. It will review both the neoclassical and institutional positions. The U.S. based nuclear power industry is used as a case study for exploration and empirical study.

This dissertation will attempt to answer the basic question of 'Why do nuclear power plants emit radioactive elements into the environment?'. The Nuclear Regulatory Commission's explanation for this phenomenon is purely a technical one. Certain by-products of the fission process used by the nuclear industry, its members have argued, must certainly escape into our air and water for purely technological reasons. This essay explores a broader approach, which includes technical, regulatory, and financial considerations. Certain regulatory criteria on emissions have been developed by the Atomic Energy Commission (AEC), the Nuclear Regulatory Commission (NRC) and the Environmental Protection Agency (EPA). These emissions criteria have been established to control the levels of emissions by nuclear power plants and thus limit the risk to the general public.

Other aspects to the question of "why" are the regulatory and financial environments under which the companies operating the nuclear plants exist. The U.S. nuclear industry is primarily in the private sector, and thus the question of why must be expanded to include the consideration of economic incentives and disincentives. Pricing, rates of return, the allowable rate base and other financial standards are under the purview of state regulatory bodies.

Chapter one will be an introductory chapter in which I shall attempt to provide a historical perspective on the nuclear power industry. In chapter two I plan on discussing the radioactive emissions, the estimated environmental accumulation of those emissions, and the development and change of the emissions standards. Chapter three will be a theoretical and philosophical essay on the theory of the firm and its specific application to the regulated monopoly. Chapter four shall contain an econometric model linking emissions and financial variables, along with the results of the tests and interpretations of those results. Chapter five will be the concluding analysis.

A word of caution, however, before we begin, is provided by the NRC,

> [A]t present, it is difficult to compare effluent releases of previous years, due to, among other contributors, variability in reporting structure and release requirements. Comparisons with respect to power generation are similarly difficult due to factors which affect the releases such as cladding defects, design features of plant radioactive waste treatment systems, operational occurences and equipment performance. In all cases, the total releases were below the limits set forth in applicable regulations and in technical specifications for each plant.[1]

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[1]Nuclear Regulatory Commission, Radioactive Materials Released From Nuclear Power Plants, Annual Report 1978 (Washington, D.C.: March 1981), 4.

This essay shall attempt to control for these various factors noted above, while it expands the realm of explanation. In brief, this essay explores the question of whether financial constraints imposed upon regulated monopolies impact their environmental behavior.

CHAPTER I

A HISTORICAL PERSPECTIVE ON NUCLEAR POWER AND REGULATION IN THE UNITED STATES

> Since the discovery of nuclear fission, the United States has provided world leadership in the development of nuclear energy for peaceful purposes. No other single technological innovation holds as much promise for alleviating energy shortages around the world; no other raises such grave questions of risk to public health and safety.[1]

The discovery of fissionable material by Otto Hahn and Fritz Strassman in 1938 and the development of the atomic bomb by the Manhattan Project were the first two significant events in the development of the technology necessary for nuclear power plants. During the 1940's in the United States, Federal regulation of nuclear materials and the nuclear industry began as the military developed ways to produce fuel. The Atomic Energy Act of 1946 (also known as the McMahon Act) was passed. This act, it was hoped, would continue to ensure the U.S. monopoly on nuclear weapons. The monopoly, however, was very short-lived as the U.S.S.R. detonated its first weapon in 1949. The creation of the Atomic Energy Commission (AEC) was also part of the 1946 act; the AEC was designed to provide civilian review and oversight for the military on the control

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[1]Frank G. Dawson, Nuclear Power (Seattle: University of Washington Press, 1976), v.

of nuclear weapons. The AEC was also mandated to develop potential peaceful applications for nuclear power. In that vein, a new committee was formed in 1947 within the AEC called the Reactor Safeguards Committee, which was to investigate nuclear power plants and their expected hazards. While some emphasis was placed by the AEC in this direction, the bulk of its activities was directed toward weaponry. Dawson noted that little of the Atomic Energy Commission's (AEC) expenditures were for "nuclear reactor development purely for electric power production. The main interest was still on....weapons."[2]

The first stage in the move toward privatization in the industry occurred in 1953, when the AEC authorized the development of a "full scale" nuclear power plant project.[3] Westinghouse Electric was given the right to develop this light-water reactor at Shippingport, Pa., while full ownership control was to remain with the AEC. Dusquesne Light Company was to operate the facility and receive the power generated.

The pressurized light water reactor (PWR) design was selected, in part, because more was known about that type than any other. The technology came from a number of earlier water-cooled reactors and specifically from the work on the Navy's Submarine Thermal Reactor (STR) and on the large ship-reactor program.[4] This development of

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[2]Dawson, 42.

[3]Dawson, 42.

[4] Dawson, 43.

the submarine reactor was perhaps the most significant event for the industry as we know it today.

The ground breaking ceremony was held for the Shippingport, Pa., nuclear power plant was held on Sept. 6, 1954.

> President Eisenhower emphasized the symbolic nature of this peaceful use of the atom by initiating an electrical signal at Denver, Colorado, that (sic) used a neutron source and a fission detector and that was transmitted across the country to start a remote-controlled bulldozer at the Shippingport site.[5]

In 1957, this first commercial nuclear power plant in the United States, at Shippingport, Pa., started operations. Apart from the Shippingport development, the Eisenhower administration continued to push for privatization. This move toward privatization is suggested in a historical perspective from the NRC which noted that,

> [S]purred by this demonstration and developments abroad, by the burgeoning demand for electricity, and by reports from the Joint Committee expressing dissatisfaction with AEC's lack of progress in reactor development, the Eisenhower administration urged Congress to amend the 1946 act so that private industry could enter the nuclear energy business.[6]

In 1954, Congress did just that, and General Electric and others joined Westinghouse and entered the industry to develop their own

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[5]Dawson, 43.

[6]U.S. Congress, Office of Technology Assessment, Nuclear Power in an age of Uncertainty (Washington, D.C.: February, 1984),144.

reactors. By 1957, however, these companies complained about potential liability problems and Congress responded with the Price Anderson Act, which limited potential liability to $560 million per accident. This was further amended in 1988 to $750 million. This private production of nuclear facilities by different firms helped to create the great diversity of design among the 110 operational plants in the U.S. which has since emerged.

Regulation for the safety of the public was also part of the amended act:

> [I]n 1955 and 1956, AEC issued the first sets of "basic regulations for civilian atomic industry" under the amended Atomic Energy Act. According to then-AEC Chairman Lewis Strauss, "the AEC's objective in the formulation of the regulations was to minimize government control of competitive enterprise....[and] open the way to all who are interested in engaging in research and development (R&D) of commercial activities in the atomic enèrgy field." The basic notion underlying this first regulatory scheme was to allow industry the discretion to choose plant designs and build them using its own judgement on how best to satisfy the requirement for a " reasonable assurance that the health and safety of the public will not be endangered." The assumption at that time was that the industry would be able to handle the technology well, and regulation would entail only a brief design review of safety-related components and periodic inspections. As the civilian nuclear power industry grew, it became apparent that both the industry and AEC had underestimated the complexity of ensuring safety and, therefore, the degree of regulation that would be appropriate. Regulatory activity expanded throughout the 1960's and 1970's along with an increasing appreciation for the probability and consequences of reactor accidents; this in turn contributed to increased public participation in the regulatory process. Regulatory

guidelines also increased in scope and complexity with the rapid evolution of nuclear technology.[7]

Whether the industry, the AEC, or the NRC recognized the problems internally, or were forced to by interested critics, is a matter for continuing debate. Intervenors in the licensing process, interested members of Congress, and dissenters within the AEC and the NRC have all played a role.[8]

In 1964, nuclear power went private with the passage of an amendment to the Atomic Energy Act of 1954, and private production and full ownership of nuclear power began.[9] Prior to this amendment, ownership had remained with the AEC as licenses to operate were given to the power plant owners. Nine plants went on-line in the sixties; another fifty-eight in the seventies; and, another forty-three in the eighties.[10] As of February, 1990, there were 110 operating commercial nuclear power plants within 34 different states in the United States, with another eleven in various stages of construction or in start-up.[11] There was also tremendous growth in

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[7]U.S. Congress, 144.

[8]See John L. Campbell, Collapse of an Industry: Nuclear Power and the Contradictions of U.S. Policy, Ithaca, N.Y.: Cornell University Press, 1988, especially chapters 2,3,4 and 5 for details of this debate.

[9]Corbin Allardice and Edward R. Trapnell, The Atomic Energy Commission (New York: Praeger Publishers,1974): 46.

[10]Department of Energy, Energy Information Administration, Monthly Energy Review, July 1987, (Washington, D.C.: July 1987), tables 8.1 and 8.2, 85-86.

the production of electricity by nuclear power plants during the 1970's and 1980's. In 1974, for instance, 48 power plants produced 6.1% of the electricity in the U.S.; this total increased to 68 plants producing 11.4% in 1979; in 1984, the totals were 86 plants and 13.6% of the U.S. total; and, currently, the 110 plants produced 23.4% of the U.S. total.[12] Since 1978, however, no new plans for additional plants have been made, due in part to financial considerations such as increased costs of construction due to increases in the real rate of interest, and increased public and regulatory concerns about the external dangers of nuclear power. For example, one author noted these financial situations by stating that:

> [N]uclear plant costs are high because of massive cost overruns and low levels of operating reliability....Given the dismal performance of many nuclear units, management is fearful of either a regulatory disallowance of new plant or, with growing deregulation, an inability to bring plants on line at a price that is competitive with alternative sources of power.[13]

One need only refer to the $6 billion cost for the Seabrook, N.H. facility for one reactor when the original estimate for two reactors was less than $1 billion, or to the disallowance of expenditures for

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[11]Department of Energy, Energy Information Administration, Monthly Energy Review, February 1990, (Washington, D.C.: February 1990), tables 8.1 and 8.2, 85-86.

[12]Department of Energy, 1990, tables 8.1 and 8.2, 85-86.

[13]Harry M. Trebing, "Regulation of Industry: An Institutional Approach," Journal of Economic Issues XXI, no. 4 (December 1987): 1728-1729.

the Commonwealth Edison Co. (Ill) Braidwood #1 plant in order to find examples of the financial problems in the industry.

Today, thirty years of information (financial, environmental, and technical) on the nuclear power industry exists. There is now a thirty year history of regulatory change, a thirty year history of financial operations and financial performance of each firm, a thirty year history of solid waste, liquid waste, and gaseous waste production by each plant, and, a thirty year history of growing public awareness of both the advantages and disadvantages of the production of electricity from nuclear power.

The public and private corporations which operate these plants function under the regulatory auspices of the Nuclear Regulatory Commission (NRC) (originally the Atomic Energy Commission (AEC)) and their respective State Public Utilities Commission (PUC), or similarly named body. The NRC must approve the initial application to build a plant (the construction permit); then the operating permit (first a low power testing permit and then a full power operational license); then the NRC monitors each facility on its adherence to all safety and operational regulations, while the PUC's must approve the rate structure of each firm, and the allowable rate of return to each firm. Various citizen groups, (for example, Public Citizen), also oversee the operations of the plants. The companies which own commercial nuclear power plants are, then, arguably, among the most heavily regulated firms within the United States.

> Nuclear power is one of the most intensely regulated industries in the United States, and the scope and practice

of regulation are among the most volatile issues surrounding the future of nuclear power....Every aspect of the nuclear industry-from the establishment of standards for exposure to radiation to the siting, design, and operation of nuclear powerplants....is regulated at the Federal, State, or Local level.[14]

The owners of each nuclear power plant in the United States are granted a license by their respective state utility commission to provide electrical power to a specified geographic area, and thus each qualifies as fitting the definition of a regulated monopoly. These regulated monopolies have received increasing attention of late, most notably because of the Three Mile Island, plant #2, mishap in 1979 and the Chernobyl, USSR, disaster in 1986. The routine operations of these plants, because of these and other major events in the past ten years, have also been more closely scrutinized. One of those routine matters is the emission of radioactive elements into the environment.

Nuclear power plants, it may be argued, produce two joint outputs: electricity and nuclear waste. The waste comes in two forms: contained solid waste and uncontained releases of gaseous and liquid radioactive elements into the environment. Disposal and/or storage of the contained solid waste thus are internal costs[15]; the

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[14]U.S. Congress, 144.

[15]This is a strong assumption which is not entirely true, as the federal government provides subsidized waste disposal facilities. Since, however, this paper deals with only emissions, this assumption is made for convenience.

uncontained releases are external ones. The NRC has promulgated rules on the levels of releases of the various radioactive elements under the assumption that those levels of releases cause minimal external costs.

Each nuclear power plant in the U.S. routinely emits radioactive effluents into the environment. For these emissions, the NRC has listed in the Federal Register the concentration levels of two hundred and sixty (260) radioactive isotopes.[16] Nuclear power plant operators are required to keep the emissions from their plants below these levels. The NRC has also published the totals of the annual radioactive emissions from each nuclear power plant in reports entitled Radioactive Materials Released From Nuclear Power Plants.[17] In every annual edition of those reports through 1978 the NRC has stated that, "[I]n all cases, the total releases were below the limits set forth in applicable regulations and in technical specifications for each plant".[18] This remarkable achievement requires a more detailed analysis. The statement that the emission

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16Office of the Federal Register, National Archives and Records Administration, Code of Federal Regulations (Washington, D.C.: January 1, 1987), Part 20, Appendix B, 274-283.

17See the bibliography for the Nuclear Regulatory Commission reports from 1974-1985.

18Nuclear Regulatory Commission, Radioactive Materials Released From Nuclear Power Plants, Annual Report 1978, (Washington, D.C., March 1981), 4.

releases were below the limits is, however, conspicuously absent from the 1979 report forward.

The NRC noted that,

> [R]eleases of radioactive materials are governed by 10 CFR part 20 and 50 and by limits established in the technical specifications for each facility. The requirement for reporting effluent releases by nuclear power plant operators is described in 10 CFR 50.36a. Through its Office of Inspection and Enforcement, the Nuclear Regulatory Commission maintains a knowledge of radioactive releases from licensed nuclear reactors to ensure that they are within regulatory requirements.[19]

Specifically, the Federal Register, 10 CFR 20.106 stated, "[A] licensee shall not possess, use, or transfer licensed material so as to release to an unrestricted area radioactive material in concentrations which exceed the limits specified in appendix B, table II"[20] The Federal Register, in part 10 CFR 50.36a, stated that,

> [T]he submission of a report to the appropriate NRC Regional Office....within sixty (60) days after January 1 and July 1 of each year specifying the quantity of each of the principal radionuclides released to unrestricted areas in liquid and gaseous effluents during the previous six (6) months of operation, and other such information as may be required by the Commission to estimate maximum potential

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[19]Nuclear Regulatory Commission, Radioactive Materials Released From Nuclear Power Plants, Annual Report 1978, (Washington, D.C., March 1981), 1.

[20]Office of the Federal Register, National Archives and Records Administration, Code of Federal Regulations (Washington, D.C.: January 1, 1987), Chapter 1, Part 50, 256.

annual radiation doses to the public resulting from effluent releases.[21]

Why look at these emissions? One reason is "that the total amount of radioactivity in an operating reactor is about 15 billion Ci [curies]" [22] and the question therefore arises as to how much of these are released into the environment. One of the annual emissions reports highlighted that there

> were slightly over 6.3 million Ci of radioactivity released from nuclear power plants during the year. However, data reported by the licensees showed, and the results of AEC'S (now NRC'S) inspection program confirmed, that the established limits on amounts of radioactivity in effluents from nuclear power plants were low in comparison with the 10 CFR 20 limits.[23]

The emissions are, along with electricity, a final product of the production process, and, as an external cost to each plant, they are indicative of the overall performance of each plant. The comparison of the levels of emissions and the financial constraints and performances of each plant and company should reveal how regulated monopolies respond to financial and environmental regulatory constraints.

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[21]Office of the Federal Register, 457.

[22]Anthony V. Nero, Jr., A Guidebook to Nuclear Power (Berkeley: University of California Press,1979), 35.

[23]Nuclear Regulatory Commission, "Summary of Radioactivity Released in Effluents from Nuclear Power Plants During 1973", in Nuclear Safety, Volume 16, no. 6, William R. Casto, editor, (Washington, D.C.: November/December 1975), 737.

One report which analyzed the potential longer term impact of radioactive emissions noted that:

> [A]s with all power generation methods, nuclear power plants impinge to some extent on the biosphere. Although the controlled and accidental releases of relatively small amounts of radioactivity from operating nuclear power and reprocessing plants have been maintained well below specified limits, it is important that the proper measures be taken in sufficient time to ensure that the anticipated future widespread use of nuclear power does not present an infringement upon those limits nor a potential hazard to the plant operators or to the public.[24]

Some other studies have analyzed the accumulated impact of released radioactive effluents into the environment, but none has attempted to measure the releases in the context of an economic model to explain the differences between plants. Three specific studies which have looked at the concentrations of radioactive isotopes in the environment are those of: David Forman, et al., which was a review of cancer patterns near Great Britain's nuclear installations[25]; Mackenzie's review on the concentration of americium and plutonium (two highly radioactive elements which are generated and released by nuclear power plants) in the North

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[24]Atomic Energy Commission, Division of Reactor Development and Technology, <u>The Potential Radiological Implications of Nuclear Facilities in the Upper River Basin in the Year 2000</u> (Washington, D.C.: January 1973), i.

[25]David Forman, etal., "Cancer Near Nuclear Installations," <u>Nature</u> 329, no. 6139 (8 October 1987), 499-505.

Sea[26]; and, Cobb's analysis of leukemia rates in Massachusetts.[27] The NRC, it should be noted, has followed a mandate on its monitoring of emissions "to determine if there is a buildup of radioactivity in the environment".[28] Other research by this author, discussed within chapter two, has also dealt with this issue.

The overall and pervasive regulation of the new nuclear industry has a much earlier (and uniquely American) history. The groundwork for the regulation is found in a famous 1877 U.S. Supreme Court case, Munn versus Illinois, which was triggered by a law passed in Illinois which regulated maximum prices and which required licenses for grain elevators and warehouses. Two partners, Munn and Scott, were sued for their failure to abide by the law. The defense argued that the Illinois law was unconstitutional as they were a private business and thus should not be regulated by the state. The U.S. Supreme Court ruled that their business was "affected with a public interest" thus it was a "thing of common interest and use".[29] The U.S. Supreme Court also noted that although there were nine other grain operators, that they all met on occasion to set prices.

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[26]A.B. Mackenzie, R.D. Scott and T.M. Williams, "Mechanisms for Northward Dispersal of Sallafield Waste," Nature 329, no. 6134 (3 September 1987), 42-45.

[27]Sidney Cobb, et al., "Leukemia in Five Massachusetts Coastal Towns," American Epidemiological Society (March18, 1987).

[28]Nuclear Regulatory Commission, Annual Report 1975, (Washington, D.C.: April 1976), 85.

[29]Munn v. Illinois, 94 U.S. 113 (U.S. Supreme Court, 1877), 126.

Thus the U.S. Supreme Court ruled that they acted as a virtual monopoly and held that the state could legitimately regulate them.[30] Over the next six decades, many far reaching (and at times conflicting) decisions were made on "public interest". In 1933, the Nebbia case in New York virtually stopped this hodge-podge of conflictual decisions by the U.S. Supreme Court declaring that:

> [I]t is clear that there is no closed class or category of businesses affected with a public interest....[A] state is free to adopt whatever economic policy may reasonably be deemed to promote public welfare, and to enforce that policy by legislation adopted to its purpose. The courts are without authority either to declare such policy, or, when it is decided by the legislature, to override it. If the laws passed are seen to have a reasonable relation to a proper legislative purpose, and are neither arbitrary nor discriminatory, the requirements of due process are satisfied.[31]

This concept of public interest is important here not for the regulation of utilities, as this developed separately from the general regulation of firms (See ICC, 1887 and that 25 states had railroad regulation at this time), but for the regulation of the environment as an item of public interest. The social and environmental legislation of the sixties and seventies (e.g., the Clean Air Act; the Clean Water Act) had to have an historical basis and the statement " to adopt

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[30]Munn v. Illinois, 135.

[31]Nebbia v. New York, 291 U.S. 531 (U.S. Supreme Court, 1933), 536-537.

whatever economic policy may reasonably be deemed to promote public welfare"[32] provided that groundwork.

Suffice it to say at this juncture that debate has continued on the limitation of and external costs of the radioactive releases from nuclear power plants, which is discussed further in chapter two and that debate has continued on the value of regulation within a free market society, which is discussed further in chapter three. Within chapter four, an empirical analysis has been done which looked at whether these two areas have come into conflict with one another.

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[32]Nebbia, 537.

CHAPTER II

EMISSIONS, ACCUMULATION AND EMISSIONS STANDARDS

There have been a number of studies on the normal and abnormal releases of radioactive material from U.S. based nuclear power plants. These studies have included simple release information, reviews of that release information, estimations of excess cancers caused by the emissions, and empirical studies of induced cancers in particular geographic areas. Author after author, article after article, and expert after expert has reported that nuclear power plants do emit radioactive isotopes, but that those releases are minor, negligible, and of no concern to humanity and the environment.

In the reports referenced above, and in this author's reports, nothing beyond purely technical reasons was provided to explain the level, frequency, or variability for the releases. A thorough literature review revealed no reports which looked for the economic reasons, if any, for these emissions. My interest in doing this type of review was spawned by previous research done in 1988[1] and 1990[2].

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[1] Richard England and Eric Mitchell, Estimates of Environmental Accumulations of Radioactivity Resulting From Routine Operation of U.S. Nuclear Power Plants, 1974-1984, (Durham, N.H.: University of N.H., Institute for Policy and Social Science Research, August 1988).

In the first of these two reports, estimates of the environmental accumulation of nine particular isotopes emitted by nuclear power plants were made; these nine elements and their accumulations are discussed within this chapter. The second research, which was a review of the regulatory positions of the NRC over the 11 years studied, concluded that "stricter nuclear emissions standards today would help to protect society against unexpected, but unacceptably high, health consequences in the years to come".[3]

Recent events have made these three analyses timely. In January, 1988, the Public Service Company of New Hampshire, a 36% owner of the Seabrook Station Nuclear plant, filed bankruptcy. This raised the specter of a bankrupt firm running a power plant, as the NRC has ruled that bankruptcy would not be a hindrance to the licensure of the Seabrook plant. The Union of Concerned Scientists has alleged that the continued operation of the Yankee-Rowe plant in Rowe, Mass., poses a threat because of its advanced age. Yankee-Rowe is the oldest operating plant in the United States.

The concern about the radioactive releases from nuclear power plants has been essentially a concern for protecting public health and safety. This has also been a thorny issue of just how much environmental radioactivity is safe from society's perspective. The NRC itself has apparently been satisfied that its regulatory efforts have prevented substantial damage to environmental quality and

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[3]England and Mitchell, "Federal Regulation", 558-559.

public health by the nuclear power industry. After all, the Commission has required that "routine releases of radioactive effluents from....power reactors and any resultant exposure be kept 'as low as reasonably achievable'"[4] and has claimed that discharges have been "[o]n the whole,....small fractions of the limits set forth in NRC regulations"[5].

For example, the 1974 emissions report from the NRC highlighted that,

> [T]he total measured amount of radioactivity released in airborne effluents increased slightly (about 2%) while radioactivity released in liquid effluents decreased (about 6%) in 1974 compared to 1973. In all cases, the total releases were below the limits set forth in applicable regulations and in technical specifications for each plant.[6]

In 1975, deficiences in the data released by the NRC were noted in another report. "At present, it is difficult to compare effluent releases with those of previous years due to....variability in reporting structure and requirements....In all cases, the releases were below the limits set...."[7] However, by 1985, the change in the

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[4]Nuclear Regulatory Commission, Annual Report 1975 (Washington, D.C.: April 1976), 10.

[5]Nuclear Regulatory Commission, Annual Report 1975, 46.

[6]Nuclear Regulatory Commission, Radioactive Materials Released from Nuclear Power Plants 1974 (Washington, D.C.: May 1976), 4.

[7]Nuclear Regulatory Agency, Radioactive Materials Released from Nuclear Power Plants (1975) (Washington, D.C.: March 1977), 3.

quality of data was noted in that "[O]ver the years the quality and detail of the licensee data have improved substantially...."[8]

Sailor and Colbert, in that same report from the NRC, further detailed population dose surveys and interpretations and they offered the following conclusions. First, emissions from plants have been within the regulations, and have been decreasing over time; and second, that the "average population dose commitments were in the range of 0.05 to 0.5% of the NRC Societal Goal".[9]

Nuclear power plants have, however, continually released radioactive effluents into the environment. The levels of emissions have depended upon the technology chosen for production (boiling water reactor (BWR) versus pressurized water reactor (PWR)), the pollution control equipment either originally designed into the plant or retrofitted per NRC decree, the age of the plant, the hours of criticality[10], other technical and operational criteria, along with a host of other factors. These other factors have included general maintenance and events from a level one to a level five.[11] The

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[8]Nuclear Regulatory Commission, Summary of Historical Experience With Releases of Radioactive Materials From Commercial Nuclear Power Plants in the United States (Washington, D.C.: March 1985), 15.

[9]Nuclear Regulatory Commission, Summary of Historical Experience, xvi.

[10]During the fissioning process within the reactor when the generation of neutrons is sufficient to maintain a constant level of the fission rate the reactor is said to be critical.

purpose of this paper is to try and identify the appropriate measure of profitability, if any, that may have contributed to the level and variability of the emissions.

Specific emissions information on each U.S. plant has been compiled and published annually by the NRC. The reports for the years 1974-1984, inclusively, were used for this dissertation. The reports were titled, Radioactive Materials Released From Nuclear Power Plants[12], and were derived from semi-annual reports submitted to the NRC by each plant. These reports were then compiled by the Brookhaven National Laboratory. These NRC reports have also been summarized and can be found in Nuclear Safety.[13] The information was unclassified, and provided specific annual curie release totals, by element, by plant.[14] Information prior to the 1974 report (though sketchy) was also available in several ways. For information for the years 1972 and 1973, the AEC[15], NRC[16], and

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[11]Events are a euphemistic phrase used by the NRC for mishaps. These mishaps, if classified as violations of policy, are categorized in terms of severity from a level 1, the highest level, to a level 5, the lowest level.

[12]See the bibliography for the reports from the U.S. Nuclear Regulatory Commission for the years 1974 through 1984.

[13]See, e.g., Nuclear Regulatory Commission, "Summary of Radioactivity Released in Effluents from Nuclear Power Plants During 1973," Nuclear Safety 16, no. 6, William R. Casto, ed. (November/December 1975), 734-738.

[14]An exception to this was the 1978 report, which provided information in quarterly totals.

EPA[17] all had reports. Earlier information was available either through the licensee docket or the NRC Public Document Room[18], or could be found summarized by the EPA[19] covering the years 1958-1970. Comparable world-wide information was available from United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).[20]

The annual emissions, in curies (Ci), of all the releases (both gaseous and liquid for 191 different radioactive elements) from the 89 operating commercial nuclear power plants in 67 separate reporting locations in the U.S. during the period 1974-1984 were collected. (See table 2.1 on pages 52 and 53.) Emissions of .000005

15Atomic Energy Commission, Report on Releases of Radioactivity in Effluents and Solid Wastes from Nuclear Power Plants in 1972 (Washington, D.C.: August 1973).

16Nuclear Regulatory Commission, Summary of Radioactivity Releases from Nuclear Power Plants During 1973 (Washington, D.C.: January 1975).

17Environmental Protection Agency, Summary of Radioactivity Released in Effluents From Nuclear Power Plants From 1973 Thru (sic) 1976 (Washington, D.C.: December 1977).

18Nuclear Regulatory Commission, Summary of Historical Experience, xvi.

19Environmental Protection Agency, Radioactive Waste Discharges To The Environment From Nuclear Power Facilities, Addendum 1 (Washington, D.C.: October 1971).

20United Nations Scientific Committee on the Effects of Atomic Radiation, Sources and Effects of Ionizing Radiation: 1977 report to the General Assembly, with annexes (New York: United Nations,1977).

Ci and greater were rounded to five decimal places. Other adjustments to the emissions data were for those readings which were less than the detection equipment's calibration level. For these calibrated readings, the following criteria were used. If the readings were more than twice the size of the average of all the other year's actual readings, then one-half of the amount was placed in the data base. Readings less than or equal to twice the average were recorded in the data base as reported in the NRC reports. Observations in these two categories of less than .000005 Ci also were not included. Further details on the data selection has been provided within Chapter IV.

A subset of twenty-three elements and combinations was then chosen where releases were demonstrated across years, and across a significant percentage of the plants. These elements and combinations of elements were also chosen in order to reflect a broad array of both gaseous and liquid emissions. The elements and combinations included tritium (H3b), chromium 51 (Cr-51), magnesium 54 (Mn-54), Iron 59 (Fe-59), cobalt 60 (Co-60), krypton 85 (Kr-85), krypton 85M (Kr-85M), strontium 89 (Sr-89), strontium 90 (Sr-90), niobium/zirconium Nb/Zr-95, silver 110M (Ag-110M), Iodine 131 (I-131), xenon 133 (Xe-133), cesium 134 (Cs-134), xenon 135 (Xe-135), cesium 137 (Cs-137), barium/lanthanum 140 (Ba/La-140), cerium 141 (Ce-141), cerium 144 (Ce-144), and neptunium 239 (Np-239). Combined releases of all noble gasses, all I-131 and particulates, and all mixed fission and activation gasses for each plant have also been collected.[21] Other data collected from these reports include construction date and solid waste amounts shipped per year.

The releases were tabulated in curies (Ci) per year released, and the gaseous and liquid releases have been added together to have one total release per year per plant.

The emissions information has been gathered from various Nuclear Regulatory Commission (NRC) and Environmental Protection Agency (EPA) reports. Every attempt to ensure the accurate replication of that information has been made, including secondary appraisal and retrieval of information, random audit procedures, and primary and secondary calculations of the totals. Emissions information on each and every radioactive emission from each nuclear power plant has been reviewed and compiled for the years 1973-1984 on some elements (as data allowed), and on all elements as reported for the years 1974-1984. This time frame reflected not only the period of growth within the industry, but also included a number of years prior to and after the Three Mile Island accident. It also incorporated the period where the information on emissions became more and more accurate.

In order to provide the reader with an introduction to the issue of accumulation and its potential long-term impact, let us take a look at the first operational plant within the United States, Shippingport,

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[21] Nuclear Regulatory Commission, Radioactive Releases from Nuclear Power Plants, Annual Reports 1974-1984 (Washington, D.C., various years), individual plant summaries and PWR, BWR tables.

a plant which was not operational during the years covered by this study, 1974-1984. For instance, in 1958 and 1959, specific curie release information on tritium was available. In 1958, Shippingport released 50.0 curies of tritium; in 1959, another 64.0 curies were released.[22] Given this information and the half life of tritium, which is 12.3 years,[23] the portion of the emissions from those two years which still remained in the environment as of 1984 was calculated. Given the 12.3 year half life, 94.5% of the previous year's emission of tritium will still be in the environment after one year's time. If one continued the procedure for the entire time frame, one found the following: of the 114 curies of tritium released in 1958 and 1959, 27.5 curies still remained in the environment at the end of 1984. In table 2.2, on page 54 at the end of this chapter, I have listed all the tritium releases from Shippingport from 1958-1970, and the balance which still remains in the environment. This is also displayed graphically on page 55. Of the total 353.14 Ci tritium releases from Shippingport, 28.2% of them still remained in the environment at the end of 1984. By the end of the year 2058 (100 years after the start of Shippingport), 1.48 Ci will still remain in the environment. In 2084, the balance will be down to .34 Ci.

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[22]Environmental Protection Agency, Radioactive Waste, Addendum-1, 9.

[23]A.M. Platt, J.V. Robinson, and O.F. Hill, Nuclear Fact Book, 2d ed. (Chur, Switzerland: Harwood Academic Publishers, 1985), 148.

The initial releases of tritium (1958-1960) from the Shippingport plant were substantially higher than in all subsequent years (to a magnitude of 1.5 over the next closest year, 1968) which suggested two items of interest: 1) a learning curve of usage in the control of emissions from nuclear power plants does exist, and can be tested from the data from the other firms and the other elements to be investigated, and 2) high initial emissions in the first years of operation lead to a rapidly rising stock of radioactivity in the environment, which can only be reversed by having subsequent yearly emissions be less than the amount of the stock which decays radioactively each year. Any emissions level greater than the radioactive decay flow will lead to further accumulation of that element in the environment. Besides the tritium listed above for Shippingport, nuclear power plants in the United States have routinely emitted over one hundred different radioactive elements into the environment each year, which are reported to the NRC by the owners of each plant.

The possible long-term threats to environmental quality and public health posed by discharges of radioactive materials during the routine operation of commercial nuclear power plants have apparently received little attention when compared to nuclear plant accidents, evacuation plans, and the treatment and disposal of solid radioactive waste.[24] Because some types of nuclear power plant

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[24]An exception to this generalization is Leda Hartman, "Downwind from Slow Death?", New Hampshire Times, September 17, 1986, 4.

emissions stay radioactive for a long time and because they can also enter biological food chains, these materials can accumulate in the environment and thus potentially affect public health in an adverse manner. Hence, routine discharges of radioactive materials at nuclear power plants deserve serious scrutiny by regulators, the public, scientists, Congress, and the media.

In order to lend support to this contention, annual emissions data for the 89 licensed nuclear reactors in operation during 1974-1984 have been assembled and calculations have been made of the estimates of the environmental accumulation of twenty radioisotopes by the end of 1984 resulting from these routine emissions. These results are summarized in graphical displays on pages 55 through 67 at the end of this chapter.

Although over one hundred different radioactive materials are routinely released by nuclear power plants[25], the selection has been made of twenty isotopes for this preliminary study; these are listed in table 2.3, on page 56. These particular materials are not necessarily the most hazardous radioisotopes from a public health perspective; nor are their volumes of discharge from nuclear power plants necessarily the greatest. Rather, they represent a wide cross section of elements released by U.S. power plants.

As table 2.3 indicates, fifty percent of an emission of cesium 137 is still radioactive in that form thirty years after its discharge. Similarly, one-half of an emission of strontium 90 will persist in

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[25]For the period 1974-1984, 191 were reported.

the environment after 28 1/2 years have elapsed. In the case of tritium, one-half of a discharge remains after 12.3 years. It might appear that neither xenon 135 nor neptunium 239 pose a potential problem of environmental acumulation because of their brief half-lives. These materials, however, were selected for study because they transform after emission into cesium 135 and plutonium 239, both of which persist almost indefinitely in the environment.

Once discharged into the environment (either directly or indirectly in the case of cesium 135 and neptunium 239), these radioactive materials not only persist but can and do enter food chains. For example, deposits of cesium 137, for example, can and do enter the tissue of foraging animals, thereby entering our milk and meat supplies.[26] Tritium, which is a radioactive form of hydrogen, can end up in the form of tritiated water and circulate freely throughout the biosphere.[27]

The data analyzed in this report measure selected radioactive emissions from eighty-nine commercial nuclear power plants located in the U.S. As table 2.1 shows, these plants vary in their initial date of operation, reactor design, electrical generating capacity, and proximity to human populations. What they have in common is that they generate electricity and also routinely emit radioactive materials.

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[26]John W. Gofman, Radiation and Human Health (San Francisco: Sierra Club Books, 1981), 539.

[27]Gofman, 425-427.

Since these published data do not report at what moment within each calendar year these emissions occurred, an extreme assumption about the discharge timing has been used in order to derive the estimates of environmental accumulation of these twenty radioactive substances by the end of 1984. I have assumed that annual emissions from each plant always occurred on January 1. This assumption tended to give a low estimate of the actual figure since that date would give each annual emission the maximum time to decay radioactively by the end of each year.[28]

It should be noted, however, that this timing assumption still suggests that the estimates could be lower than the actual figures for one or more reasons. First, the estimates in the graphical displays on pages 57-69 neglect radioactive emissions prior to 1974, even though they certainly did occur, because of paucity of published data. Second, the reliability of published data not only prior to 1974, but up until 1979, is open to some question since prior to that year the U.S. Nuclear Regulatory Commission did not routinely conduct its own emissions measurements in order to confirm the accuracy of licensee-provided data.[29] Hence, one can conclude that the estimates of radioactive accumulation contained

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[28]Annual decay rates are linear extrapolations from table 2 in Yen Wang, CRC Handbook of Radioactive Nuclides (Cleveland, Ohio: The Chemical Rubber Company), 4.

[29]Nuclear Regulatory Commission, Summary of Historical Experience, 3.

in this report are conservative ones and are almost certainly lower than the actual figures.

What I have done, then, is to take the published emissions data and, taking into account the radioactive half-life of each isotope, I have calculated how much of each year's emission had not yet decayed by the end of each year. That balance was then added to the emissions from the next year where, again, a calculation was made of the undecayed portion at the end of that year. This has been done for all the years from 1974-1984. This then gives an estimate, measured in curies, of the accumulated balances of the isotopes with a half-life greater than 180 days at the end of 1984 resulting from the routine operation of United States' commercial nuclear power plants during 1984 and previous years.[30]

The calculations indicate that tritium (H3b), as shown on page 57, has accumulated steadily since 1974; that the environmental inventory of strontium 90, on page 59, has increased steadily since 1974; that the environmental accumulation of cesium 137, on page 61, grew rapidly during the middle 1970's and since then has continued to increase, though at a much reduced rate of growth; and that cesium 135, on page 60, has been slowly accumulating because

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[30]For any radioactive material, one curie is that physical quantity of the material which produces 37 billion atomic disintegrations per second. Since the propensity to decay varies among materials, an equal number of curies of two different substances may not represent an equal physical mass of those substances. Nor does an equal number of curies of different substances necessarily pose an identical public health risk.

of routine emissions of its parent isotope, xenon 135, which are also demonstrated on page 60. Other elements studied and their results were: magnesium 54's, on page 57, accumulation peaked in 1975, and has steadily declined since then; cobalt 60, on page 58, peaked in 1978, and though declining, remains relatively high when compared to the level of annual emissions; krypton 85, on page 58, accumulated balances remain high, though slightly declining, in spite of dramatically reduced emissions since 1978-79; cesium 134, on page 59, for both emissions and accumulation, has steadily decreased since 1976; cerium 144, on page 61, accumulation peaked in 1978, and both emissions and accumulation have decreased ever since; neptunium 239, on page 60, emissions have decreased since 1978, but the accumulated balances of plutonium 239, also on page 62, its daughter element, continue to increase due the relatively long half-life of plutonium. For those elements studied that have relatively short half-lives (less than 180 days), and thus with little to no potential to accumulate, the trend since 1978-79 for all elements except chromium 51, page 63, niobium/zirconium 95, on page 65, and cerium 141, on page 67, has been generally less emissions over time, in spite of rapid growth in the number of plants coming on line. These include Fe 59, Kr 85M, Sr 89, Ag 110M, I 131, Xe 133, Ba/La 140, Cr 51, and Nb/Zr 95; these are shown without accumulation on pages 63 to 67. This is most notable on page 66 where the aggregate balances of fission and activation gasses are reflected, on page 68 where iodine 131 and particulates are shown, and on page 69 where mixed fission and activation gasses are charted. The explanation for the different patterns shown by Cr 51, Nb/Zr 95 and Ce 141 may be the standardization of reporting requirements previously noted. Relatively few plants reported these elements prior to 1979.

Whether or not the quantities of nuclear power plant emissions which have already accumulated in the environment pose a serious threat to human health is scientifically controversial. One study of cancer mortality rates near the San Onofre (CA) nuclear power plant does not indicate an unusually high number of cancer deaths in that vicinity.[31] It has been difficult to ascertain exactly how threatening some of these trends have been from a public health perspective, as this topic has remained highly controversial, or where these radioactive materials have gone since their discharge into the environment. However, the persistence and even accumulation of some radioactive substances in the environment as a consequence of routine nuclear power plant operations does warrant closer scrutiny by licensees, regulators, scientists and the electorate at large. Whether the instensification of federal regulation has actually resulted in very low risks is not obvious. The analysis of that issue would require the review of all releases of radioactivity by nuclear power plants and assessing their environmental and public health impact. No claim is made to have done that here.

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[31]James Enstrom, "Cancer Mortality Patterns around the San Onofre Nuclear Power Plant, 1960-1978", American Journal of Public Health (January 1983): 83-91.

Before focusing on the period from 1974-1984, it is important to reiterate one facet of the early history of U.S. nuclear power. This is the relatively lax regulatory stance of the U.S. Atomic Energy Commission versus private nuclear plant operators, a stance which persisted into the 1970's. Cohn reported the following:

> [B]ecause the activities of the AEC were initially directed towards expanded weapons production and bomb testing, and then towards the rapid commercialization of nuclear power, the Commission placed a relatively low priority on hazard data collection....Minimal monitoring oversaw industry release levels. Centralized AEC funding of radiation research also encouraged a methodological inbreeding which underestimated the scope of nuclear hazards.[32]

Mazuzan and Walker reported in a similar vein that President Eisenhower had explicitly sought minimal federal regulation for the infant industry as "[M]inimum regulation that protected national security and public health and safety appeared as the only logical way to proceed if the new industry was to be allowed the necessary flexibility to develop fully."[33]

Several developments in the 1960's eventually led to tightening of federal regulation of the industry. One was the growing popular concern about potential radiation hazards, an awareness which came

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[32]Stephen M. Cohn, "The Political Economy of Nuclear Power, 1946-82" (Ph.D. Diss., University of Massachussetts, Amherst, 1986), 293-4.

[33]George T. Mazuzan and J. Samuel Walker, Controlling the Atom: The Beginnings of Nuclear Regulation 1946-1962 (Berkeley: University of California Press, 1985), 91-2..

from the atomic bomb testing. Another important development was the discovery by environmental critics of commercial nuclear power that they could use AEC licensing hearings to raise public doubts about the safety of proposed reactors. As Cohn has observed, "[D]uring the mid-sixties critics gained a public platform for hazard discussion in 16 radiation related plant licensing challenges."[34] This is also perhaps reflected by altered opinions on the siting of power plants. The early concerns of owners of nuclear power plants on the siting of nuclear power plants are perhaps best summed by this prescient statement: "[I]t is my position that nuclear power plants can be....operated in the cities of the world. Because they do not "burn" fossil fuels, they do not release pollutants to the atmosphere....[t]hey can be built in total safety."[35]

This optimistic approach on siting and safety has been reconsidered because of recent events at the Three Mile Island plant, the Chernobyl disaster, and by public opposition to the Shoreham, N.Y. and Seabrook, N.H. facilities. In contrast, the President's Commission on TMI to the NRC recommended that, "[T]he Agency should be required, to the maximum extent feasible, to locate new power plants in areas remote from concentrations of population."[36]

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[34]Cohn, 297.

[35]L.H. Roddis, Jr., "Metropolitan Siting of Nuclear Power Plants", in Environmental Aspects of Nuclear Power Stations, by the International Atomic Energy Agency (Vienna: International Atomic Energy Agency, 1971), 723.

In brief, emissions rules are stated in the Federal Register and within the technical specifications of each nuclear power plant. Maximum allowable levels (and concentrations) of releases are specified for each plant for over 260 radioactive elements.[37] Statements from the NRC indicate that no nuclear power plant has ever violated the annual emission standards that each plant operates under, even though the releases vary greatly, for the years 1974-1984, the period covered in this report. This history of exemplary performance by these regulated firms deserves closer scrutiny. These totals that plants are allowed to emit are derived in conjunction with analyses of background radiation and other industrial/military emitters totals within the power plant's geographic area. Dispersion of the releases are determined for both air and water releases. General weather patterns, wind direction, and other relevant criteria are considered. Population dose limits are calculated within this entire scenario, and the risk from the releases is stated in terms of excess cancers per exposed population. Nuclear power plant operators are required to keep the emissions from their plants below these levels. The NRC has also published the totals of the annual radioactive emissions from each nuclear power plant in annual reports titled, Radioactive Materials

[36]Nuclear Regulatory Commission, 1979 Annual Report (Washington, D.C.: March 1980), 45.

[37]Office of the Federal Register, National Archives and Records Administration, Code of Federal Regulations (Washington, D.C.: January 1, 1987), Part 20, Appendix B, 274-283.

Released From Nuclear Power Plants[38]. In the editions of those reports up to 1978 (this statement disappears in the reports from 1979 and forward), the NRC stated that, "[I]n all cases, the total releases were below the limits set forth in applicable regulations and in technical specifications for each plant".[39] V.L. Sailor and J..J. Colbert noted in their NRC report that "[T]he quotation cited applies to the total annual release and is not necessarily intended to be valid for certain types of restrictions incorporated in the technical specifications, e.g., momentary rates of release, or integrated quarterly releases."[40]

As, in another report, the NRC stated, "[D]uring 1975, an instance (sic) occurred in which the radioactive material in gaseous effluents from a nuclear power plant exceeded NRC limits on two occasions."[41] Sailor and Colbert also reported that:

> [A]n examination of LERs [licensee event reports] covering a period from 1969 through early 1984 reveals a few cases in which emissions have exceeded restrictions in the technical specifications for rates of release over periods varying

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[38]See the bibliography for the Nuclear Regulatory Commission reports from 1974-1984.

[39]Nuclear Regulatory Commission, Radioactive Materials Released From Nuclear Power Plants, Annual Report 1978 (Washington, D.C.: March 1981), 4.

[40]Nuclear Regulatory Commission, Summary of Historical Experience, 6.

[41]Nuclear Regulatory Commission, Annual Report 1975, 46.

from a few minutes, hours, or, in a very few cases, several days.[42]

The NRC, in its 1985 Annual Report, stated:

> [I]n May, 1984, the Sacremento Munincipal Utility District reported that calculated doses to an off-site individual resulting from releases of radioactive liquid effluent from its Rancho Seco Nuclear Power Plant (Cal.) exceeded the exposure standards of 40 CFR 190 (as referenced in 10 CFR 20.105) for the period 1980 through the first quarter 1984....The excessive doses resulted from leaks in the steam generators at the plant....The NRC contracted the Oak Ridge National Laboratory to conduct an evaluation of the environmental contamination around the plant....The study team found elevated levels of cesium-134, cesium-137, and smaller amounts of cobalt-60 in the water and silt samples immediately below the area where the plant discharges its water into a nearby stream....Higher than background levels of radioactivity were also detected in samples of fish, beef, game birds, and vegetation.[43]

Even the "traumatic accident at Three Mile Island is expected to "produce between none and one fatal cancer," according to an investigation sponsored by the Commission even though over 10 million curies were released.[44] These optimistic claims ignore the

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[42]Nuclear Regulatory Commission, Summary of Historical Experience, 6.

[43]Nuclear Regulatory Commission, 1985 Annual Report (Washington, D.C.: June 1986), 44-45.

[44]Nuclear Regulatory Commission Special Inquiry Group, Three Mile Island: A Report to the Commissioners and to the Public, Volume 1 (Washington, D.C.: 1980), 153.

fact, however, that estimates of the public health effects of "low-level" concentrations of environmental radioactivity are subject to a great degree of uncertainty. As noted by Eisenbud, "[T]here are inherent statistical problems that prevent us from measuring the effects of low-level radiation."[45] Saunders and Wade point out that

> estimates of these hazards to man (sic) arise largely from a limited number of cases where groups have received sufficiently high doses for the effects to be measured against the general background of other risks.... There is continuing debate as to how the human data for....[these] groups....should be extrapolated to the much lower dose levels associated with the operation of the nuclear industry.[46]

The most widely accepted model, recommended by the International Commission on Radiological Protection (ICRP) and utilized in the post-TMI special inquiry commissioned by the NRC, is that there is no radiation dose which is perfectly safe and that there is a linear relationship between radiation dose and cancer risk.[47] However, also in 1980, the National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation (BEIR), in BEIR III, recommended the use of "a linear-quadratic model to express the

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[45]Merril Eisenbud, "Sources of Ionizing Radiation Exposure", Environment, December 1984, 33.

[46]P.A.H. Saunders and B.O. Wade, "Radiation and Its Control," in Nuclear Power Technology-Volume 3, Nuclear Radiation, ed. W. Marshall (Oxford: Clarendon Press, 1983), 12.

[47]Nuclear Regulatory Commission Special Inquiry Group, Three Mile Island: A Report, 403.

relationship between low-level gamma whole-body exposures and radiation induced cancers. Previously, a linear relationship had been recommended."[48] After a survey of available research on the health effects of "low level radiation", another author concluded as follows: "[I]t is thoroughly reasonable to say that cancer and lukemia induction by radiation is proportional to dose right down to the lowest conceivable doses[49]....[T]here is no [safe] threshold dose."[50] However, Lambert observed that

> ....linear, linear quadratic, quadratic, and other models have been fitted to the dose response data....[T]he choice of dose-effect relations at high doses can result in risk estimates differing by an order of magnitude at low doses....[G]oodness of fit cannot really be the arbiter of truth because in many cases all models seem to fit the data tolerably at low doses.[51]

How should nuclear utility regulation proceed in the face of such scientific uncertainty? One response would be to observe that scientific assessments of the seriousness of radiation health effects have increased repeatedly during recent decades. In 1934, for example, the ICRP recommended a maximum occupational

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[48]Nuclear Regulatory Commission, 1980 Annual Report (Washington, D.C.: March 1981), 188.

[49]Gofman, 411.

[50]Gofman, 415.

[51]B.E. Lambert, "Radiation-Induced Cancer Risks", The Lancet, May 7, 1988, 1045.

exposure of 70 rem per year.[52] That level was reduced to 15 rem per year in 1950 and once again to 5 rem per year in 1977.[53] In 1975 the NRC stated that:

> [O]n April 30, the Commission announced a significant new regulation....which provided definite numerical guidance to NRC licensees on how to comply with the previously enunciated requirement that levels of radioactive material in effluents from light-water-cooled reactors and resultant doses to the public be kept "as low as reasonably achievable.[54]

The guidance recommended that liquid effluents be kept to to 3 millirems to the total body and 10 millirems for any organ and that gaseous effluents be kept to 5 millirems total body and 15 millirems to skin. To some extent, this tightening of radiation standards reflects the long latency period between radiation exposure and onset of resulting cancers and lukemias. That is, past estimates of the dose-response relationship were too low because the complete, long-term health effects of past radiation exposure had not yet been observed.

In 1975, the NRC "adopted a landmark technique-a quantitative approach-for assessing the cost-benefit of achieving further

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[52]A rem measures the amount of energy from a radioactive source which is absorbed per kilogram of tissue, after adjusting for differences in the biological destructiveness of different types of radioactivity, e.g., x-rays, neutrons, heavy ions. A millirem is one/one thousandth of a rem.

[53]Saunders and Wade, 16-17.

[54]Nuclear Regulatory Commission, Annual Report 1975, 43.

reductions in emissions of radioactive material."[55] They also announced that all of the NRC monitoring of emissions were "to determine if there [has been] a buildup of radioactivity in the environment".[56]

Implementation of the cost-benefit analysis was difficult to achieve, due to the unknown, and ever changing, costs relative to exposed populations. In that regard, in 1976, the NRC conducted and reported on the following as:

> [A] major effort was made during the year to improve the models used by the staff for estimating effluent levels, environmental dispersion, and dose calculations; to employ more realistic assumptions; and to develop guidance for licensees on implementing the cost-benefit analysis requirements contained in Section IID of the new regulation (Appendix 1 to 10 CFR Part 50).[57]

Self-regulation by the utilities, under monitoring by the NRC, was still evident in 1976 as:

> [E]ach nuclear facility is required to monitor releases of gaseous and liquid radioactive effluents during normal operation. NRC inspectors check the licensee's radiological monitoring and waste systems to assure they are built as designed and operated to keep releases within regulatory limits.[58]

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[55]Nuclear Regulatory Commission, Annual Report 1975, 44.

[56]Nuclear Regulatory Commission, Annual Report 1975, 85.

[57]Nuclear Regulatory Commission, Annual Report 1976 (Washington, D.C.: April 1977), 67.

[58]Nuclear Regulatory Commission, Annual Report 1976, 68.

Continued weaknesses in the overall procedure were also noted in 1976, as:

> [E]ffluent monitoring and measuring studies are directed toward improving surveillance of licensee performance in response to regulations. These efforts are essential to enable effective inspection and enforcement of controls on nuclear plant operations.[59]

Cohn made known the fact that before the 1979 TMI accident the AEC and the NRC relied almost completely upon licensee measurements of radioactive emissions from operating power reactors except for spot checking 7-8 plants per year.[60] These spot checks did reveal that plant measurements were fairly accurate.[61] In point of fact, each plant at this time may have had different estimation techniques, and perhaps was required to report effluents in a manner that was inconsistent with other plants, depending upon what was contained in their respective technical specifications.

In 1977, the Environmental Protection Agency, under the provisions of the Clean Air Act Amendments, became involved with the actual level of the emissions and also with the emissions standards. The 1977 Annual Report from the NRC reported that:

> [T]he Administrator of the Environmental Protection Agency (EPA) must determine within two years whether emissions

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[59]Nuclear Regulatory Commission, Annual Report 1976, 193.

[60]Cohn, 328.

[61]See, e.g., Environmental Protection Agency, Radiological Surveillance Study at the Haddam Neck PWR Nuclear Power Station (Cincinnati, Ohio, 1974).

of radioactive pollutants "will cause, or contribute to, air pollution which may reasonably be anticipated to endanger public health." If an affirmative determination is made, he must list each pollutant under one of three sections of the Act and promulgate national primary and secondary ambient air quality standards, new source performance standards or hazardous air pollution emission standards, depending on where the pollutant is listed. While the administrator must implement and enforce the standards, he is required to enter into an interagency agreement with the NRC to minimize duplication of effort in exercising jurisdiction of the Act.[62]

On Dec. 1, 1979, the EPA's Environmental Radiation Protection Standards became effective. Compliance with the requirements from the EPA was noted in the 1979 Annual Report, as follows:

> [M]ost nuclear power plants that meet the requirements on radioactive effluents promulgated by appendix 1 to 10 CFR Part 50 have been shown generically to meet part 190. To assure full compliance, the model Radiological Effluent Technical Specifications (RETS), contained in NUREGs-0482 and-0473, have been modified to include Part 190 requirements as a limiting condition for operation.[63]

Continued emphasis on emissions was again noted in the 1978 Annual Report, and one continued to see modifications and enhancements to the NRC review procedure.

> Before issuing a license, the NRC assesses the probable radiological impact to the public of both the normal operation of nuclear power plants and of adverse, but improbable events, of varying likelihood. Such assessments are necessary to assure the health and safety of the public and the protection of the environment. From the results of

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[62]Nuclear Regulatory Commission, Annual Report 1977 (Washington, D.C.: April 1978), 9.

[63]Nuclear Regulatory Commission, 1979 Annual Report, 100.

continuing research, as well as from regular monitoring of both the radioactive effluents and radioactivity in the environment, these assessments are regularly upgraded to insure accuracy and reliability.[64]

In 1979, in light of the TMI accident and mounting public concerns, the NRC made major statements on emissions, especially their goal of ALARA, as the NRC announced that:

> [S]ignificant steps are being taken in improving our understanding of the potential health effects from exposure to low-level radiation. Holding radiation exposures as low as reasonably achievable under normal operating conditions is a fundamental objective of NRC's radiation protection activities.[65]

The President's Commission, engaged to review the accident at the Three Mile Island facility, recommended that, "EXPANDED AND BETTER COORDINATED RESEARCH INTO HEALTH-RELATED RADIATION EFFECTS SHOULD BE ESTABLISHED".[66] The Commission also recommended continued study into the biological effects of low level exposures of radiation and into the exposure levels that either workers or the general public should be exposed to. They also strongly suggested that the NRC find a "means for mitigating the adverse health effects of exposure to ionizing radiation and the

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[64]Nuclear Regulatory Commission, Annual Report 1978 (Washington, D.C.: February 1979), 48.

[65]Nuclear Regulatory Commission, 1979 Annual Report, 6.

[66]Nuclear Regulatory Commission, 1979 Annual Report, 53. [Capitals and bold-face in original].

genetic or environmental factors which predispose individuals to incurring adverse effects".[67]

The NRC has stated that it "agrees with the recommendation."[68] The President's Commission also recommended that "utilities must make sufficient advance preparation for the mitigation of emergencies, by having radiation monitors available for normal or off-normal conditions; by having enough instruments, respirators, and other equipment for normal or off-normal conditions...."[69] The NRC replied that "[T]he recommendation of the NRC Task Force on Emergency Preparedness to expand coverage and improve offsite monitoring capability for accidents is being implemented by all operating plant licensees, and NRC has improved its capability in this area."[70]

In 1980, the recommendations began to be implemented as the era of self regulation and reporting by the utilities began to close. The NRC reported that:

> [A]nother major program undertaken by NRC during fiscal year 1980 is the measurement of the radiation levels in the environment around nuclear power plants. This program is being conducted around 49 nuclear power plant sites, which include all all operating reactors and three reactors scheduled for operating license decisions in the near

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[67]Nuclear Regulatory Commission, <u>1979 Annual Report</u>, 53.

[68]Nuclear Regulatory Commission, <u>1979 Annual Report</u>, 53.

[69]Nuclear Regulatory Commission, <u>1979 Annual Report</u>, 53-54.

[70]Nuclear Regulatory Commission, <u>1979 Annual Report</u>, 53.

> future. As other reactors approach the operational stage, their sites will be added to the program. Thermoluminescent dosimeters (TLDs) are used to measure the cumulative direct radiation levels at the point of location. Approximately 50 TLDs have been installed at each site, covering all sectors of the compass, population centers, and high public interest locations out to a distance of about 10 miles.
>
> The purposes of the program are to (1) provide an independent verification of the accuracy of the licensee's environmental direct radiation measurements, (2) measure the ambient radiation levels in the vicinity of operating plants for use in assessing population doses resulting from routine operation, and (3) provide a continuously maintained network of TLDs that can be used for timely assessment of cumulative environmental doses under accident conditions.[71]

Emphasis on RETS, ALARA, and upon the TLD's continued through the 1980's. The TLD's were placed around 55 sites in the U.S. in 1981 to measure radiation levels. The sites included "all operating reactors and five others expecting operating licenses in the near future".[72]

In 1981, the NRC reported that:

> [A]n analysis was made during fiscal year 1981 of the reported operational data on effluents from 66 reactors, spanning approximately 300 reactor-years of operation. This analysis shows that the annual releases of radioactive materials in effluents predicted in the pre-operational environmental impact statements were generally consistent with those reported during operation. This

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[71]Nuclear Regulatory Commission, 1980 Annual Report, 143.

[72]Nuclear Regulatory Commission, 1981 Annual Report (Washington, D.C.: June 1982), 91.

analysis also provides a basis in operational experience from which effluent predictions may be improved.[73]

In 1982, the NRC noted that their:

> ....staff has been developing a major revision of the Commission's basic radiation protection standards (10 CFR Part 20). The revision would implement certain recommendations contained in the International Commission on Radiological Protection (ICRP) Publication 26, would update the annual limits on intake and derived air concentrations of radionuclides.... and would reflect developments in the principles that underlie radiation protection and recent advances in related sciences.[74]

By July, 1985, "RETS had received technical approval at all operating plants and were implemented at 80 percent of them. Essentially all operating reactors were expected to be operational under RETS by early 1986."[75]

In the late 1980's, there has been continuing investigation into exposure levels. The report by the U.S.-Japan Joint Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki, Final Report, released in 1987, which showed that, "....the average doses the survivors received were lower than previously believed, and thus risk estimates will have to be adjusted upward, but exactly how much is the subject of considerable debate."[76]

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[73]Nuclear Regulatory Commission, 1981 Annual Report, 45.

[74]Nuclear Regulatory Commission, 1982 Annual Report (Washington, D.C.: June 1983), 138.

[75]Nuclear Regulatory Commission, 1985 Annual Report, 41.

Roberts also noted that, "In 1965 Japanese and American scientists came up with a tentative dosimetry for the survivors, and it has guided cancer risk estimates and radiation protection standards throughout the world ever since. It turns out, however, that those calculations were wrong."[77]

Warren Sinclair, president of the National Council on Radiation has stated, as papraphrased by Leslie Roberts, that

> ....radiation risks appear to be a factor of two or three higher than earlier estimates. For the young, risk factors could be up by a factor of five or six....And, if the dose-response curve turns out to be linear, the risk estimate would rise by a factor of two again.[78]

Roberts continued and noted that:

> [F]orty-three years later, U. S. and Japanese physicists are still trying to figure out exactly what happened in August 1945, when the United States dropped two atomic bombs on the cities of Hiroshima and Nagasaki. Crude measurements were taken at the time, but the exact yield of the two atomic bombs, and especially the radiation dose the population received, remain unclear. The answers are of more than academic interest- most of what we know about the biological effects of radiation are based on the study of some 90,000 survivors of those two attacks.[79]

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[76]Leslie Roberts, "Atomic Bomb Doses Reassessed", Science, 18 December 1987, 1649.

[77]Roberts, 1649.

[78]Roberts, 1651.

[79]Roberts, 1649.

These new findings may cause the NRC to reassess its emissions requirements when the final data is complete. As they do their review, prudence would suggest that careful regulation of environmental inventories of radioactive materials with long half-lives be maintained until this scientific issue of radiation "threshold doses" has been resolved.

TABLE 2.1

NUCLEAR POWER PLANT CHARACTERISTICS

PLANT	TYPE	SIZE	OWN	LEAD OWNER	CONST(YR)	CRIT(YR)
ARKANSAS 1	PWR	850	PR	ARK. P & L	68	74
ARKANSAS 2	PWR	912	PR	ARK. P & L	71	78
BEAVER V. 1	PWR	835	PR	DUQUESNE LIGHT	69	76
BIG ROCK PT. 1	BWR	72	PR	CONSUMERS POW.	60	62
BRWN'S F.1/2/3	BWR	1065	PU	TVA	66	73.4.6
BRUNSWICK 1.2	BWR	821	PR	CAROLINA P & L	70.69	76.5
CALLAWAY	PWR	1171	PR	UNION ELECTRIC	75	84
CALVERT C. 1/2	PWR	845	PR	BALTIMORE G & E	68	74.6
COOK 1/2	PWR	1030	PR	IND. & MI. POW.	69	75.8
COOPER	BWR	778	PU	NEB. PUB. POW.	68	74
CRYSTAL RIV 3	PWR	825	PR	FLORIDA POWER	68	77
DAVIS BESSE 1	PWR	906	PR	TOLEDO EDISON	70	77
DIABLO CAN 1	PWR	1086	PR	PACIFIC G & E	68	84
DRESDEN 1	BWR	200	PR	COMM. ED.	58	59
DRESDEN 2/3	BWR	794	PR	COMM. ED.	65.66	70.1
DUANE ARNOLD	BWR	538	PR	IOWA ELEC. L & P	70	74
FARLEY 1	PWR	829	PR	ALABAMA POWER	70	77
FARLEY 2	PWR	829	PR	ALABAMA POWER	70	81
FITZPATRICK	BWR	816	PU	N.Y. POWER AUTH.	69	74
FT. CALHOUN	PWR	478	PU	OMAHA PUB. POW.	68	73
FT. ST. VRAIN	BWR	330	PR	PUB. SERV. COL.	68	74
GINNA	PWR	470	PR	ROCHESTER G & E	68	69
GRAND GULF 1	BWR	1250	PR	MISS. P & L	74	82
HADDAM NECK	PWR	582	PR	CT. YANK. A. P.	64	67
HATCH 1	BWR	776	PR	GA. POWER	68	74
HATCH 2	BWR	784	PR	GA. POWER	68	78
HUMBOLDT BAY	BWR	65	PR	PACIFIC G & E	60	63
INDIAN PT. 1/2	PWR	965	PR	CON. ED.	66	73
INDIAN PT. 3	PWR	965	PU	N.Y. POWER AUTH.	67	76
KEWAUNEE	PWR	535	PR	WISC. PUB. SERV.	67	74
LACROSSE	BWR	50	PU	DAIRYLAND POW.	62	67
LASALLE 1/2	BWR	1078	PR	COMM. ED.	73	82.4
MAINE YANKEE	PWR	825	PR	ME. YANK. A. P.	68	72
MCGUIRE 1/2	PWR	1180	PR	DUKE POWER	71	81.3
MILLSTONE 1	BWR	660	PR	N.E. NUC. ENER.	66	70
MILLSTONE 2	PWR	870	PR	N.E. NUC. ENER.	69	75
MONTICELLO	BWR	545	PR	NORTH. STATES P.	66	70

TABLE 2.1

NUCLEAR POWER PLANT CHARACTERISTICS

NINE MILE PT. 1	BWR	620	PR	NIAG/MOHAWK P.	63	69
NORTH ANNA 1/2	PWR	907	PR	VIRGINIA POWER	69	78.80
OCONEE 1/2/3	PWR	887	PR	DUKE POWER	67	73.3.4
OYSTER CREEK 1	BWR	650	PR	GPU NUCLEAR	63	69
PALISADES	PWR	805	PR	CONSUMERS POW.	68	71
PEACH BOT. 2/3	BWR	1065	PR	PHILA. ELEC.	67	73.4
PILGRIM	BWR	655	PR	BOSTON EDISON	67	72
POINT BE. 1/2	PWR	497	PR	WISC. ELEC. POW.	67	70.2
PRAIRIE IS. 1/2	PWR	530	PR	NORTH. STATES P.	68	73.4
QUAD CIT. 1/2	BWR	789	PR	COMM. ED.	66	71.2
RANCHO SECO 1	PWR	918	PU	SACRA. MUN. UTIL.	69	74
ROBINSON 2	PWR	700	PR	CAROLINA P & L	67	70
SALEM 1	PWR	1115	PR	PUB. SERV. E & G	68	76
SALEM 2	PWR	1115	PR	PUB. SERV. E & G	68	80
SAN ONOFRE 1	PWR	436	PR	SO. CAL. EDISON	64	67
SAN ONOFRE 2/3	PWR	1070	PR	SO. CAL. EDISON	74	82.3
SEQUOYAH 1/2	PWR	1148	PU	TVA	69	80.1
ST. LUCIE 1	PWR	830	PR	FLA. P & L	69	76
ST. LUCIE 2	PWR	830	PR	FLA. P & L	77	83
SUMMER 1	PWR	900	PR	S. C. E & G	73	82
SURRY 1/2	PWR	788	PR	VIRGINIA POWER	66	72.3
SUSQUEH. 1/2	BWR	1065	PR	PA. P & L	73	82. 4
TMI 1	PWR	819	PR	GPU NUCLEAR	68	74
TMI 2	PWR	880	PR	GPU NUCLEAR	69	78
TROJAN	PWR	1130	PR	PORTLAND G. E.	70	75
TURKEY PT. 3/4	PWR	693	PR	FLA. P & L	67	72. 3
VT. YANKEE	BWR	514	PR	VT. YANKEE N. P.	67	72
YANKEE ROWE	PWR	175	PR	YANKEE ATOM. E.	58	60
WNP2	BWR	1100	PU	WASH. PUB. POW.	72	84
ZION 1/2	PWR	1040	PR	COMM. ED.	68	73. 3

Legend:
PWR=PRESSURIZED WATER REACTOR
BWR= BOILING WATER REACTOR
SIZE IS STATED IN MEGAWATTS
PR=PRIVATE FIRM
PU=PUBLIC COMPANY

TABLE 2.2

SHIPPINGPORT TRITIUM EMISSIONS AND ACCUMULATIONS

YEAR	BEGIN BAL.	EMISSIONS	TOTAL	DECAY %	END BALANCE
1958	0	50.0	50.0	5.5	47.25
1959	47.25	64.0	111.25	5.5	105.13
1960	105.13	99.0	204.13	5.5	192.9
1961	192.90	13.2	206.1	5.5	194.77
1962	194.77	1.33	196.1	5.5	185.31
1963	185.31	2.17	187.48	5.5	177.17
1964	177.17	1.39	178.56	5.5	168.74
1965	168.74	3.04	171.78	5.5	162.33
1966	162.33	27.3	189.63	5.5	179.2
1967	179.2	34.8	214.0	5.5	202.23
1968	202.23	35.2	237.43	5.5	224.37
1969	224.37	20.0	244.37	5.5	230.93
1970	230.93	1.71	232.64	5.5	219.85
1971	219.85	0	219.85	5.5	207.76
1972	207.76	0	207.76	5.5	196.33
1973	196.33	0	196.33	5.5	185.53
1974	185.53	0	185.53	5.5	175.33
1975	175.33	0	175.33	5.5	165.68
1976	165.68	0	165.68	5.5	156.57
1977	156.57	0	156.57	5.5	147.96
1978	147.96	0	147.96	5.5	138.82
1979	138.82	0	138.82	5.5	132.13
1980	132.13	0	132.13	5.5	124.86
1981	124.86	0	124.86	5.5	118.0
1982	118.0	0	118.0	5.5	111.51
1983	111.51	0	111.51	5.5	105.37
1984	105.37	0	105.37	5.5	99.58

CHART 2.1

SHIPPINGPORT TRITIUM EMISSIONS AND ACCUMULATIONS

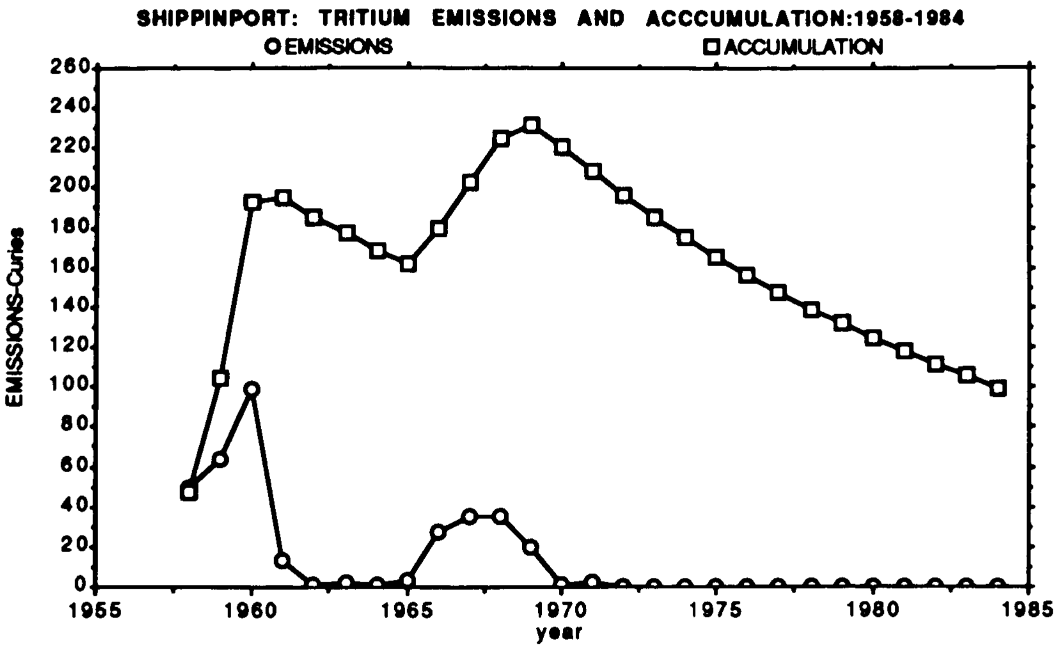


TABLE 2.3

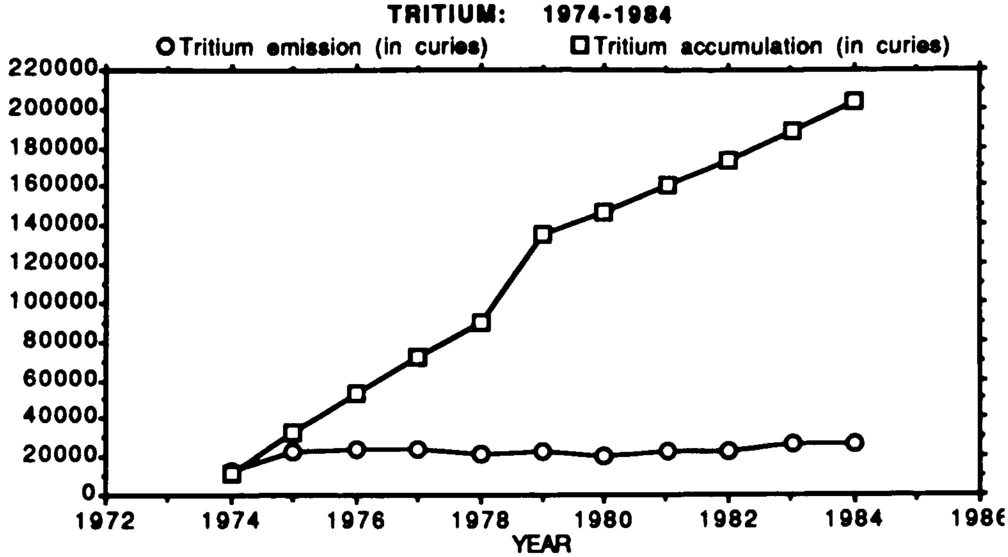
ELEMENT CHARACTERISTICS

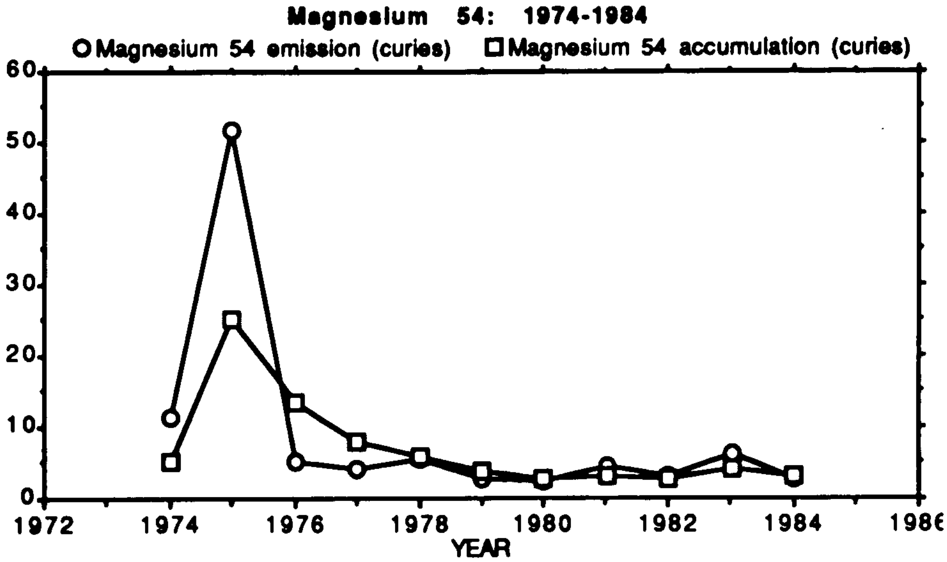
ELEMENT	SYMBOL	HALF-LIFE	ANNUAL DECAY RATE*
Tritium	H3b	12.3 yrs	5.5%
Chromium 51	Cr 51	27.7 days	100.0%
Magnesium 54	Mn 54	312.2 days	55.508%
Iron 59	Fe 59	44.6 days	100.0%
Cobalt 60	Co 60	5.3 yrs	12.22%
Krypton 85	Kr 85	10.3 yrs	6.5%
Krypton 85M	Kr 85M	4.4 hrs.	100.0 %
Strontium 89	Sr 89	50.5days	100.0%
Strontium 90	Sr 90	27.7 yrs	2.44%
Zirconium 95	Zr 95	64.0 days	97.73%
Niobium 95	Nb 95	35.2 days	100.0%
Silver 110M	Ag 110M	24.6 secs	100.0%
Iodine 131	I 131	8.04 days	100.0%
Xenon 133	Xe 133	5.29 days	100.0%
Cesium 134	Cs 134	2.26 yrs	26.4%
Xenon 135	Xe 135	9.17 hrs	100.0%
Cesium 137	Cs 137	29.7 yrs	2.3%
Barium 140	Ba 140	12.79 days	100.0%
Lanthanum 140	La 140	40.2 hrs	100.0%
Cerium 141	Ce 141	32.5 days	100.0%
Cerium 144	Ce 144	284.5 days	58.89%
Neptunium 239	Np 239	2.33 days	100.0%
Cesium 135	Cs 135	3 million yrs	0%
Plutonium 239	Pu 239	24,400 yrs.	.0029%

*=linear extrapolation

CHART 2.2

Emissions and Accumulation (in curies): 1974-1984





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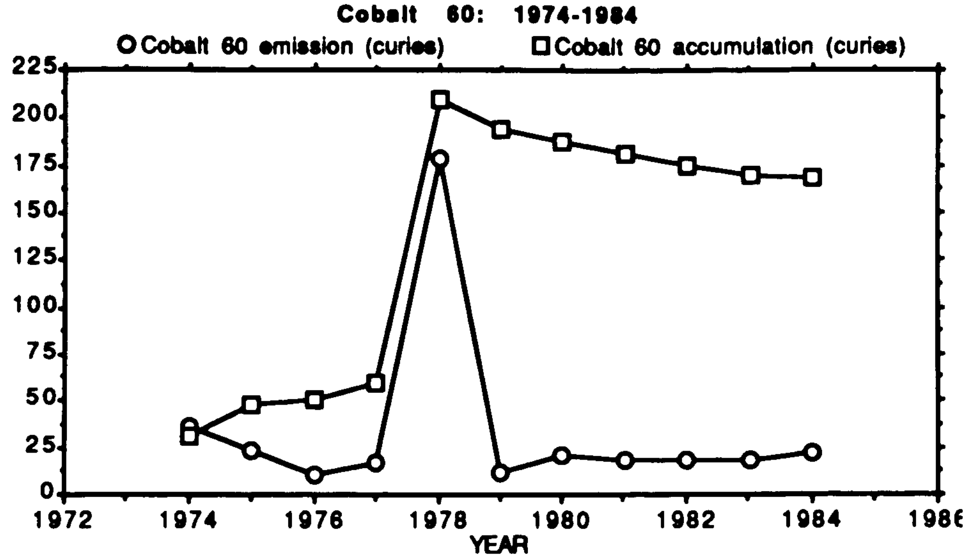

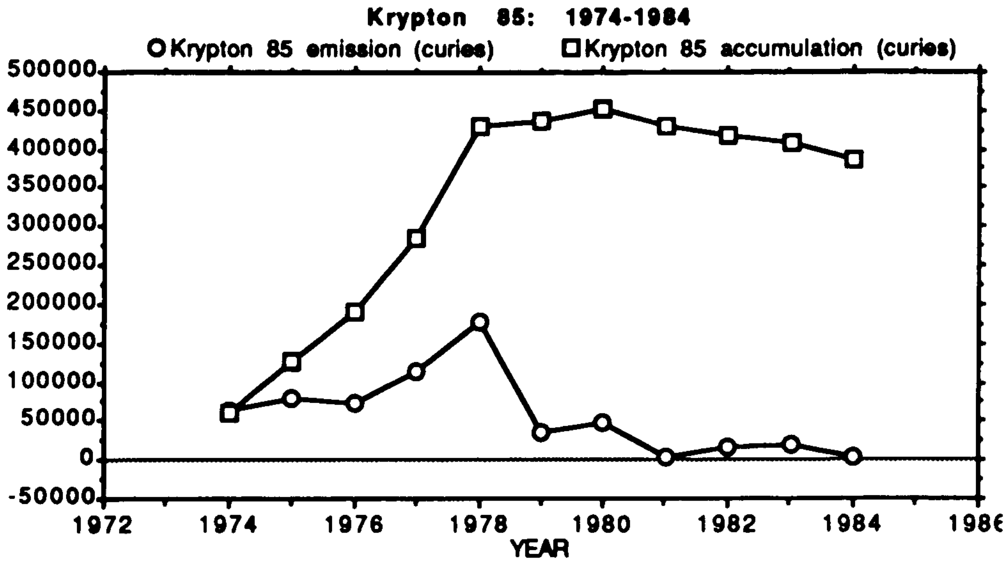

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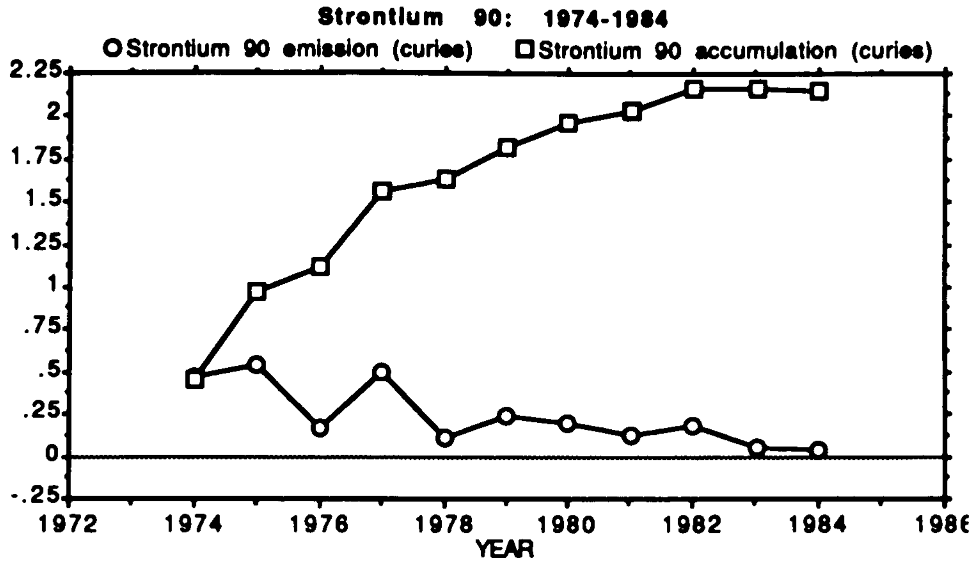

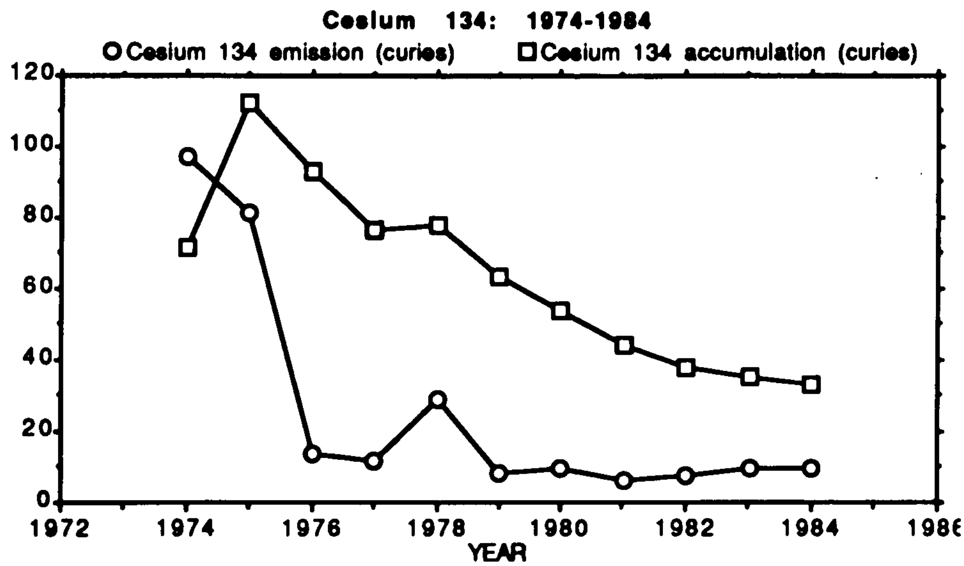

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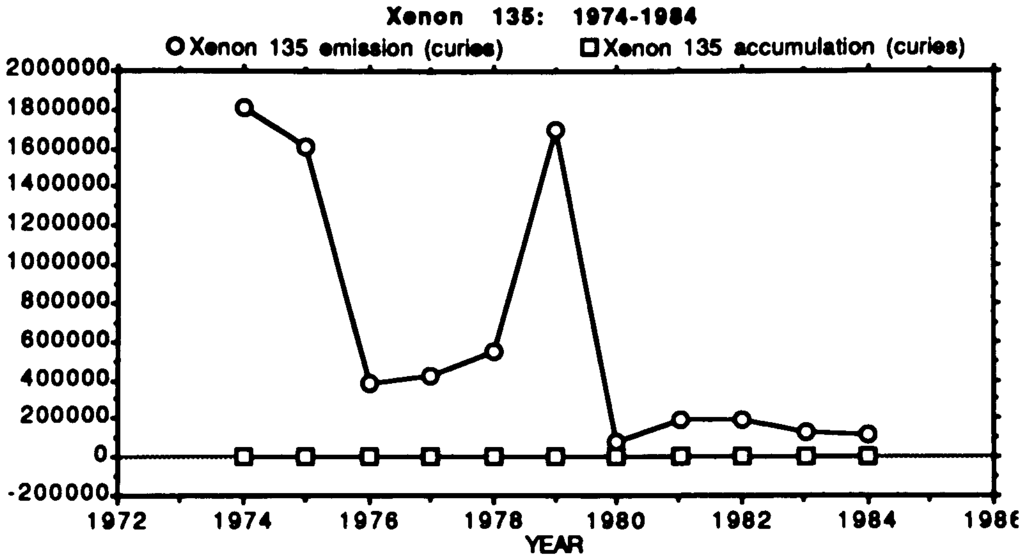

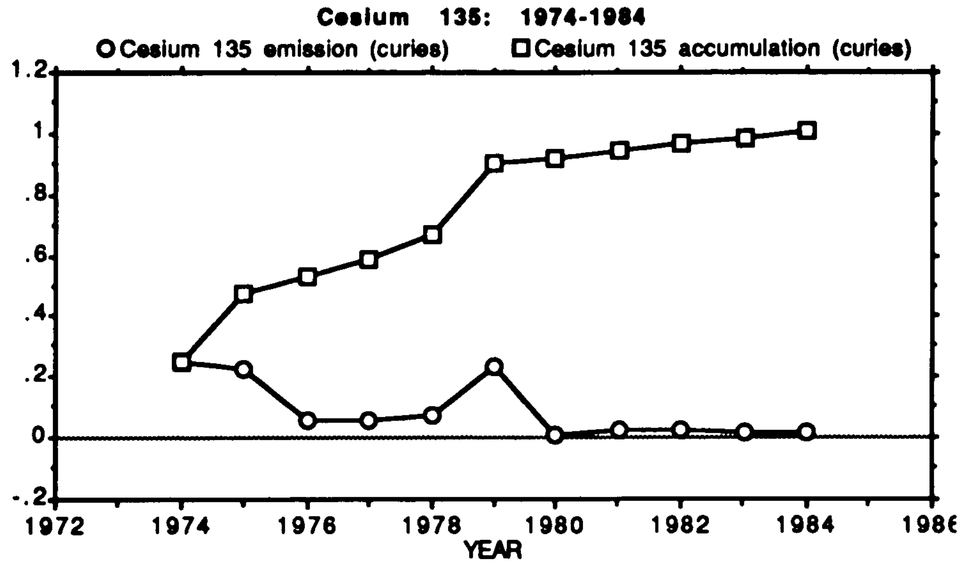

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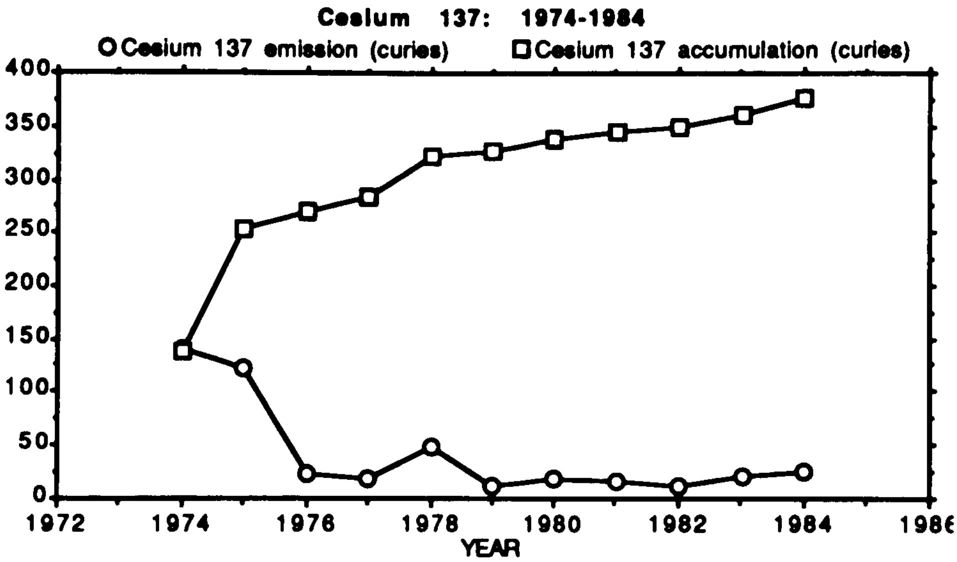

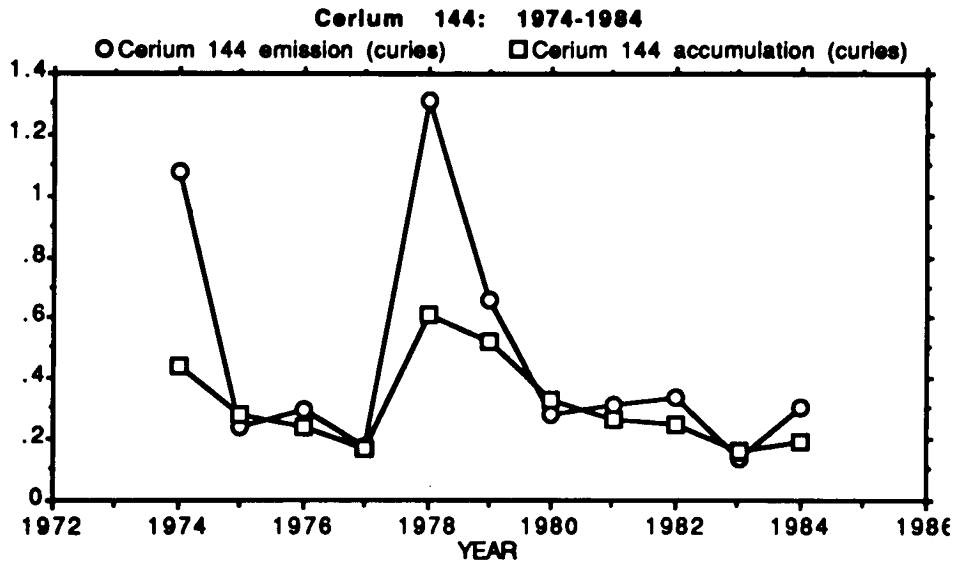

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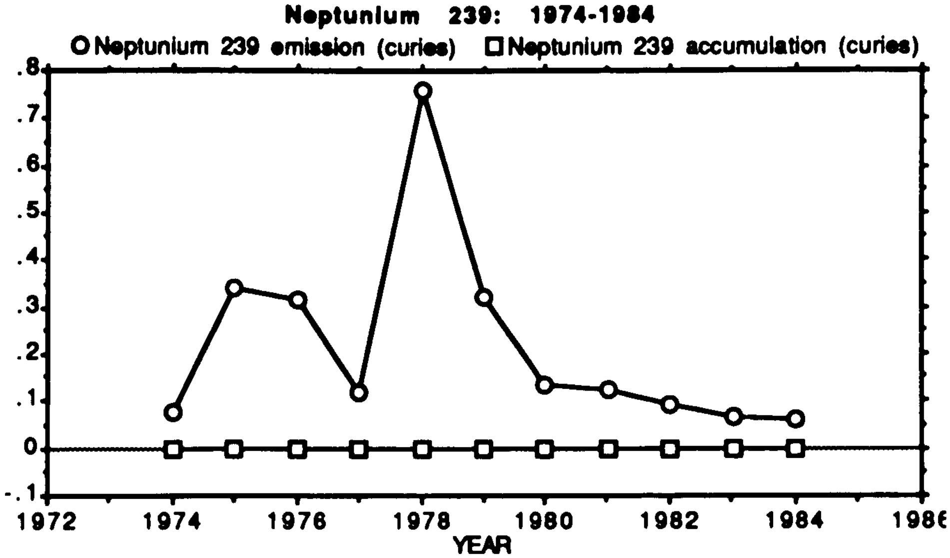

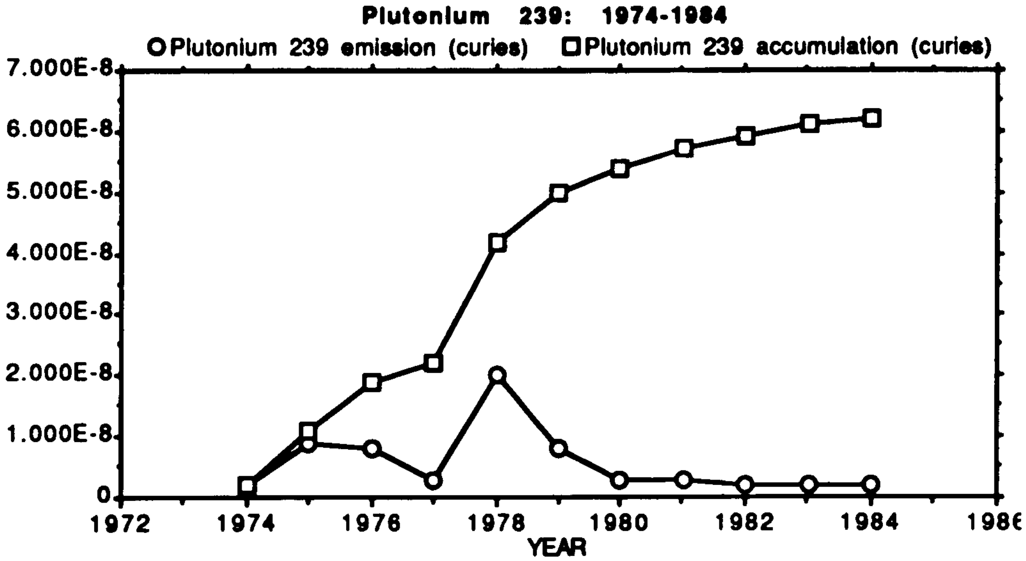

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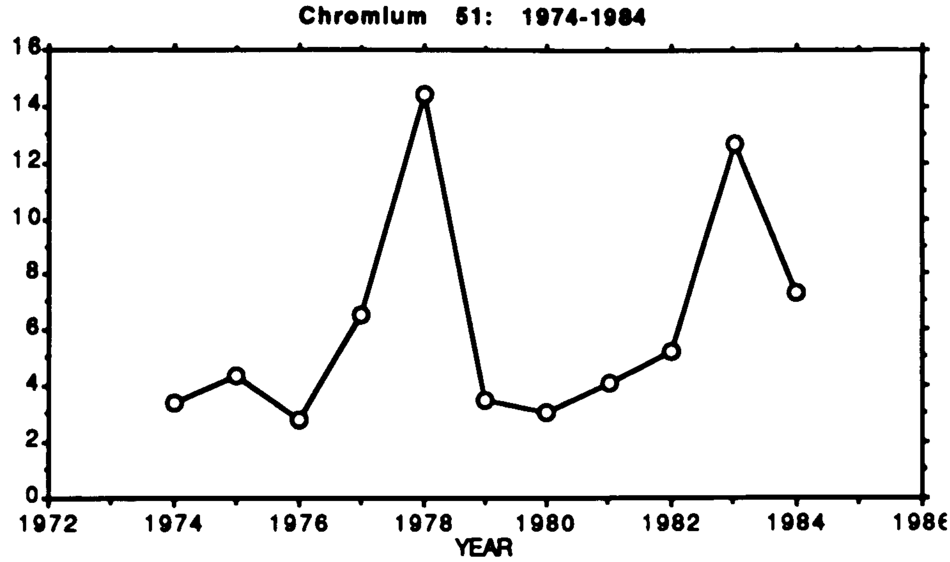

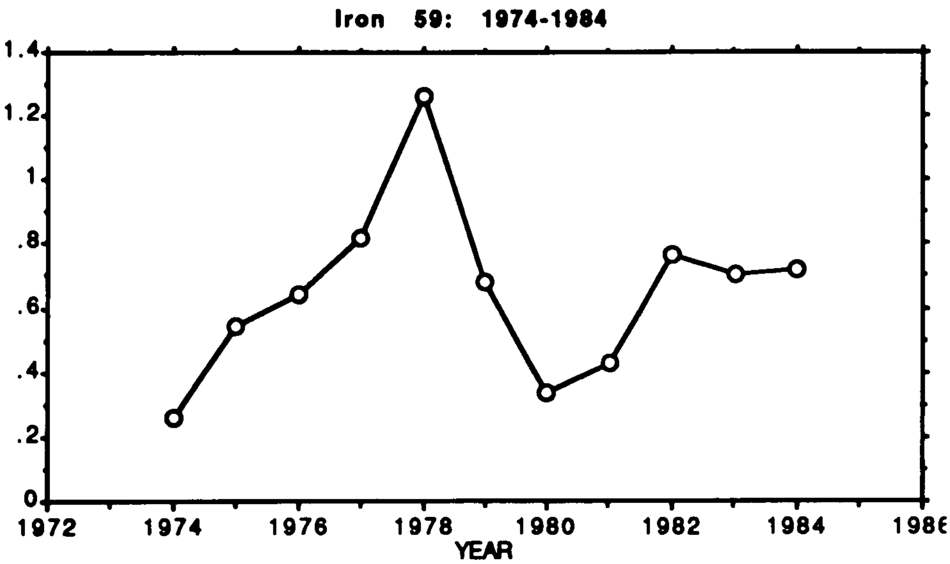

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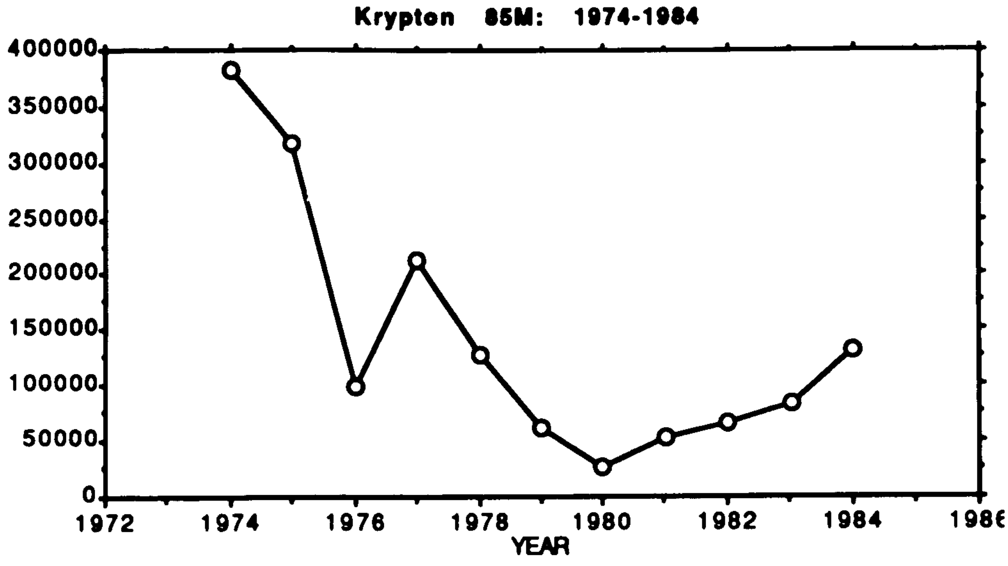

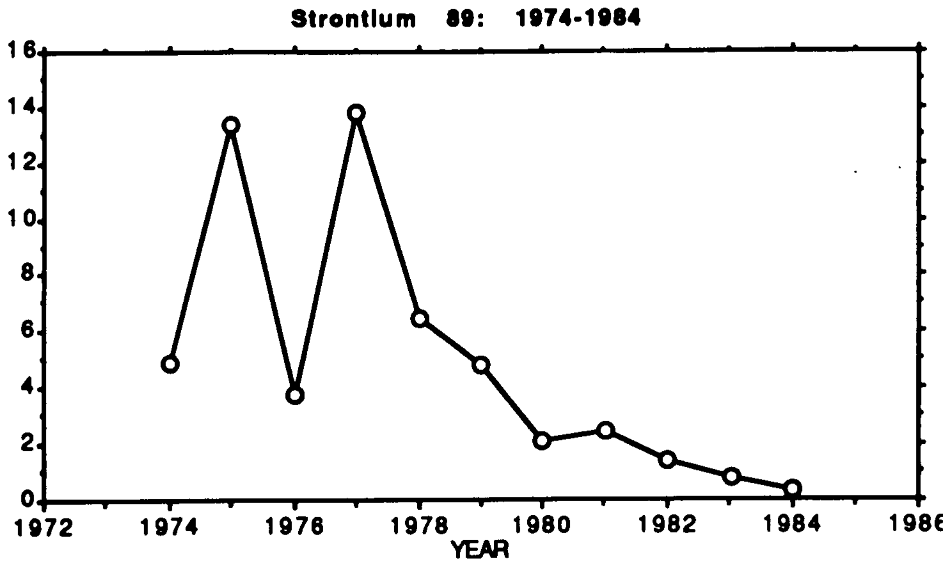

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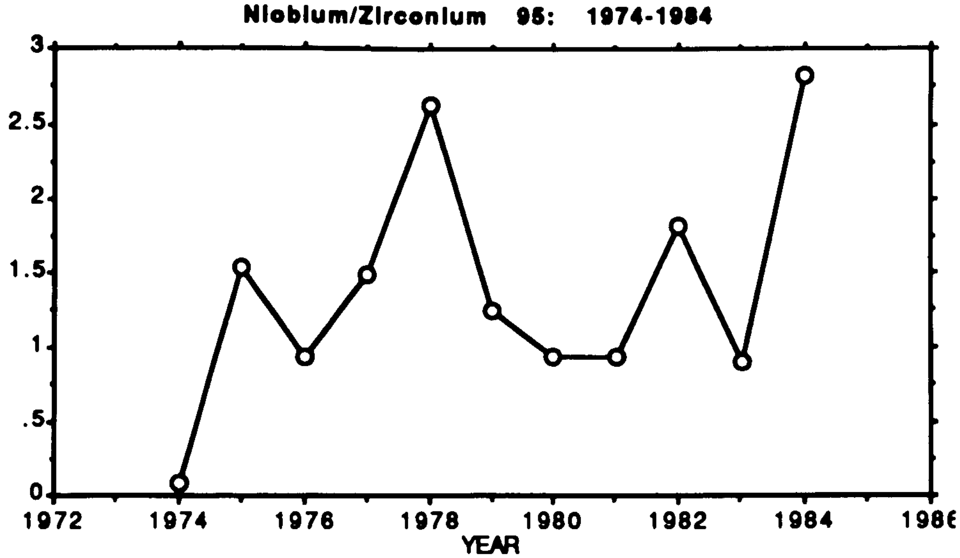

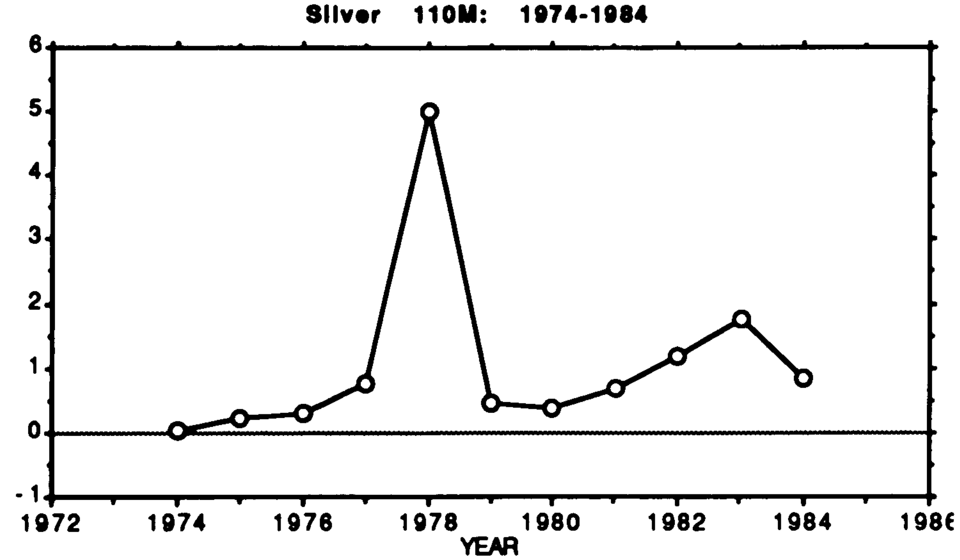

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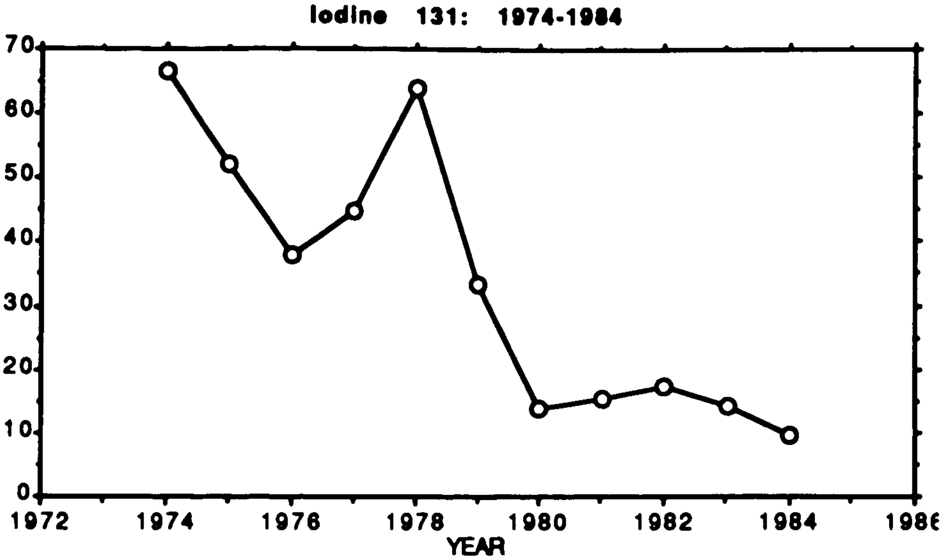

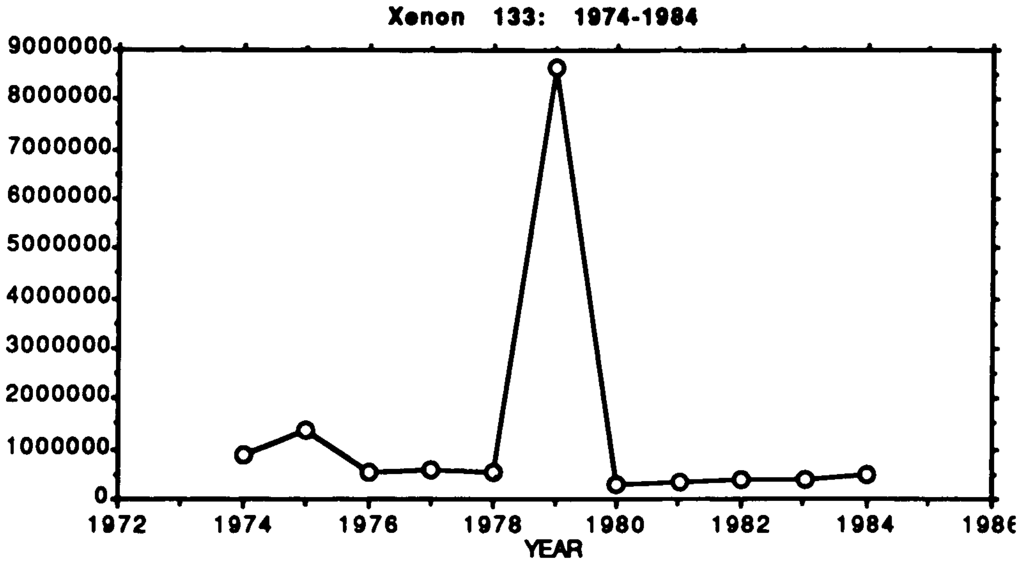

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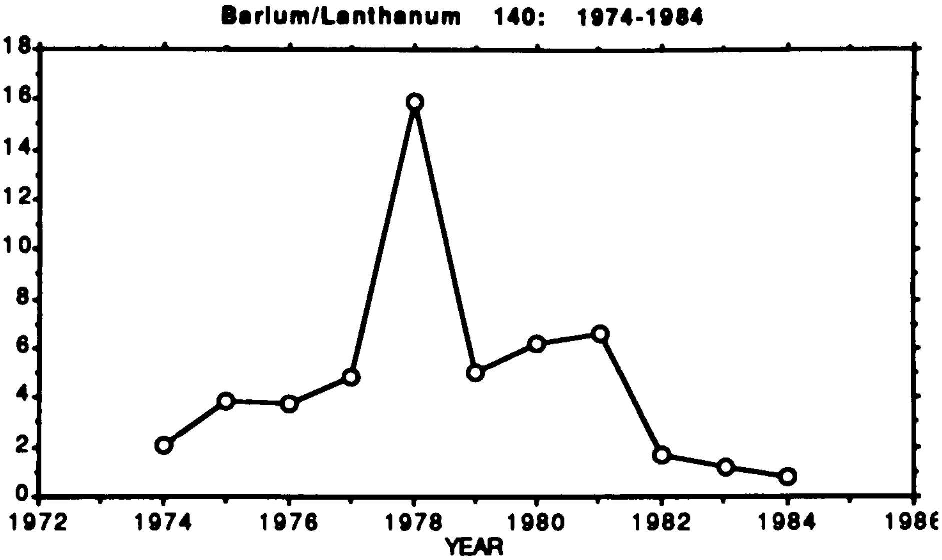
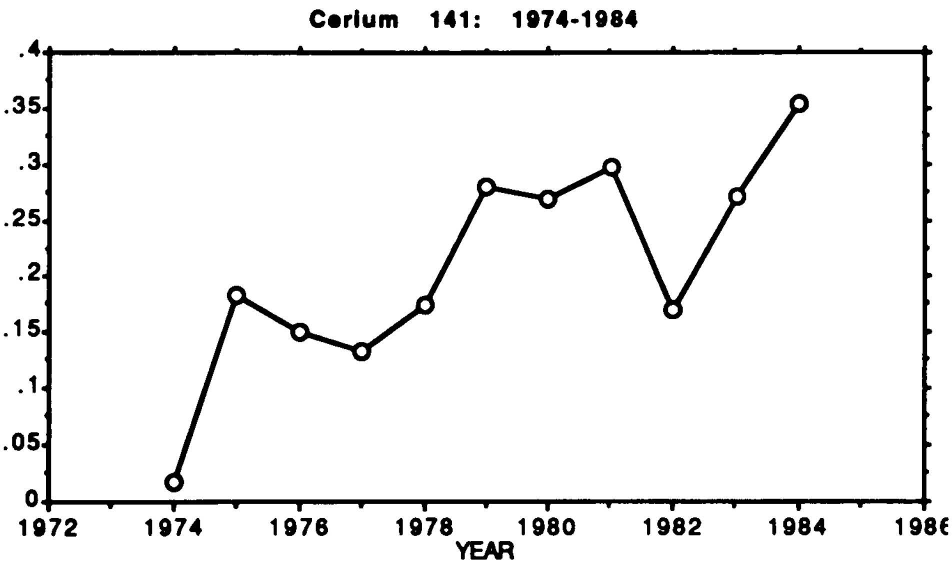
<u>Emissions and Accumulation (in curies): 1974-1984</u>





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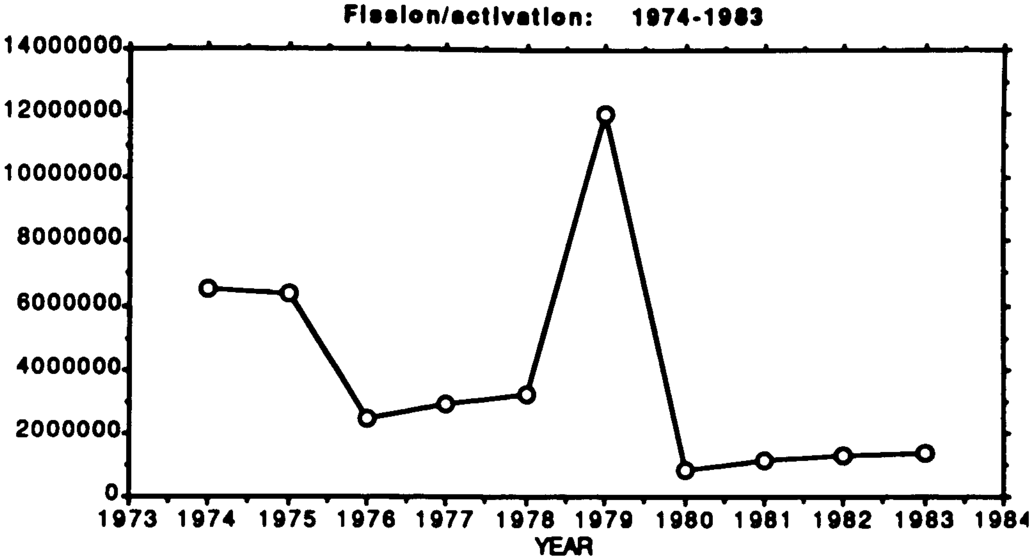

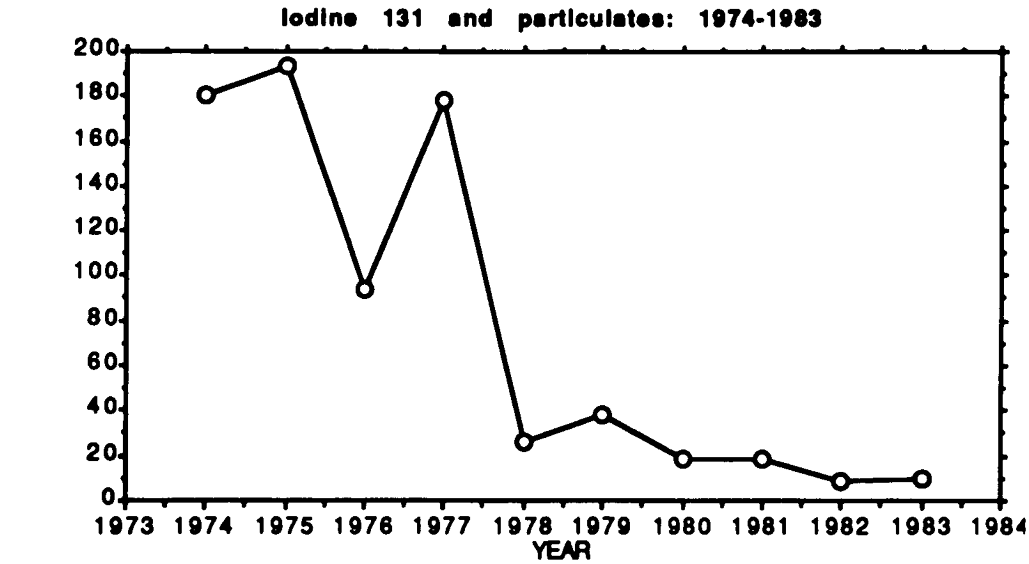

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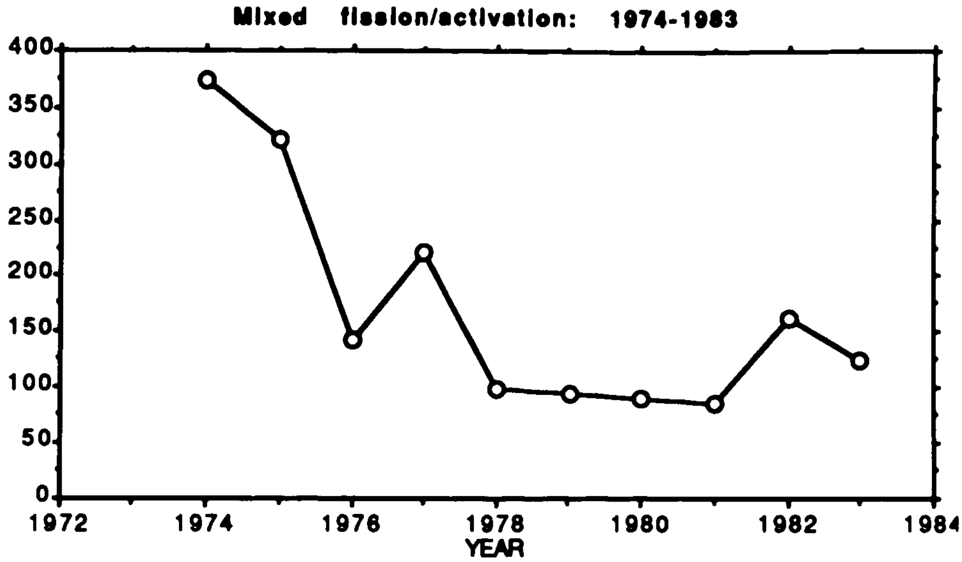
Emissions and Accumulation (in curies): 1974-1984



CHAPTER III

THEORETICAL ESSAY ON REGULATION

What would explain the behavior of a regulated monopolist, as is the case for the owners of each plant in the nuclear power industry, as to the release of radioactive isotopes into the environment? In order to answer that question, a review of theoretical positions on the regulated firm must be done. The choice, however, of which theoretical framework to use in analyzing the behavior of a regulated firm within a market society is made less easy by the many competing offerings within the body of economic science. This essay will consider two, those of the neoclassical and institutional economists' positions on regulation and methodology; will review the Averch-Johnson (A-J) effect, a position which is accepted by both viewpoints; will contain a discussion on externalities, and will conclude with a brief behavioral perspective on the firm. However, far too often the historical development of modern economic models, theories, and methodologies is submerged and forgotten in our everyday usage of those same models, theories, and methodologies. This essay will also consider that set of issues.

Theoretical and applied treatises on the behavior of firms are replete within the economics profession. From the atomistic world of business within Adam Smith's An Inquiry into the Nature and Causes of the Wealth of Nations to Joan Robinson's The Economics of Imperfect Competition, to more modern presentations such as Harvey Averch and Leyland Johnson's, "Behavior of the Firm Under Regulatory Constraint", in The American Economic Review, economists have been attempting to theorize and explain the behavior of firms.[1]

Theories of the firm tend to focus on their pursuit of profit, their choice of price and output, and the impact of the market structure on those choices. Within the theories of the firm is a special case, that of the regulated monopoly. Theories of the regulated monopoly tend to focus on how best to replicate or approximate the competitive results of price, output, and profitability (i.e., produce where MC=ATC=P) within the regulated environment. The concern is that the impact of the regulation should be such that the "public interest" is served.

> To some, P=MC is a pillar of welfare economics and the foundation for rational public policy; to others it is largely irrelevant. At the base of the controversy remain a number of important conditions that have to be satisfied before the concept can be convincingly shown to produce an optimal

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[1]Harvey Averch and Leland L. Johnson, "Behavior of the Firm Under Regulatory Constraint," The American Economic Review 52, no. 5 (December 1962): 1052-1069; Joan Robinson, The Economics of Imperfect Competition (London: Macmillan Co. Ltd., 1934); Adam Smith, The Wealth of Nations (Harmondsworth, Middlesex, England: Penquin Books, Ltd., 1982).

> outcome. Acceptance of the theoretical level requires an admission that the following conditions have been satisfied. First, all externalities pertaining to the service must be reflected in P=MC; second, the current distribution of income must be acceptable; and, third, deviations from P=MC elsewhere in the economy must not require compensating adjustments in the utility sector (that is, there must be no second-best problem).[2]

Much of the theoretical work on firms has come from industry studies. These studies have been used to support or to refute existing theoretical positions; they have also been used to create new theoretical positions. What those studies have had in common, however, was the historical framework within which each industry was analyzed. The lattice of analysis may have purported either a universalist, a time specific, or even a systemic macroeconomic historical approach to be the most appropriate. The universalist approach has been most often used by neoclassicists; the time specific and the systemic by the institutionalists.

An industry study on commercial nuclear utilities must be structured to include those institutions which most affect the decisions of each firm in the industry and must be framed to include the important legislative and political histories of regulation which have impacted each firm and the industry as a whole.

It is clear to this writer that while the neoclassical paradigm and its usage of the formalist method provides an extremely useful set of tools for analysis, only by the incorporation of the institutional

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[2]Harry M. Trebing, "Realism and Relevance in Public Utility Regulation," Journal of Economic Issues 8, no. 2 (June 1974): 214-215.

method into the formalist will one be provided the level of analysis and interpretation necessary for the review of the nuclear power industry. The fact remains that nuclear power in the United States is a heavily regulated industry; it is regulated by very strongly ingrained institutions at both the federal and state level and that the impact of these entities may not be fully explained by the use of just the formalist approach.

Modern economics owes a great debt to both the neoclassical and the institutional economists. However, the use of the word institution is often misunderstood, misdefined, and miscategorized. Frequent usage of institution within this essay necessitates a lucid definition within which ambiguities and misconceptions can perhaps be minimized. An institution is often thought by people to be a physical entity, oftentimes seen as an edificial embodiment. This popular conception can be seen in the everyday use of terms such as the White House, Congress, or the like which give the subsequent attribution of characteristics to those institutions. Federal, State and local government agencies also fit this popular conception of an institution. The NRC, the AEC and the respective state PUC, three major regulatory institutions studied within this dissertation, may also be seen this way.

However, an institution is much more than the physical structure. An institution may be an idea, "a mental construct"[3], a way of

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[3]Walter C. Neale, "Institutions," Journal of Economic Issues XXI, no. 3 (September 1987): 1184.

thinking, or an inviolate conclusion universally, or at least widely, shared by society. Paradigms within economics, economic models, economic methods, humanistic beliefs, scientific or political dogma, and a host of others can be considered institutions under this broadened definition. Monopoly, regulated monopoly, the 'fair' rate of return, acceptable levels of radioactive emissions, methods and thought processes of the main regulatory bodies, and the public's acceptance (or indifferent acquiescence to) or understanding of same can be, or can become, an institution. Walter Neale, for one, has suggested that,

> An institution is identified by three characteristics. First, there are a number of people doing. Second, there are rules giving the activities repetition, stability, predictable order. Third, there are folkviews.....explaining or justifying the activities and the rules.[4]

This expanded sense of an institution is appropriate for the three institutions (NRC,AEC, and PUC's) which have been studied here. The sense of doing in the above citation refers, in essence, to a market type arrangement, and the "doing" part to the fact that people are conducting economic activity. The sense also is that the marginalist maximization of utility may not be the motivator; but that people are maximizing something, or are doing something, a much vaguer and broader conception of economic activity.

Neale further noted that, "An institution does not stand alone. It fits into the system of institutions, so that changing the rules of

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[4]Neale., 1182.

one institution means that the rules of other institutions must adapt and so change."[5] In terms of whether this interconnectedness provides enhanced analytic power, Neale stated that this "illustrates how using institutions as the unit of analysis makes a difference" as institutions and their rules of behavior do not stand in isolation.[6]

Paul Bush further extended the institutional framework to include the consideration that,

> "Society" may be thought of as a set of institutional systems. An "institutional system" in turn, may be thought of as a set of institutions. And an "institution" may be defined as *a set of socially prescribed patterns of correlated behavior.* [7]

Without the use of this pyramid of nested relationships within the analysis, much that is going on may be missed or be left unexplained. The interconnectedness within the institutional approach is invaluable.

It is perhaps ironic (and some would say, unfortunate) that as the U.S. economic and political system resorted to the use of ever increasing Federal agencies (institutions) to deal with the set of problems that manifested during the 1930's, the institutional economists and their methods began their decline. Clearly, macroeconomic conditions during the 1930's predominated political

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[5]Neale, 1195.

[6]Neale, 1190.

[7]Paul D. Bush, "The Theory of Institutional Change," Journal of Economic Issues XXI, no. 3 (September 1987): 1076.

and economic discussions. As the world then emerged from World War II, and the economics profession replaced the Classical macroeconomic system with the Keynesian one, the microeconomic analysis of the institutionalists began to wither. The increased availability of much more accurate National Income Account data, coupled with the microeconomic research into the investment and consumption functions of Keynes, drew the economics profession away from the institutionalist methodology. While the legislative creation of governmental entities continued unabated into the late 1980's, the methods developed by the institutionalists were no longer used by a majority of economists. Concurrent with this was the proliferation of the formalist method, espoused by Milton Friedman and others, which drew more and more members of the profession farther away. When one then subsequently includes the James Buchanan contribution that individuals within the government maximize their own utility rather than the collective public utility, institutional economics was unable to compete for academic attention.

Today, society and the economics profession is focused upon deregulation and on market oriented solutions to world-wide problems. It may therefore be unwise for this writer to develop and attempt to resuscitate and reintegrate the institutional methodology into the neoclassical and formalist camp.

However, as a preface to the development of my model that derives from the following essay and my subsequent interpretations of the information generated by the statistical tests, I do consider it necessary to consider these two different approaches to theory and to model building. My task would have been unnecessary were I to accept the formalist approach, as, in the words of T. Kuhn, "[W]hen a scientist can take a paradigm for granted, he [sic] need no longer, in his major works, attempt to build the field anew, starting from first principles and justifying the use of each concept introduced."[8]

This non-acceptance of the formalist approach by other economists has led some to a different one, and within that alternative approach they have suggested that:

> [M]uch of the criticism levelled by institutional economists at their neoclassical counterparts has related to the assumptions which were made which support their theory and their empirical research....the methodology of the neoclassical models builds from restrictive assumptions regarding structural and institutional change, the objective functions to be maximized, the distribution of income, and the welfare standards to be imposed. The result is a set of constraints that preclude scholarly consideration of alternative social arrangements.[9]

This criticism has been repaid in kind, as the rise to prominence (within the United States, at least) of the neoclassical, positivistic, constrained maximization approach over the Institutionalist and Marxian conceptions after 1945 is well known and is perhaps best

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[8]Thomas S. Kuhn, The Structure of Scientific Revolutions (Chicago: The University of Chicago Press, 1962), 19-20.

[9]Harry M. Trebing, "Regulation of Industry: An Institutional Approach," Journal of Economic Issues 21, no. 4 (December 1987): 1721.

personified by Milton Friedman's 1953 essay.[10] Wilber and Harrison have commented on that essay, by stating that:

> [M]odern economics has been given its most explicit espousal of logical positivism in the works of I.M.D. Little and especially in Milton Friedman's *Essays in Positive Economics* . In search of a legitimate methodology, Friedman's work can be seen as an attempt to counter the charges leveled at standard economics by both institutionalists and Marxists. Principally, these charges centered on the neoclassical theory of the firm. The institutionalists claimed that standard assumptions concerning the behavior of entrepreneurs were contradicted by empirical evidence and therefore unrealistic. Friedman's now classic chapter 1 of his *Essays* was an attempt to show the irrelevance of this charge and thereby restructure economic theory into a logical positivist form.[11]

Discussions and criticisms of that particular approach have been numerous.[12] Philip Mirowski, in particular, noted that:

> [A]lthough many institutionalist economists maintained a lively interest in philososphical issues, they tended to get sidetracked into such controversies as the meaning of Milton Friedman's essay on the "methododlogy of positive economics" (an article so incoherent that it could support

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[10]Milton Friedman, "The Methodology of Positive Economics," chap. in Essays in Positive Economics (Chicago: The University of Chicago Press, 1953), 3-43.

[11]Charles K. Wilber and Robert S. Harrison, "The Methodological Basis of Institutional Economics: Pattern Model, Storytelling, and Holism," Journal of Economic Issues 12, no. 1 (March 1978): 65-66.

[12]See, for example, Bruce Caldwell, Beyond Positivism (London: George Allen & Unwin, 1982) and Donald N. McCloskey, The Rhetoric of Economics (Madison, Wi.: University of Wisconsin Press, 1985).

any reading), or else into behavioralism of a mechanistic cast, which neutralized all hermeneutic problems of interpretation.[13]

While the basic assumptions of the neoclassical paradigm need not be reviewed in great detail here, those of the institutionalists, as they are not as widely known, should be. Walter Neale has stated the differences between the two succintly as:

> [S]tandard economists regard economic behavior as universal over time and place. Institutional economists regard it as specific to time and place. The standard economist holds that economic behavior is maximizing (and vice-versa). The institutional economist thinks of the economy as the ways in which a society provisions itself. The standard economist derives his explanations in large part from the assumed motive of all individuals: to wit, maximizing something good, like profit or satisfaction. The institutionalist focuses upon the rules and opportunities for action, simply assuming that each individual is always moved by one or another purpose.[14]

These fundamental differences between neoclassical economists and practicioners of the formalist approach and the institutionalists has led to very diverse approaches to analysis and analytic method. The delineation between these two camps within the profession is not as distinct as each side would have you believe since both sides do use the methods of the other. The most succinct encapsulation of this divergence is the fundamental distinction between the use of

[13]Philip Mirowski, "The Philosophical Bases of Institutionalist Economics," Journal of Economic Issues 21, no. 3 (September 1987): 1032.

[14]Neale, 1180-1181.

deduction and induction, and the subsequent separation of the deductive versus the inductive method. This ongoing debate, regrettably, has degenerated into a positive versus normative, facts versus non-facts, analytic versus interpretive, and finally into scientific versus non-scientific. This is perhaps best explained by "[B]ut most economists have become positivists, that is, they see empirical verification as the key to economic science. Institutionalists, however, still see much of modern economics as incapable of explaining the real world. An analysis of why is necessary."[15]

Wilber and Harrison, in a forthright and critical article on this topic noted that:

> [C]ontemporary philosophy of science has been drawn upon to understand institutionalist methodology and how it differs from that of standard economics. The principal task of modern scientists has been to understand, interpret, and explain the reality which surrounds them. However unified this purpose may appear, the question of how to go about this process of explanation has been the source of great controversy. At the heart of it is the issue that modern sciences are differentiated only by differences in subject matter, not in method. Formalism, including logical positivism and a priori rationalism, expresses this view. Most of standard economics falls into this category. Holism, including pattern models and storytelling, expresses the belief that a change in subject matter requires a change in method. Institutional economics, radical political economy, and Marxism fall into this category.[16]

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[15]Wilber and Harrison, 64.

The preoccupation with prediction, with universality, and with falsifiability for those followers of the Friedman approach, has led two economists to state that:

> [D]ue to the ahistorical and universal nature of positivists' general laws, there is a *logical necessity* that explanation and prediction be symmetrical. Moreover, it is critical to the vitality of this symmetric relation that tentatively held hypotheses, in practice, be potentially falsifiable, but as yet nonfalsified. Indeed, explanation is not considered adequate unless it could have served as the basis of prediction.[17]

These same two economists, when they discussed what they perceived to be the enhanced methods and approaches by the institutionalists, stated that for them:

> [T]he primacy of subject matter over method, then, is a crucial element of holistic methodology....The holist believes in the primacy of subject matter; he believes that whatever else a method may be, it should at least be adequate to the particular thing described and should not distort it....opposing this view are the logical positivists. They assert that whatever else method is, it should first and foremost be "scientific".[18]

Institutionalist models have continued to maintain the thought that, "[S]ince at least Veblen's time, institutionalists have recognized that formal methods-whether of the *a priori* rationalist

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[16]Wilber and Harrison, 62.

[17]Wilber and Harrison, 65.

[18]Wilber and Harrison, 81-82.

type or of the logical positivist covering law model-fail to explain the nature of social reality."[19]

The nature of this reality requires the interconnectedness and completeness of the institutionalist approach as:

> [T]hese characteristics of institutionalism-holistic, systemic, evolutionary-combined with the appreciation for the centrality of power and conflict and the recognition of the importance of nonrational human behavior, differentiate institutionalism from standard economics. Formal models simply cannot handle the range of variables, the specificity of institutions, and the nongenerality of behavior.[20]

Formalism has produced "models that are capable of yielding lawlike statements. These formal laws are not empirical generalizations but are logical deductions that make *a priori* statements about necessary connections between abstract entities...."[21].

The start to the building of a formalist model can be perhaps best summed up by the following:

> [F]ormalism is a method that consists of a formal system of logical relationships abstracted from any empirical content it might have in the real world. For example, the theory of the firm in standard economics deals with the behavior of the firm involved in *any* process of production, using *any* inputs at *any* set of relative prices with *any*

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[19]Wilber and Harrison, 71.

[20]Wilber and Harrison, 72.

[21]Wilber and Harrison, 63-64.

technology. It is characterized by the use of mathematics (at least implicitly) and by the development of an axiomatic, deductive structure.[22]

Institutionalism, on the other hand, has produced models which were:

> [F]rom the viewpoint of the holist the primary function of laws and theories (within the pattern model) is to provide understanding; from the viewpoint of the logical positivist (within the formal model), it is to allow predictions. Within the context of the pattern model, the pattern which provides the explanation does not uniquely determine the parts. Thus, knowledge of the whole pattern and of some of the parts does not necessarily enable the holist to predict any or all of the unknown parts.[23]

The use of either philosophical approach, or method, or model building, should, over time, be reduced to a preferred approach. When we specifically consider the regulation of enterprises or the regulation of an industry as the area of focus within either approach, we should hope to see a synthesis and a convergence from the empirical studies done.

For the institutionalist model of regulation or theory of regulation, an ever richer data base should have afforded the institutional economist the opportunity to expand his pattern model in a way which would incorporate new events and new information.

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[22]Wilber and Harrison, 62.

[23]Wilber and Harrison, 77-78.

Under the Friedman/formalist/rationalist approach, new empirical information should have either affirmed previously held theoretical positions or falsified them. This continuing process of test/affirm and test/falsify should also have resulted in a theoretical convergence. For, as Thomas Kuhn noted, "[W]hat is surprising, and perhaps also unique in its degree to the fields we call science, is that such initial divergences should ever largely disappear. For they do disappear to a very considerable extent and then apparently once and for all."[24]

A review, however, of the results of both the institutionalist and the formalist approach over the past 30 years reveals that neither result has occurred. Institutionalist economists still conduct industry studies which remain specific to only those industries, and which do not afford the opportunity for falsification. Thus, no discernible theoretical pattern has emerged from the institutionalists which has been accepted by a majority of economists. The need to bear in mind the specific problem, the specific industry, and the specific point in time of the analysis has obviated the emergence of a unified theory of regulation.

The formalist approach, which may be purported to be accepted and followed by a majority of economists, has too yet failed to reveal a singular theoretical approach to regulation. In that vein, Trebing noted that:

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[24]Kuhn, 17.

> [N]eoclassical efforts to explain regulatory behavior have essentially built upon the earlier work of historical revisionists such as Marver Bernstein and Gabriel Kolko. Bernstein proposed a regulatory life cycle for commissions that progressed from youthful vigor to old age, at which time the infirm agencies could easily be captured by industry interests. Kolko took a much more critical stand, arguing that commissions were, in fact, creations of the industry seeking to be regulated.[25]

In that regard, George Stigler noted that "[T]wo main alternative views of the regulation of industry are widely held. The first is that regulation is instituted primarily for the protection and benefit of the public....The second view is that essentially that the political process defies rational explanation...."[26]

The lack of convergence within standard economics, despite the formalist approach, has led that group into a three tiered analytic framework. Within standard economics, although the assumptions remain consistent, and the framework of analysis is the constrained maximization approach, and despite similar empirical analyses, Trebing again noted that,

> [T]here is no single neoclassical model of regulation that encompasses the rationale for regulation, the proper analytical tools to apply in implementing regulation, and the options for improving regulatory performance. Rather, there are three separate lines of neoclassical thought that deal with economic and social regulation. The first focuses on dimensions of market failure. The second focuses on

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[25]Trebing, "Regulation of Industry," 1718.

[26]George Stigler, "The Theory of Economic Regulation," The Bell Journal of Economics and Management Science 2 (Spring 1971): 1.

> theories of regulatory behavior. The third attempts to integrate regulation into an overall interest-group theory of government.[27]

If there has been any convergence of opinion within the two approaches, it may be that there has been a normative majority conclusion drawn within each camp concerning the efficacy and need for regulation. The institutionalists beleieve that regulation is and has been a necessity, while the neoclassicals and the formalists typically prefer that market oriented solutions be effected. A unified theoretical consensus has not yet developed.

From Veblen onward, a review of the institutional appproach has, however, revealed consistencies. These consistencies, Trebing noted, are "that the institutionalist model is built upon five major postulates"[28] which are:

> [F]irst, the need for government intervention exists....Second, regulation must endeavor to promote public interest or societal values that cannot be derived exclusively from monetary or market-oriented measures.... Third, when properly applied, regulation seeks to promote higher levels of efficiency and greater individual choice....Fourth, strategies of actors in the regulatory process can have a significant impact on the outcome.....Fifth, since the evolutionary process makes any set of goals and methods provisional and intermediary, it follows that the form of regulatory intervention may change over time.[29]

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[27]Trebing, "Regulation of Industry," 1716.

[28]Trebing, "Regulation of Industry," 1714.

[29]Trebing, "Regulation of Industry," 1714-1715.

In either approach, each successive stage of the analysis has been preceeded by theoretical suppositions; those then lead to the development of the institutions and their rules of behavior; we then proceed to a stage of analyses of the rules and the institutions (does theory fit the reality, or vice-versa?); this is then followed by new theoretical suppositions and then new analysis is undertaken.

Major technological change within any of the stages causes complications which require reappraisal, reinterpretation, new empirical work, and then contemporaneous theorizing.

Wilber and Harrison concluded their discussion on the delineations between the two sides with criticisms of both approaches. Their argument stated:

> [H]owever, there are severe limitations to holism. First, because of their lack of precision, the use of holist concepts must be continually monitored by reference to observation, cases and examples. Holism separated from its empirical base easily becomes loose, uncontrolled speculation....A second problem is that the impreciseness and generality of holist concepts make any definitive verification of hypotheses impossible.[30]

They further commented that:

> ....the structure of holistic theories is concatenated (linked together) rather than hierarchical, as in formal theories........As such, a concatenated theory with its several independent sections and subsections provide a many-sided, complex picture of the subject matter. A hierarchical theory, in contrast, is always one-sided. It takes one set of relations, one structure, or a single process and abstracts

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[30]Wilber and Harrison, 83.

> it out of the coherent whole and subjects it to logical study.[31]

Wilbur and Harrison's criticism of the formalist method suggested that extreme rigor will in fact lead to stagnation, and that therefore, the need for a synthesis of approaches was now necessary. They stated that:

> [T]he precision and rigor that characterize formal theories are not unqualified virtues. If a school of thought....begins to overemphasize precision and rigor it will tend to fall into theoretical stagnation and preoccupation with logical and empirical detail....A central problem of any methodology is how to strike a balance between precision and rigor, on the one hand, and vagueness and suggestiveness, on the other, and how to relate the two so they synergize rather than cancel each other.[32]

There is one area where the two approaches do agree and almost converge and this concerns the Averch-Johnson (A-J) effect. In 1962, two theorists, Harvey Averch and Leyland Johnson argued that the rate base, rate of return rules on regulated monopolies could lead to increased capital expenditures by a monopolist and thus inefficient production would result. They argued as follows:

> [I]n judging the level of prices charged by firms for services subject to public control, government regulatory agencies commonly employ a "fair rate of return" criterion: After the firm subtracts its operating expenses from gross revenues, the remaining net revenue should be just

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[31]Wilber and Harrison, 80-81.

[32]Wilber and Harrison, 84.

> sufficient to compensate the firm for its investment in plant and equipment. If the rate of return, computed as the ratio of net revenue to the value of the plant and equipment (the rate base), is judged to be excessive, pressure is brought to bear on the firm to reduce prices. If the rate is considered to be too low, the firm is permitted to increase prices. [33]

Averch and Johnson went on to argue, (within a two factor isocost model employing capital and labor), that:

> if the rate of return allowed by the regulatory agency is greater than the cost of capital but is less than the rate of return that would be enjoyed by the firm were it free to maximize profit without regulatory constraint, then the firm will substitute capital for the other factor of production and produce where cost is not minimized.[34]

In that regard, Zajac noted that:

> [T]he Averch-Johnson model of the regulated firm is now well-known, as is the conclusion that a profit-maximizing firm, regulated on fair rate of return, "operates inefficiently in the sense that (social) cost is not minimized at the output it selects," and, that "the firm adjusts to the [regulatory] constraint by substituting capital for the cooperating factor [labor]....It [A-J effect] has also raised a fundamental issue: Regulation based on an objective of fair return may in fact be driving regulated firms to socially undesirable operations.[35]

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[33]Harvey Averch and Leland L. Johnson, "Behavior of the Firm Under Regulatory Constraint," <u>The American Economic Review</u> 52, no. 5 (December 1962): 1052.

[34]Averch and Johnson, 1053.

[35]E.E. Zajac, "A Geometric Treatment of Averch-Johnson's Behavior of the Firm Model," <u>The American Economic Review</u> 60, no. 1 (March 1970): 117.

This perhaps is what Averch and Johnson have been remembered for. However, they also considered the case of a firm under such a constraint producing at a loss in a secondary market where the ability to do this was provided by the rate of return given in the regulated sector. They also provided additional critiques and extensions on their original hypothesis.

Over time other writers joined the discussion and extended, clarified, and/or criticized their theory. Takayama [36], Stein and Borts[37], Baumol and Klevorick[38], Meyer[39] and Zajac[40] represented examples of extensions and clarifications by economists on the original A-J paper of 1962. Takayama lightly criticized Averch and Johnson for confusion in their paper about movement along a curve and a shift of a curve. In his reformulation of Averch and Johnson, he found "that the new reformulation will give the same answer as

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[36]Akira Takayama, "Behavior of the Firm Under Regulatory Constraint," The American Economic Review 59, no. 3 (June 1969): 255.

[37]Jerome L. Stein and George H. Borts, "Behavior of the Firm Under Regulatory Constraint," The American Economic Review 62, no. 5 (December 1972): 970.

[38]William J. Baumol and Alvin K. Klevorick, "Input Choices and Rate-of-Return Regulation: An Overview of the Discussion," The Bell Journal of Economics and Management Science 1, no. 3 (Autumn 1970): 162-190.

[39]Robert A. Meyer, "Regulated Monopoly Under Uncertainty", Southern Economic Journal 45, no. 4 (April 1979): 1121-1129.

[40]Zajac, "A Geometric Treatment....", 117.

Averch-Johnson, namely that a firm will tend to invest more with the introduction of an active constraint".[41] Stein and Borts extended the Averch-Johnson analysis to show that "the Averch Johnson conclusions can be explained on the basis of the traditional and powerful theory of the firm which uses the Viner-Wong envelope".[42]

Baumol and Klevorick noted, "As a contribution to the theory of regulation the work of Averch and Johnson represents a significant landmark.....This still leaves open, however, the issue of the significance of the A-J results for policymaking".[43]

Robert A. Meyer noted very strongly, (and this can be used as a criticism of many economic models), that:

> ....in a general risk aversion formulation for the single output firm one cannot establish the well-known A-J effect without much stronger assumptions than appear reasonable a priori, provided one requires the regulatory constraint is always met. These results sound the death knell of comparative static analyses of changes in regulatory policy as studied by Takayama and Baumol and Klevorick.[44]

One can certainly doubt whether this prognostication has been borne out. Statements about the assumptions relative to the A-J hypothesis include:

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[41]Takayama, 255.

[42]Stein and Borts, 970.

[43]Baumol and Klevorick, 188.

[44]Meyer, 1121-1122.

> ....the Averch-Johnson analysis also rests on the usual assumptions of the classic theory of the firm-perfect knowledge of markets and production, profit maximization, and operation at static equilibrium. In addition, the analysis implicitly assumes a behavior of both the firm and the regulators which will allow the firm to operate at the K max point. Since, to some extent, these assumptions are violated in the real world, it is instructive to consider situations where some of them do not hold. Perhaps most critical are the assumptions of a static equilibrium and the assumption that the profit maximizing firm will have enough information to operate at the K max point. For example, good engineering may allow the firm to operate with close to minimum cost technology. On the other hand, demand information is generally difficult and expensive to obtain and uncertain, thereby making difficult the determination of the shape of the profit hill.[45]

Johnson, in 1973, did a reassessment of the original paper, where he stated:

> [M]ajor assumptions of the model are that (a) the firm seeks to maximize profit, (b) the market cost of capital is constant (c) the allowable or "fair" rate of return exceeds the cost of capital, and (d) no regulatory lag exists. Under these assumptions, the model leads to conclusions that the capital/labor ratio is greater than that which would minimize cost at the level of output selected by the firm....[46]

Zajac extended the A-J model to consider not only the substitution of capital for labor, but to explain how a firm, even if constrained, might still produce at minimum cost, and thus social inefficiency

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[45]Zajac, "A Geometric Treatment....", 121.

[46]Leyland L. Johnson, "Behavior of the Firm Under Regulatory Constraint: A Reassessment," The American Economic Review 63, no. 2 (May 1973): 90.

would be avoided. In this regard, he said, "With regulatory lag taken into account, the profit maximizing firm's best strategy is not clear; it may be to operate with minimum-cost inputs rather than the overly-capital intensive inputs implied by the A-J effect."[47]

When Zajac also considered the impact of regulatory lag, he concluded that the firm might be more prone to maximize the return on stockholder's equity rather than the return to capital, as he stated that if:

> profit maximization is replaced by maximization of stockholder's rate of return (return to equity capital), another and perhaps more tenable model of management's objective. Here it is found that, without further assumptions on management behavior, the firm is not driven to a unique capital-labor mix.[48]

Zajac also considered the impact of other constraints, as "[T]he modern utility operates under constraints other than rate of return regulation, e.g., regulation on quality of service and maintenance of safety standards."[49]

Many other writers, and this has perhaps passed into the realm of popular wisdom, considered the A-J effect for its impact on gold-plating, or upon rate base padding.[50]

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[47]Zajac, "A Geometric Treatment....", 117.

[48]Zajac, "A Geometric Treatment....", 117-118.

[49]Zajac, "A Geometric Treatment....", 124.

[50]See, for example, Edward E. Zajac, "Note on 'gold-plating' or 'rate base padding'," The Bell Journal of Economics and Management Science 3 (Spring 1972): 311-315.

In a review of the theory of the firm, two authors considered Zajac's article, and noted the following:

> [E.]E. Zajac's article deals with the Averch-Johnson model of regulated utilities. In this case, rather than change the objective function, he adds a constraint: percentage return on capital cannot exceed some "fair return" set by the regulating agency. The result is that profit maiximzation leads to the use of more capital and less labor than is otherwise optimal for the firm. Although this model may seem to have a behavioral flavor, it probably should be viewed as neoclassical. The fair return constraint, after all, is imposed from the outside and is part of the objective economic situation for the management. Given that situation and profit maximization, this model follows, with no need for consideration of the actual nature of the firm. The field of public utilities is, of course, an appropriate place for a behavioral approach. Zajac mentions several alternatives to the Averch-Johnson model. These must all depend upon some alternative to profit maximization, however, and so are clearly on a different plane.[51]

Both Johnson and Averch have provided retrospective reassessments on their original paper, where they enumerated other items that needed consideration. In those, they have also provided a framework for further investigation. In Johnson's 1973 paper, he questioned whether "the Averch-Johnson effects [are] merely an intellectual curiosity, or do they describe serious distortions in the behavior of regulated firms? Unfortunately the answer is not clear."[52] In response to the fact that their review in their original

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[51]Richard M. Cyert and Charles L. Hendrick, "Theory of the Firm: Past, Present, and Future; An Interpretation", Journal of Economic Literature 10, no. 2 (June 1972): 403.

[52]Johnson, "Behavior....A Reassessment", 91.

paper included only one example, that of A T & T, Johnson suggested that, "[O]f course, many contrary examples....can be enumerated. "[53]

When Johnson looked at other problems that regulated firms face, he commented that the A-J effect was not "enough to overcome the reluctance of utilities to adopt environmental controls involving facilities that would add to the rate base."[54]

When Johnson tried to separate the theoretical from the empirical, he stated, "[T]o the extent that Averch-Johnson effects operate, they do so subtly: the firm can engage in activities for a number of reasons that seem plausible; to separate the real from the merely plausible reasons is not easy."[55] He concluded by saying that:

> [W]hat remains seriously lacking is empirical analysis to give us a better quantitative notion of how the firm is affected under a variety of circumstances encountered in the real world, to provide a sounder basis for reassessing the costs and benefits of current regulatory practices, and to evaluate the desirability of alternative regulatory concerns.[56]

H.A. Averch further noted that, "[R]egulation remains a problem in political economy. Actual outcomes depend as much on political and

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[53]Johnson, "Behavior....A Reassessment", 95.

[54]Johnson, "Behavior....A Reassessment", 95.

[55]Johnson, "Behavior....A Reassessment", 91.

[56]Johnson, "Behavior....A Reassessment", 96.

bureaucratic necessity as they do on economic analysis and 'rational' benefit-cost estimates."[57]

Empirical investigation on the A-J hypothesis has been inconclusive, at best. One author has stated that:

> [R]ecently, considerable attention has been focused on empirical examination of the reaction of a monopoly firm to a regulatory constraint based on "a fair return to capital". Under this, the most common form of regulation in the United States, the firm's prices are set such that the rate-of-return to capital earned not exceed some rate set by the regulatory authority.[58]

Smithson went on to discuss other empirical research, with the results both supporting and not supporting the hypothesis. In that regard, he stated that, "[T]he hypothesized overcapitalization has been investigated empirically by three researchers, with the results of Courville and Spahn supporting the hypothesis while those of Boyes indicated no significant effect."[59]

On some other studies, Smithson commented that, "[T]he results of econometric studies by Petersen and Hayashi and Trapani have supported this hypothesis (that if the regulatory constraint is

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[57]John Eatwell, Murray Milgate, and Peter Newman, eds. The New Palgrave Dictionary of Economics (London: The MacMillan Press Ltd., 1987). s.v. "Averch-Johnson effect," by H.A. Averch, 162.

[58]Charles W. Smithson, "The Degree of Regulation and the Monopoly Firm: Further Empirical Evidence," Southern Economic Journal 44, no. 3 (Jan. 1978): 568.

[59]Smithson, 568.

tightened (lowered), the firm will be induced toward further overcapitalization)."[60]

Difficulties were noted in the ability to estimate demand functions, and in the problems associated with determining the rate of return. Smithson commented accordingly:

> [H]owever, in order to estimate these demand functions, data on the statutory rate-of-return to capital allowed by regulatory authorities would be required.....Unfortunately for purposes of estimation, these rate bases may differ radically. It is therefore necessary to construct this rate-of-return variable. Clearly, since the regulated monopoly firm is a profit maximizer, it will at equilibrium earn the maximum rate-of-return allowed.[61]

Smithson also noted that Petersen used actual rate-of-return to equity and Hayaski and Trapani used a three year average of the actual rate-of-return to capital. Clearly, none of these are looking at the rate-of-return earned versus the rate of return allowed, as I do within my model. In spite of these attempts to ascertain the viability of the A-J hypothesis through empirical research, one noted institutional economist has exhorted:

> [A]t the present time, much of the work on the A-J effect consists of theoretical refinements. Anticipated advances since the publication of the original article in 1962 have been disappointing, and this suggests an ironic prognosis: Any real improvement in the theory of the regulated firm

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[60]Smithson, 568.

[61]Smithson, 573.

> will depend on successful studies of actual corporate behavior of public utilities. In other words, the initiative for further advance rests with sophisticated institutional analysis. By the same token, a better understanding of the interaction between the A-J effect and regulatory reform also rests on an institutional examination of potential inconsistencies involved in reconciling the A-J effect with a system of incentives and penalties seeking to motivate utility management.[62]

In a different style of empirical research from those done under the A-J hypothesis, three recent studies on railroads, airlines, and trucking have attempted to ascertain if the "popular wisdom" concerning safety and profits (i.e., movement in the same direction) has been borne out by the evidence for regulated firms. Golbe (1986), in her study on airlines found, "[T]hus, it does not appear that profit-reducing changes in regulation will lead to less safe airlines."[63]

Golbe (1983), in her other study which focused on the railroads, found,

> ....1) profitable railroads have fewer accidents per mile than do unprofitable roads; 2) for profitable roads, if there is any relationship at all between accidents and profitability, it is positive...; and, 3) for unprofitable roads, accident rates rise as losses rise.[64]

Beard (1988), in his study of deregulation and safety in trucking, found significant correlation between accidents and firms' cash

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[62]Harry M. Trebing, "Realism and Relevance", 214-215.

[63]Devra L. Golbe, "Safety and Profits in the Airline Industry," The Journal of Industrial Economics 34, no. 3 (March 1986): 305.

[64]Devra L. Golbe, "Product Safety in a Regulated Industry: Evidence From the Railroads," Economic Inquiry 21, no. 1 (January 1983): 39.

flow equity positions.[65] While this type of approach (accident rates to profit rates/financial stability, which Beard identified as his 'imminent bankruptcy variable) represented another form of investigation into financial constraints on a regulated firm, the connection to the A-J hypothesis was quite clear. Both Golbe and Beard were looking at the resultant impact on safety considerations, given that financial results were constrained. Their interest, (as is mine), was on whether less than optimal financial results impacted safety considerations.

Economic analysis applied to environmental problems has been a recent phenomenon. As one author noted:

> [A]fter World war II, tools of economic theory and statistical methods, and data concerning resources and the environment, have improved steadily. In addition, society rapidly became conscious of environmental problems in the 1960's and of shortages of fuels and resources in the 1970's. The result has been rapid growth in research by natural scientists, engineers, and economists on resource and environmental problems. Although serious inadequacies remain in the analysis and the data, environmental economics can now be treated in a unified and comprehensive way that was impossible as recently as the 1960's.[66]

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[65]Thomas R. Beard, "Bankruptcy, Safety Expenditure, and Safety Regulation in the Motor Carrier Industry," (Ph.D. diss., Vanderbilt University,1988).

[66]Edwin S. Mills and Philip E. Graves, The Economics of Environmental Quality, 2d. ed. (New York: W.W. Norton & Co.,1986), 4.

Typically, within the accepted paradigm of neoclassical analysis, with the use of the formalist approach, the identification of costs versus benefits of any attempt to alleviate an environmental problem is taken. This has developed into the identification, within a supply and demand framework within a market, that there would be an oversupply of a particular product if some of the costs were not being borne by either the producer or the consumer of the good being produced, as in "[N]eoclassical theory states that market failures arise when the market does not bring about an optimum allocation of resources."[67]

Various methods to internalize these external costs have been developed, and these include fees, taxes, penalties and the like. There has even been the suggestion that permits for effluent releases be issued, and that markets for the buying and selling of these be developed. This would allow the non-interference into the marketplace by authorities.

Much of the argumentation either for or against any of these methods has centered around the ability to identify the monetary value of either the costs associated with the externality (and who bears it) and the value of the benefits derived from correction as in "all of these models give little or no explicit recognition to social values that cannot be reflected in monetary values....Once the

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[67]Trebing, "Regulation of Industry," 1716.

external dis-economy is corrected, the factor is properly priced and both production and output can meet competitive criteria."[68]

Trebing reported that:

> [T]he proper procedure for controlling pollution, according to Alchian, is to access the value of the abuse, identify the resource owner, and then be sure that all costs are shifted to the user. In this fashion, the consumer will determine the appropriate level of pollution without recourse to government regulation.[69]

This non-recourse to regulation is because there "is a dislike for affirmative government intervention and an almost theological commitment to competition and market-oriented solutions."[70]

Two final arguments need to be considered. The typical production function says little about the adoption of new technology; in essence, whenever a new technology has been adopted, it has been simply assumed that the workers and the management would be able to operate the new technology embodied in the equipment with no time period needed for learning. A large body of literature has developed which has explored the consideration that a learning process goes on which in fact must be considered. The approach has been to look at labor productivity over time to see how this has

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[68]Trebing, "Regulation of Industry," 1721.

[69]Harry M. Trebing, "The Chicago School versus Public Utility Regulation," Journal of Economic Issues 10, no. 1 (March 1976): 113.

[70]Trebing, "Regulation of Industry," 1720.

improved.[71] This consideration is especially important for the adoption of nuclear plant technology, for, as noted within chapter two, each plant in the United States is effectively a customized facility which has required each staff to incorporate new learning curves. In that vein, an article by Jostow and Rozanski specifically looked at nuclear power plants and the ability to adopt the technology. In this regard, they noted that, "[T]echnical progress due to learning by doing plays an important role in determining the productivity of nuclear power plants."[72] They stated that their research indicated that the rate of growth in the capacity factor at about 5% per year; that PWR's learning curve was faster than the BWR's; and, that larger plants are much worse than the smaller plants in terms of learning by doing.

On one final note, there is also a significant body of literature on the impact of absentee ownership on the operations of a firm. In that regard, the Oliver Williamson article asked the question, "What ramifications, if any, does internal organization have for the long-standing dilemma posed by the separation of ownership from

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[71]See, e.g., Kenneth J. Arrow, "The Economic Implications of Learning by Doing," Review of Economic Studies 29 (1962): 155-173 and Armen Alchian, "Reliability of Progress Curves in Airframe Production," Econometrica 31, no. 4 (October 1963): 679-693.

[72]Paul L. Joskow and George A. Rozanski, "The Effects of Learning by Doing on Nuclear Plant Operating Reliability," The Review of Economics and Statistics 61, no. 2 (May 1979): 167.

control?"[73] I pose this question in terms of ownership control for nuclear power plants. Please see the details in chapter 4, for:

> [T]he neoclassical theory treats the firm as a production function to which a maximization objective has been ascribed. Albeit useful for many purposes, such a construction is unhelpful in attempting to assess the purposes served by the hierarchical modes of organization. The firm as production function needs to make way for the view of the firm as governance structure if the ramifications of internal organization are to be accurately assessed."[74]

Williamson noted that Friedrich Hayek insisted that " attention" be paid "to the details of social processes and economic institutions" because of the "unavoidable imperfections of man's knowledge".[75]

Both intuitive wisdom and economic theory would suggest that some relationship should exist between profits (or overall financial standing) and radioactive emissions for nuclear power plants. Whether that will be a positive or negative relationship will be explored. The difficulty in analyzing this proposition has been explored both theoretically (the A-J hypothesis and a general profit maximizing model with two constraints) and empirically. Within

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[73]Oliver E. Williamson, "The Modern Corporation: Origin, Evolution, Attributes," Journal of Economic Literature 19, no. 4 (December 1981): 1537-1538.

[74]Williamson, 1539.

[75]Williamson, 1541.

chapter four, the model developed to explore this proposition is presented.

A neoclassical model of profit maximizing behavior by a regulated firm would suggest that all firms would exhibit the behavior which best approximates the most profitable behavior. If it were more profitable to contain and capture the radioactive pollutants than to release them, we would then see the firm do so. This may take place within each plant by design changes, the addition of filtration or hold-up equipment, or by various other methods (i.e., additional personnel, more frequent maintenance of equipment, new or improved managerial procedures, etc.). If this scenario were to hold, we would see firms making additions to their non-polluting capacity and thus the curtailment of emissions over time. We may in fact see all of these changes made, and the results manifest, and still need to do further analysis. However, Feinstein noted that,

> [N]uclear power plants embody a complex technology, and in response to this complexity the NRC has formulated an equally complex body of safety standards....Complying with all the standards is an expensive, time-consuming, and sometimes technically difficult task for plant management; non-compliance is often a tempting alternative.[76]

The earlier comment by Meyer[77] has brought us to the need for a thorough review of the "behavior of the firm under regulatory constraint" as it has applied to the firms producing electricity from

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[76]Jonathan S. Feinstein, "The Safety Regulation of U.S. Nuclear Power Plants: Violations, Inspections, and Abnormal Occurences," Journal of Political Economy 97, no. 1 (February 1989): 119.

[77]See footnote 43 on page 84.

nuclear power plants. The specific operations and the unique regulatory posture by the NRC and the respective PUC's will make an excellent case study.

It seems to this writer that nuclear power plant operators have four overlapping and overriding concerns about their production, and thus an extension of the Averch-Johnson model is necessary in order to establish a theoretical framework within which to analyze the behavior of each nuclear power plant, and thus to analyze the behavior of the firm under regulatory constraint. The four overlapping and overriding concerns are as follows: 1) to maximize profits, or rate of return on allowed asset base, while maintaining (in the public's eyes) a reasonable charge for each kilowatt of electricity; 2) to protect the investment in the plant facilities by maintaining reasonable quality control to ensure the continued usage of the plant for its expected life span and to maintain the license from the NRC to operate the plant (both the Pilgrim plant in Mass. and the TVA's plants in the south have been closed by the NRC for regulatory discrepancies); 3) to abide by the federal regulations on emissions in order to forestall fines (even though each plant may apply for and receive permission from the NRC to release effluents over and above the limits) or shutting down, and to abide by the rules on emissions in order to perserve their investment; and, 4), to control and diffuse public opposition to nuclear power and to each specific plant by, a) maintaining a low level of emissions and by b) keeping and maintaining a low profile in the public press. These four propositions will come into conflict with one another and the goal should be to ascertain which of the four propositions has been more powerful. In other words, as profits have fallen (or the guaranteed rate of return has not been reached), have emissions levels risen? Has quality control suffered if profits have fallen; have plant operators been willing to risk contamination of their plant by not maintaining the equipment, due to unusual and unexpected expenses in some period which have impacted profits? How have the general levels of emissions changed as profits have changed?

The comparison of the levels of emissions, the resultant accumulation of the isotopes, and the financial performances of each company should reveal whether supportive data for the extended Averch-Johnson "Behavior of the Firm Under Regulatory Constraint" model exists.

This general profit maximizing framework can be used to test overall emissions levels and their relationship to overall profits. In brief, one would posit that emissions are a function of profits, measured here as a comparison of the actual rate of return compared to the allowed rate of return. One would expect to find here that the less profitable firms would emit higher levels of emissions. One may find, however, that the more profitable firms are so because they do not expend monies on the control of emissions. One may also find here that certain elements are correlated with profits while others are not.

It may, therefore, be easier to ascribe the A-J effect if we were to discuss the utility's original choice to invest in nuclear facilities or not, rather than using it for on-going operations once the original choice of technology has been made. Ferreting out the A-J effect once a plant is operating (and contemporaneously identifying capital expenditures which relate to emissions control) may not be so easy. We may find, I suspect, that the effect of the original capital decision may far outweigh any continued A-J effects once operational.

Thus, theoretically, we must take an assumption of the original A-J hypothesis, i.e., constrained profit maximization, and hope that empirically we capture the result of not only the A-J impact on profitability but also on environmental results. A-J assumed that profit maximization would be the behavior exhibited by the firm, and for the regulated monopolist described herein, we have the constraint of the state PUC rate of return and rate base considerations.

The applicability of the A-J hypothesis for nuclear power plants in terms of the adoption of emissions control equipment, which, when added to the rate base would raise the profits to the firm, is not so clear. While there are many capital additions which will aid in reducing the levels of emissions from each plant, other factors within the overall operation contribute to emissions levels. These include maintenance procedures on plant and equipment and other normal operational expenses, e.g., the changing of the fuel rods. Clearly, these types of expenditures or lack thereof will alter emissions levels. How then would one try to use the A-J hypothesis to ascertain whether it applies to these firms. What I propose herein is a theoretical and empirical model which will simultaneously test both of Johnson's statements. How will, and how does, a firm respond to both regulatory constraint in financial areas (prices, profits, rate base and rate of return) and to environmental constraints (specific NRC emissions requirements)? Do the regulatory constraints in one area impact the results in the other?

The development of the Public Utilities Commissions (PUC's) and their rate of return rules and procedures were developed to try and control the perceived implications of an unregulated monopoly. The rules were then developed within that framework as an attempt to replicate what was seen to be the better competitive result without the competition, Given that the each nuclear power plant is highly capital intensive, and, given that each rate of return guaranteed by each utility commission allows capital expenditures to be included in the rate base[78], we should expect to see each firm, once they have chosen the nuclear production method, to adhere to both NRC and EPA pollution requirements if to do so requires additions to their capital stocks which can be included in their rate bases.

Alternatively, for those expenses which are not applicable to the rate base, do we see an increase in emissions if the firm has failed to achieve the rate of return prescribed by the regulatory body? A reasonable cross section of elements released across all plants may

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[78]An exception to this is the State of New Hampshire's Construction Works in Progress (CWIP) law which does not allow the addition to the rate base any investment in new generating facilities until those facilities are generating electricity.

aid in determining which of the above has held between 1974 and 1984.

Thomas Kuhn, in a statement that can be portrayed as being applicable to institutional economists and their methods, said:

> [W]hen in the development of a natural science, an individual or group first produces a synthesis able to attract most of the next generation's practicioners, the older schools gradually disappear. In part their disappearance is caused by their members' conversion to the new paradigm. But there are always some men who cling to one or another of the older views, and they are simply read out of the profession, which thereafter ignores their work. The new paradigm implies a new and more rigid definition of the field. Those unwilling or unable to accomodate their work to it must proceed in isolation or attach themselves to some other group.[79]

Mr. Mirowski, though, has also reminded us that:

> [B]ecause neoclassical economics is irreparably committed to the imitation of nineteenth-century physics, the DMD {Durkheim/Mauss/Douglas] thesis predicts that it will find itself progressively isolated from cultural conceptions, defending an increasingly reactionary conception of Natural Order as mechanically deterministic and static. Institutional economics, on the other hand, with its Peircian pedigree, should be well positioned to participate in the reconstruction of economic theory from a hermeneutic perspective. this reconstruction is not merely wishful thinking; there are signs that it is already well under way.[80]

Finally, Mr. Trebing has exhorted economists to consider that:

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[79]Kuhn, 18-19.

[80]Mirowski,1033.

> [M]any other factors shape the nature and objectives of the regulatory process as well as the rights, actions, and objectives of the major participants in that process. An orthodox theory of regulation, hoping to provide a generalized insight, would have to be able to integrate all of these considerations. That the orthodox economists have been unable to do so again reinforces the previous conclusion, notably that a significant advance will await a comprehensive recognition of the relevant institutional phenomena.[81]

However, since this paper will be focusing on the individual actions of firms constrained by both Federal and State regulations on effluents and profitability, respectively, and, given that the statistical information collected by both Federal and State regulators will reflect the accepted conceptions of the dominant philosophy within an economic system, it seems best to choose that framework for analysis. One must recognize, however, that the analysis of the empirical results may highlight deficiences within the theoretical framework. This is where the inductive analysís of the institutionalists will be used.

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[81]Trebing, "Realism and Relevance," 217.

CHAPTER IV

ECONOMETRIC SPECIFICATION, METHODOLOGY, TESTING AND RESULTS

What follows within this chapter is the discussion of the development of and explanation for the testable model, the results generated by the equations, and initial interpretation of the results.

The bridge between economic theory and econometric testing is fraught with many perils. Will the econometric tests be a full translation of what has been suggested by the economic theory? Will the data be available in sufficient quantity and reliable quality in order to both adequately test the economic theory and to also satisfy the statistical requirements? In a similar vein, Peter Kennedy noted "that in practice good results depend as much on the input of sound and imaginative economic theory as on the application of correct statistical methods. The skill of the econometrician lies in judiciously mixing these two essential ingredients."[1]

In economics, this was translated as

> Any model in any science must ultimately be justified on the basis of the knowledge about the real world that is generated by the model. This new knowledge may come from empirical work resulting from hypotheses derived from the model or from theoretical results that lead to other models

[1]Peter Kennedy, A Guide to Econometrics, 5th ed. (Cambridge, Ma.: The MIT Press, 1984), 2.

and eventually to increased knowledge about the real world.[2]

In Chapter III, the conclusion was reached that for the regulated firm there is a connection between the financial results of the firm and its environmental behavior, under the umbrella of the externality argument.[3] That is, when a profit maximizing firm is able to externalize certain costs of production, their resultant internalized costs are reduced, and, ceteris paribus, their profits are enhanced or their losses reduced. Empirical and theoretical citations were offered in support of that thesis.

This simplified version of the overall thesis presented in chapter III is compounded by two material facts for the regulated monopolies which operate nuclear power plants within the U.S. First, the radioactive emissions are regulated by the NRC[4] and the EPA[5] and

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[2]Richard M. Cyert and Charles L. Hendrick, "Theory of the Firm: Past, Present, and Future; An Interpretation," Journal of Economic Literature 10, no. 2 (June 1972): 406.

[3]Financial results, as used in this analysis, refer to the net profits of a firm as a percent of their rate base. The rate base used is an accounting category called net utility all plant, which is the depreciated value of a firm's investment in their generating facilities. This percentage is then stated as a percent of their allowed rate of return.

[4]Office of the Federal Register, National Archives and Records Administration, Code of Federal Regulations (Washington, D.C.: January 1, 1987), Part 20, Appendix B, 274-283.

[5]Environmental Protection Agency, Summary of Radioactivity Released in Effluents from Nuclear Power Plants from 1973 thru 1976 (Washington, D.C.: December 1977), 1.

reports are made by both on the emissions.[6] Second, their financial results are constrained through a system of measures implemented and controlled by their respective state regulatory bodies.

The seminal hypothesis for this project was that because of the unique plant-specific characteristics of the U.S. nuclear industry, with its network of highly "individualized" nuclear power plants, emissions were a function of specific plant characteristics, general operational data, and of financial results and regulatory requirements.

Therefore, the first task was to choose the explanatory, independent variables which would mirror the technical differences of the plants and their operations. The second task was to determine the financial measure which most closely resembled the Averch-Johnson hypothesis.

The technical search started with NRC documents and with technical literature on the plants. One such report by V.L. Sailor and J.J. Colbert reviewed the emissions from U.S. power plants for the period 1975-1981.7 In brief, their report represented a review and consolidation of two series of reports which are issued by the NRC.[8]

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[6]Nuclear Regulatory Commission, 1979 Annual Report, (Washington, D.C.: March 1980), 100.

[7]Nuclear Regulatory Commission, Summary of Historical Experience.

[8]Nuclear Regulatory Commission, Radioactive Materials Released From Nuclear Power Plants, 1975-1981 (Washington, D.C.: December 1983.) and Nuclear Regulatory Commission, Population Dose

The authors noted that fission and activation gas releases varied the most and that BWR releases were 5 to 10 times the level of PWR, that the Iodine 131 and particulates from BWRs were 10 times larger than PWRs, that tritium releases for BWRs were about 1/20 the level as from PWRs, and that mixed fission and activation were about equal between the two types of plants.[9]

They went on to further note that variations may also be explained by shutdowns for repairs or backfitting, fuel cladding failures, the purging of containment equipment during forced outages, and the installation of augmented off gas (AOG) systems.[10] For example, Colbert and Sailor stated that,

> ....it should be noted that degraded fuel claddings (leaks in fuel rods) cause larger incremental airborne releases in BWRs than in PWRs. The reason for this is that BWRs have much shorter holdup times for release of non-condensible gases. During the 1960's and early 1970's this effect was particularly evident because the older BWRs were not equipped with augmented off-gas systems. The installation of augmented systems and the steady improvement in fuel integrity of recent years has resulted in a significant decrease in BWR airborne emissions.
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> The boiling water reactors emit more non-condensible gases than pressurized water reactors because of the steam cycle....PWRs do not have this quantity of gas to

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Commitments Due to Radioactive Releases From Nuclear Power Plant Sites in 1975-1981(Washington, D.C.: December 1983.)

[9]Nuclear Regulatory Commission, Summary of Historical Experience, 9.

[10]Nuclear Regulatory Commission, Summary of Historical Experience, 10.

deal with since no steam condensation occurs in the primary loop....Thus, on average, BWRs emit substantially more fission and activation gaseous radioactivity than do PWRs. Summary data....show emissions in this category ranging from as high as 3 million Ci/year to as low as 200Ci/year. The range for PWRs is about a factor of ten lower varying from about 70,000 Ci/year to as low as about 20 Ci/year.[11]

Other technical statements regarding emissions include this from I.R. Cameron:

> [T]he releases of radioactivity from nuclear power plants tend to vary markedly, depending on power level, fuel failure rate, and degree of efficiency for the removal of activity from the effluents....The general experience in operating nuclear power plants has been that there is little difficulty in keeping routine releases of activity down to levels which result in radiation exposures to the public which are far below the recommended limits....Concern has, however, been expressed about the long-term effects due to the build up of long lived isotopes....[12]

Cameron also noted that leaks of radiation occurred from the fuel, fuel pins, coolant circuits, heat exchangers, turbines, cracks and pinholes in cladding, activation in moderator, coolant, and structural materials, corrosion and erosion of structure by the coolant, and the like. These can be controlled by removal by condensor air ejector,[13]

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[11]Nuclear Regulatory Commission, Summary of Historical Experience, 10.

[12]I.R. Cameron, Nuclear Fission Reactors (N.Y.: Plenum Press, 1982), 319.

[13]The condensor air ejector removes most of the gaseous effluents present within the primary circuit, and then mixes these effluents with large volumes of air, sends them through a particulate filter,

by delaying the release to allow decay, by particulate filters, or by releasing through the stack which allows time to decay before hitting the ground. Liquid wastes can be treated by filtration, evaporation, demineralization, and by storage of the material to allow decay.[14]

The U.S. nuclear power industry (and the 89 plants reviewed in this study) is unique in many respects. The privatization of the industry which began in the 1950's and accelerated in the 1960's produced plants which can be best described as customized. Campbell reports that, "....the United States is the only major nuclear country in which almost every nuclear plant is largely custom built."[15]

In order to adequately reflect this diversity within the industry, technological and operational data for each plant were compiled. This data included reactor supplier, turbine supplier, construction company, architect, type of plant, size in megawattage, net electrical generation yearly, gross thermal production yearly and cumulative, hours of criticality, and capacity factors yearly and cumulative. Data collected in the operational category was often redundant. In the operations category, examples include net

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and then they are released to the stack for venting. See Cameron, 316.

[14]Cameron, 317-318.

[15]John L. Campbell, Collapse of an Industry: Nuclear Power and the Contradictions of U.S. Policy (Ithaca, N.Y.: Cornell University Press, 1988), 32.

electrical generation, gross thermal production, critical hours, and capacity factors. Combining two or more of these in estimation lead to severe collinearity problems. Net electrical generation and gross thermal generation were recorded either from the annual emissions reports, for the years 1974-1976[16], or from the report entitled Licensed Operating Reactors, Status Summary Report, Volumes 1-12, for the years 1977-1987.[17] Other data from these reports include the size of the plant (design electrical rating in net MWe), hours of critical operation, manufacturer of the reactor and turbine for each plant, the construction company, the architect, and the construction start and license dates.

The plants also vary in terms of operational efficiency, which can be measured by electricity production relative to the capability of the plant, or the hours of operation on-line relative to the number of hours in a year, or by the capacity utilization factors. Some plants, for example Yankee-Rowe, have been relatively trouble free and thus exhibit high efficiency; others, for example Fort St. Vrain, have been very unreliable and therefore inefficient.

The type of reactor was recorded as either a pressurized water reactor (PWR) or a boiling water reactor (BWR), with the only

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[16]Nuclear Regulatory Commission, Radioactive Releases from Nuclear Power Plants, Annual Reports 1974-1976 (Washington, D.C.: various years), individual plant summaries and PWR, BWR tables.

[17]Nuclear Regulatory Commission Licensed Operating Reactors, Status Summary Report, Volumes 1-12, (Washington, D.C.: 1977-1988), Section 2, Operating Power Reactors, various pages.

exception being Ft. St. Vrain, a high temperature gas cooled reactor (HTGR), which was classified as a BWR, following the precedent set by the NRC in its annual emissions reports, where Ft. St. Vrain emissions are grouped with the BWR's.[18] The number of plants at each location changed from the initial single plant at a site in the 1950's and early 1960's to multiple plant at the same site during the late 1960's and into the 1970's. Of the 67 geographic locations analyzed (some represent a single plant; others two or three plants; see table 2.3 in chapter II), there were 42 locations which had 56 pressurized water reactors, and 22 locations which represented 33 boiling water reactors.

The plants range in size from 50 MeW (LaCrosse) to 1,250 MeW (Grand Gulf 1). There were 60 different sized plants in this study. These size differences were grouped into three categories: 1) less than 500 MeW (11 plants), 2) from 500 to 1000 MeW (51 plants), and 3) greater than 1000 MeW (25 plants). This was done in order to analyze whether the emission release activity varied according to the relative size of the plants. The groupings gave me two dummy variables to deal with rather than 59. I wanted to find out if the technological advances in size reduced release activity, or was release activity a casualty of the technological increase in productive capacity?

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[18]Nuclear Regulatory Commission, Radioactive Materials Released from Nuclear Power Plants. Annual Report 1979 (Washington, D.C.: November, 1981), 11.

The plants vary in construction starting dates from 1956 (Dresden 1) to 1977 (St. Lucie 2), with two started in the 1950's, 65 in the 1960's, and 22 in the 1970's. The shortest time period from construction start to criticality was Yankee-Rowe (1958-1960); this period of time gradually lengthened in the 1960's, 1970's, and into the 1980's. Examples include Haddam Neck, started in 1964 and critical in 1967; Indian Point 2, started in 1966 and critical in 1973; Millstone 2, started in 1969 and critical in 1975; and, Susquehanna 1, started in 1973 but not critical until 1982.

Financial data was collected from the following reports; for 1970-1975, Statistics of Privately Owned Electric Utilities in the United States[19]; for 1976-1981, Statistics of Privately Owned Electric Utilities in the United States[20]; for 1970-1975, Statistics of Publicly Owned Electric Utilities in the United States[21]; for 1976-1981, Statistics of Publicly Owned Electric Utilities in the United States[22]; for 1982-1987, Financial Statistics of Selected

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[19]Federal Power Commission, Statistics of Privately Owned Electric Utilities in the United States (Washington, D.C.: various years).

[20]Department of Energy, Statistics of Privately Owned Electric Utilities in the United States (Washington, D.C.: various years).

[21]Federal Power Commission, Statistics of Publicly Owned Electric Utilities in the United States (Washington, D.C.: various years).

[22]Department of Energy, Statistics of Publicly Owned Electric Utilities in the United States (Washington, D.C.: various years).

Electric Utilities[23]; and, finally, for 1970-1985, Statistical Report, Rural Electric Borrowers[24].

Financial data collected included net sales, gross profit, net profit, assets, owner's equity, and dividends paid. Financial constraints on each firm were also compiled. The financial categories used from the reports were as follows: sales are all utility operating revenues; net profits are net income; assets are net utility all plant, which is the depreciated value of the firm's investment in their facilities which are used to produce power; capital is total proprietary capital for private companies or total investment and surplus for public companies; dividends are the total of dividends declared for both preferred and common stock; gross profit is total all utility operating income; and the financial constraint is the rate of return prescribed or found reasonable by the respective state regulatory body.

The financial information in this report has been gathered from reports issued by the Department of Energy and the Federal Power Commission entitled Financial Statistics of Selected Electrical Utilities[25]. The information contained in those reports "has been taken from the annual report of....private electric utilities provided

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[23]Department of Energy, Financial Statistics of Selected Electric Utilities (Washington, D.C.: various years).

[24]Department of Agriculture, 1970-1987 Annual Statistical Report, Rural Electric Borrowers (Washington, D.C.: various years).
[25]See the bibliography for a complete listing of these reports from 1973-1985.

to the Energy Information Administration...."[26] As the financial records of these utilities are a matter of public record, either through their respective PUC or through the Securities and Exchange Commission, the figures have been taken as given. No attempt for additional verification of the numbers has been made.

Ownership determination was made either from Owners of Nuclear Power Plants[27]; Owners of Nuclear Power Plants-Revision 1[28]; Owners of Nuclear Power Plants-Revision 2 [29]; or from Licensed Operating Reactors, (various years)[30] where licensee information is listed. Financial constraints were compiled from the Annual Report on Utility and Carrier Regulation, 1973-1985.[31]

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[26]Department of Energy, Energy Information Administration, Financial Statistics of Selected Electric Utilities 1985 (Washington, D.C.: February, 1987), 3.

[27]Nuclear Regulatory Commission, Owners of Nuclear Power Plants (Washington, D.C.: October 1977).

[28]Nuclear Regulatory Commission, Owners of Nuclear Power Plants-Revision 1 (Washington, D.C.: November 1978).

[29]Nuclear Regulatory Commission, Owners of Nuclear Power Plants-Revision 2 (Washington, D.C.: December 1979).

[30]Nuclear Regulatory Commission, Licensed Operating Reactors, Section 2, Operating Power Reactors, various pages.

[31]National Association of Regulatory Utility Commissioners, 1973-1985 Annual Reports on Utility and Carrier Regulation, (Washington, D.C.: National Association of Regulatory Utility Commissioners, 1974-1987), various pages.

Of the 47 companies which own these facilities, 7 are public corporations and 40 are private corporations. Various shares of ownership are also evident, ranging from 100% stock ownership to shared ownership, with the lead owner at times owning less than 50% of the stock in the corporation.

The financial constraints and financial results vary also. The constraint formulas for rate of return range from % of actual cost, to replacement cost, all the way to non-profit. The financial results also run the gamut from losses (there were only 4 years of losses in the 517 years studied) to results which were greater than the constraint imposed.

The complete data base consisted of over 232,000 separate pieces of information. Emissions information for 89 plants in 67 separate locations for 191 different elements (and combinations of elements) was collected for the period 1974-1984. Technical specifics and operational data from 1970-1987 were also collected. Financial data from 1970-1987 for the 47 separate companies, listed in chapter II, table 2.3, were also collected.

A subset of twenty-three elements and combinations of elements was then chosen for analysis (see table 2.2 in chapter II). These elements and combinations of elements were chosen to reflect a broad array of both gaseous and liquid emissions. The releases were tabulated in curies (Ci) per year released, and the gaseous and liquid releases have been added together to have one total release per year per plant. These elements and combinations have also been chosen because these emissions occurred across most plants for most years of operation. Data collected on emissions only reflected an emission in a time period if at least .000005 curie was released. Emissions less than this amount were not included in the data base. The reasons for this include the following. First, the NRC was phasing in emissions reporting standards for the plants throughout the time period of analysis, and each plant standardized its reporting format at a different time. This meant that the plants which standardized earlier were reporting on more elements and on smaller levels of emissions than those plants which delayed the standardization. Thus, there may have been as many emissions not recorded as those which I eliminated from the data base. Second, the sensitivity of measurement devices also varied by plant during this time period. This would mean that some plants with their detection devices would have been able to detect more elements emitted and at smaller levels than other plants. Third, the earlier reports (from 1974-1977) tended to reflect an emission report on an element only if the emission exceeded the level noted above. Fourth, due to the wide variability in the accuracy in measurement (+- 10-50% in some cases; factor of 2-10 in others), this writer assumed that the non-incorporation of the very small levels of emissions would not affect the test results significantly. This truncation of the data, it was hoped, would provide a more consistent set of observations throughout the entire eleven years in question. This truncation may have biased the estimates of the sample regression line, but it was felt that with the size of the data base coupled with the number of excluded observations, that this alteration would be minimal. On this point, Prof. Kmenta noted that, "[T]he restriction on the observable range of the dependent variable matters if the probability of falling below the cut-off point is not negligible."[32] Typically, a TOBIT model for estimation would be used if the probability were not negligible, as "limiting the range of the values of the dependent variable leads to a non-zero mean of the disturbance and to biasedness and inconsistency of the least squares estimators".[33] The number of observations affected by this decision is stated in table 4.1 on page 145.

The annual emissions, in curies, of all the releases (both gaseous and liquid) from the 89 operating commercial nuclear power plants in 67 separate reporting locations in the U.S. during the period 1974-1984 were collected. As noted in chapter II, emissions less than .000005 Ci were not included in the data base. Emissions of .000005 and greater were rounded to five decimal places. Other adjustments to the emissions data were for the readings which were less than the detection equipment's calibration level. For these calibrated readings, the following criteria were used. If the readings were more than twice the size of the average of all the other year's actual readings, then one-half of the amount was placed in the data base. Readings less than or equal to twice the average were recorded in the data base as reported in the NRC reports. Observations in

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[32]Jan Kmenta, Elements of Econometrics, 2d. ed. (New York: MacMillan Publishing Co., 1986), 561.

[33]Kmenta, 561.

these two categories of less than .000005 Ci also were not included. Visual displays of the emissions are contained in chart 4.1 on the pages 152-175. The first set of charts represent the emissions by year by element, measured in curies. The second set of charts represent the emissions by year in logarithmic form. Finally, table 4.5 on page 151 provides a list of the elements, giving the minimum and maximum emission, the mean of the emissions, and the standard deviation by element, all measured in curies.

In order to keep the resulting regression equations consistent across the elements subset and to capture the specific technical differences of each plant, a series of preliminary estimations were made. In these initial estimations, t statistics, the significance of each variable and changes to adjusted R^2 of added or dropped variables were noted as each came into or dropped from the equation. Correlations between the many independent variables were also noted. Included also in the preliminary testing were heteroskedastic tests (Breutsch-Pagan). My preliminary testing, while looking at t-stats and R^2's, used very similar variables for the ultimate independent variables that are in my model. For example, for the operational variable I considered net electrical generation, gross thermal production, hours of criticality of the reactor, and the percentage of capacity used. These are all very similar variables, but I chose net electrical because it was used by the NRC in the emissions reports and it is also mentioned in the technical literature. I also chose it because when electricity is being generated this indicates that the equipment of the power plant is in use, and that would include the turbines, pumps, circulation equipment, piping, etc. and that net electrical represents the power generated that is available for sale. I believed net electrical would be a "better" variable for the model than the others. I could not use any of the four in conjunction with one another because of collinearity problems.

Many of the extra technical variables collected but not used in my model were dummy variables, such as manufacturer of the reactors and turbines, the architect for the plant, and the construction company for the plant. These proved to be collinear with my other dummy variables which I ultimately did choose for my model. While the choice of net electrical generation as a independent variable would not always account for emissions released (as the reactor may be critical, thus radioactivity would be generated which may result in the release of emissions, yet the plant may not be producing any power; similarly, the plant may be shut down yet still be releasing emissions, i.e., TMI#2), net electrical generation was shown to be a significant variable for some elements. The introduction of any of the other operational variables introduced collinearity problems and the resultant large standard errors of estimation. As multicollinearity is essentially a sample problem, some of the elements in the subset exhibited the problem while others did not. In order to present the estimations that follow in a consistent format, net electrical generation was the only technical operational variable used.

My final choice of variables followed the technical literature on the emissions which indicated that one should expect differences based upon the type of plant, the age of the plant (because of design differences from early in the industry's history from the later designs), the size differences of the plants, and the electrical generation from each plant.[34]

For the financial variables chosen for the model, I followed the discussion from the Averch-Johnson material, but collected other financial information because other industrial organization literature had looked at other variables. These included dividend payment ratios, the percent of profit relative to equity, and Moody's Bond ratings, among others. I chose profits as a percent of assets (net utility all-plant) and compared this percent to the allowed rate of return. This proxy for a firm's financial motivation most closely paralleled the Averch-Johnson hypothesis for regulated monopolies and the literature on environmental issues. While arguments may be made that various financial measures may be more revealing than others of a firm's financial soundness (or lack thereof)[35], it was felt

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[34]See, for example, discussions on the relationship between emissions and electrical generation in the following reports. Nuclear Regulatory Commission, Nuclear Power Plant Operating Experience 1976 (Washington, D.C., December, 1977), 6-7 to 6-10, and, Environmental Protection Agency, Radioactive Waste Discharges to the Environment from Nuclear Power Facilities, Addendum 1, (Washington, D.C.: October 1971), 15-17.

[35]See, for example, the use of Moody's bond ratings in Jonathan S. Feinstein, "The Safety Regulation of U.S. Nuclear Power Plants:

that theoretically[36] and to again provide consistency, that the best financial variable was FIN1 [(net profit as a percent of assets) all as a percent of the state regulated financial constraint], as this most closely paralleled the A-J hypothesis. Preliminary estimations were run using other financial configurations such as profits to equity, profits to sales, profits as a percent of total assets, total dividends paid as a percent of sales, total dividends paid as a percent of assets, and total paid dividends as a percent of equity. FIN1 t-1 was added to see if there was a time delay between financial results and changes in emissions behavior, as there may have been a lag between the two. For example, if firm A did not meet its financial goals in time period t-1, was there an effect on the emissions in time period t? Data collected in the financial area were often redundant as the introduction of more than one financial variable in the equation again lead to collinearity[37] problems because of the degree of similarity of either the divisor or the numerator.

I believe the model is correctly specified. However, because of the many technical differences within each facility, and, despite the use of the fixed-effects model, I still needed a technical variable to

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Violations, Inspections, and Normal Occurences," Journal of Political Economy 97, no. 1 (February 1989), 115-154.

[36]See the discussion in chapter three on the Averch and Johnson (A-J) hypothesis.

[37]Correlation matrices were made of the various X variables and each X was regressed on the others.

capture each plants differences. The choice then was either to develop much more specific technical data on each plant[38] or to lag the emissions one time period (see the form of the equations below). Visual inspection of the emissions streams by plant over time revealed distinct patterns for each separate location. Once a plant had gone through the start-up phase, emissions by plant developed a predictable pattern which had a unique configuration by plant. Each annual emission should reflect the specific technical characteristics of each plant in normal operating conditions. The lagged emissions and the location variable both were designed to capture the specifics of each plant. As the reader will note in the estimation procedures, I addressed the econometric issues raised that the use of this variable implied by using an instrumental variable and two stage estimation procedure.

The maximum number of pooled observations per regression equation (one equation per element or combination of elements) was 737. This number represented 11 years of data over 67 separate reporting locations. The different starting dates for the plants reduced the possible number of observations to 600. The lagged structure of the equations reduced the possible number of observations by another 39, as the 1974 observations were lost,

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[38]Examples include fuel cladding, fuel cladding defects, reliability of fuel rods, date of fuel rod change, installation of augmented off-gas (AOG) systems, containment equipment and performance, implementation and maintenance of other environmental equipment, etc.

reducing the total to 561 as the maximum possible number of observations. Missing emissions, technical, or financial information reduced the number of observations used in estimation further. Refer to the regression results for the specifics on each element.[39]

One final note before I develop the model. It should be noted that the data in this analysis was not 'massaged', except as noted for emissions <.000005 Ci, and that because of the structure of the equations, which did not account for down time, that severe outliers (greater than 2 S.D.) manifested. While removal of these severe outliers improved the significance of the coefficients FIN1 and FIN1 t-1, it did not to the point of statistical significance. One author recommends two choices in this regard. The first method asks:

> [W]hat can be done about the sensitivity of least squares to outliers? The most direct solution is to recalculate the least-squares line when the outlier has been removed. By reporting both the original and the new least-squares slopes and intercepts, we can give the reader a good feeling for the sensitivity of our results to the presence of outliers.[40]

The second method requires that, "[B]ecause the decision about what makes an outlier is an arbitrary one, a better, although more

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[39]Financial data not available in the sources used for this report for TVA in 1981-2; Washington Public Power Supply, 1984; Nebraska Public Power (all years); Power Authority of New York, Sacramento Municipal, and Omaha Public Power for the years 1982-84.

[40]Robert S. Pindyck and Daniel L. Rubinfeld, Econometric Models and Economic Forecasts, 2nd. ed. (N.Y.: McGraw-Hill Book Company, 1989): 7-8.

complex, procedure would place a relatively low weight on large deviations."[41]

On this second method, the authors state that:

> [O]ne reason for the complexity of the estimation is that deviations are defined relative to a given straight line. If we were to start with the least-squares line, for example, we would determine which data points should receive less weight after calculating the deviations. The new set of weights would allow us to calculate a new straight line, a new set of deviations, and a new set of weights. The result is that this technique, often called robust estimation, involves many iterations rather than a straightforward calculation as in least squares."[42]

I have employed neither of these methods in my estimation procedures as I disagree with the dropping or lessening the impact of observations that are, in essence, inconvenient for the statistician. This problem is discussed further in chapter V.

Data Base used in the model:

EM_{ijt}=Emission (in log form) of element(i), by plant(j), in time (t)

i= 1-23, j= 1-67, t=1-11(1974-1984)

$TYPE_j$= Dummy variable for type of reactor; PWR=1, BWR=0

$YEAR_t$= Ten(10) dummy variables to indicate year of emission (EM_{ijt}); 1974=YEAR 1, 1975=YEAR 2,....1983=YEAR 10 [Default is 1984]

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[41]Pindyck and Rubinfeld, 8.

[42]Pindyck and Rubinfeld, 8 f.n.

NET E_{jt}=Net Electrical Generation (Megawatt hours-MWH) by jth plant in time t

SIZE <500$_j$=Dummy variable set at 1 if plant size in megawatt design is less than 500MWH; set at 0 otherwise

SIZE 5-1000$_j$= Dummy variable set at 1 if plant size is 500-1000MWH; set at 0 otherwise

DATE <66$_j$= Dummy variable set at 1 if plant criticality was before 1966; set at 0 otherwise

DATE 66-70$_j$= Dummy variable set at 1 if plant criticality was between 1966-1970; set at 0 otherwise

FIRSTYEAR$_j$= Dummy variable set at 1 for first two years of commercial operation, 0 otherwise

FIN1$_{jt}$= (Net profit of lead owner of jth plant divided by net utility all plant) as a percent of the Utility Commission constraint in time period t [43]

LOC$_j$= Set of sixty-six(66) location dummy variable [67 is default]

PUBLIC$_j$= Dummy variable set at 1 if a publicly held corporation; set at 0 if privately held

OWN 100%$_j$= Dummy variable set at 1 if plant$_j$ is 100% owned by one corporation; set at 0 otherwise

OWN 50-99%$_j$= Dummy variable set at 1 if 50-99% held by one corporation; set at 0 otherwise

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[43]Net utility all-plant is the depreciated value of the assets of each firm which are invested in generating capacity.

$ASSETS_{jt}$-Total net utility all plant of jth company in time t

Regression Equations:

The model developed below will be used to test the hypotheses developed within this dissertation. The Averch-Johnson model, as explored within chapter III, would suggest that a negative correlation between the levels of emissions and financial results for the firm. According to the technical literature, one would expect a positive relationship between the levels of emissions and the generation of electrical power. One would also expect to see emissions rise as the plants age. As to the effect that size of the plants will have on emissions, it may be difficult to separate the effects from the age of the plants, as the newer plants are the larger ones. The technical literature also shows that the type of plant should affect gaseous emissions, with the boiling water plants emitting higher levels of those elements. Finally, I would expect that public plants would emit lower levels of emissions, and that firms that are wholey owned would demonstrate tighter control on emissions. The model developed to investigate these hyptheses is developed below.

For this longitudinal data base, a semi-log, fixed-effect model was estimated. The fixed effects in the model refer to time and location. It was expected that the year of release and the location of the release would have specific differences. In this regard, Cheng Hsiao explained that:

> [T]he obvious generalization of the constant-intercept-and-slope model for panel data is to introduce dummy variables to account for the effects of those omitted variables that are specific to individual cross-sectional units but stay constant over time, and the effects that are specific to each time period but are the same for all cross-sectional units.[44]

The emissions were converted to logarithmic form in order to reduce the range of variability of the emissions. It is reasonable to argue that a change in financial results which lead to a change in release activity may be better captured in this form, as the variation in curies of the emissions by element was exponential in nature, while the variation in the financial variable was much more compact. The model is given by **Step I** below.

The estimation of a fixed-effect model with a lagged dependent variable requires the use of a two-stage least squares procedure. This procedure results in consistent estimates when an explanatory variable is correlated with the error term.[45] The estimation steps are as follows.

Step I: Estimate the model using ordinary least squares. Obtain from this step the model equation sum of squared errors (SSE).

$$EM_{ijt}=\beta_0+\sum_{t=1}^{J}\beta_{1j}LOC_j+\sum_{t=1}^{T}\beta_{2t}YEAR_t+\beta_3NETE_{jt}+\beta_4EM_{ijt-1}+\beta_5FIN1_{jt}$$

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[44]Cheng Hsiao, Analysis of Panel Data, (Cambridge University Press, Cambridge), 1986, 29.

[45]Hsiao, 72.

$$+\beta_6 FIN1_{jt-1}+\mu_{ijt}$$

Step II: Then find an instrumental variable (the goal being to find a variable which is highly correlated with EM_{ijt-1} that is not highly correlated with μ_{ijt}) from the following. To do this, regress lagged emissions on the explanatory variables other than the lagged emissions.

$$EM_{ijt-1}=\beta_0+\sum_{t=1}^{J}\beta_{1j}LOC_j+\sum_{t=1}^{T}\beta_{2t}YEAR_t+\beta_3 NETE_{jt}+\beta_4 FIN1_{jt}+\beta_5 FIN1_{jt-1}$$

$$+\mu_{ijt}$$

From this, obtain the fitted values of EM_{ijt-1} and call it est. EM_{ijt-1}. Use the est. EM_{ijt-1} as the instrumental variable and estimate the model in **step III**.

Step III: $$EM_{ijt}=\beta_0+\sum_{t=1}^{J}\beta_{1j}LOC_j+\sum_{t=1}^{T}\beta_{2t}YEAR_t+\beta_3 NETE_{jt}+\beta_4 est.\ EM_{ijt-1}$$

$$+\beta_5 FIN1_{jt}+\beta_6 FIN1_{jt-1}+\mu_{ijt}$$

Step IV: Obtain the sum of squared errors from **Step I** (SSE) and **Step III** (SSE*) and correct the standard errors (SE) of the coefficients from **Step III** by the square root of SSE/SSE*, calling the corrected standard error SE*. Correct the t-statistics and probabilities using the SE*.

Step V: Explore the model for heteroskedasticity by using the Breutsch-Pagan test after **Steps** I through IV were completed.[46] (Preliminary heteroskedastic tests had been run on the emissions in curies and on emissions in log form. The log form reduced this potential.)[47] Displayed on page 176 is table 4.6 which notes the statistics of the squared residuals generated by the regression equations.

The results for five elements exhibited increased heteroskedasticity relative to the procedure in **Step I**. These five included XE135, XE133, I131, KR85M and H3b. For these five elements, the following procedures were run.

Step V1: Estimate the model using ordinary least squares. Obtain from this step the model equation sum of squared errors (SSE).

$$EM_{ijt}=\beta_0+\sum_{t=1}^{J}\beta_{1j}LOC_j+\sum_{t=1}^{T}\beta_{2t}YEAR_t+\beta_3NETE_{jt}+\beta_4EM_{ijt-1}+\beta_5FIN1_{jt}$$
$$+\beta_6FIN1_{jt-1}+\mu_{ijt}$$

Step V 2: Weighted least squares was used where the form of the weight was derived from the Breutsch-Pagan heteroskedastic tests

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[46]The B/P test consisted of estimating e_i2/estimated variance= f($NETE_{jt}$, EM_{ijt-1}, $FIN1_{jt}$, and $FIN1_{jt-1}$). These four independent variables were most likely to be related to the variance of the disturbance term.

[47]The Breutsch-Pagan test was done.

on $NETE_{jt}$, EM_{ijt-1}, $FIN1_{jt}$, and $FIN1_{jt-1}$, where T=square root of the Breutsch-Pagan form.[48]

$$EM_{ijt}/T = \beta_0/T + \sum_{j=1}^{J} \beta_{1j} LOC_j/T + \sum_{t=1}^{T} \beta_{2t} YEAR_t/T + \beta_3 NETE_{jt}/T$$

$$+ \beta_4 \ln\ EM_{ijt-1}/T + \beta_5 FIN1_{jt}/T + \beta_6 FIN1_{jt-1}/T + \varnothing_{ijt}$$

Step V 3: Then find an instrumental variable (the goal being to find a variable which is highly correlated with EM_{ijt-1}/T that is not highly correlated with $\varnothing_{ijt}$) from the following. To do this, regress lagged emissions on the explanatory variables other than the lagged emissions.

$$EM_{ijt-1}/T = \beta_0/T + \sum_{j=1}^{J} \beta_{1j} LOC_j/T + \sum_{t=1}^{T} \beta_{2t} YEAR_t/T + \beta_3 NETE_{jt}/T$$

$$+ \beta_4 FIN1_{jt}/T + \beta_5 FIN1_{jt-1}/T + \varnothing_{ijt}$$

From this, obtain the fitted values of EM_{ijt-1}/T and call them estimated EM_{ijt-1}/T. Use the estimated EM_{ijt-1}/T as the instrumental variable and estimate the model in **step V 4**.

Step V 4: Using the instrumental variable estimated EM_{ijt-1}/T, estimate:

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[48]Ramu Ramanathan, Introductory Econometrics with Applications (San Diego, Ca.: Harcourt, Brace Jovanovich, Publishers, 1989): 454.

$$EM_{ijt}/T = \beta_0/T + \sum_{j=1}^{J} \beta_{1j} LOC_j/T + \sum_{t=1}^{T} \beta_{2t} YEAR_t/T + \beta_3 NETE_{jt}/T$$

$$+ \beta_4 est.\ EM_{ijt-1}/T + \beta_5 FIN1_{jt}/T + \beta_6 FIN1_{jt-1}/T + \varnothing_{ijt}$$

Step V 5: Again, retrieve the sum of squared errors from **Step V 1** (SSE) and **Step V 4** (SSE*) and correct the standard errors (SE) of the coefficients from **Step III** by the square root of SSE/SSE*, calling the corrected standard errors SE*. Then, recalculate the t-statistics and probabilities using the SE*.

This initial estimation was designed to focus upon the hypothesis that emissions would be a function of financial and technical variables. Within this initial estimation, it was anticipated that the coefficients on net electrical generation, lagged emissions, and first year would be positive. Conversely, it was expected that the coefficients on the financial variables would be negative.

Step VI: From either **step III** or **step V 4**, retrieve and define a new variable, called LOCINTj, which is the estimated intercept associated with the 66 dummy variables used to capture the location component within **step III** or **step V 4.** This stage was necessary due to the qualitative nature of many of the variables defined in the data base as variables which potentially impact emissions. The inclusion of dummy variables which do not vary by location (e.g., the SIZE dummy variables) in a fixed-effect model with location dummy variables would result in perfect collinearity among the two sets of dummy variables. Thus, a number of dummy variables which are of interest could not be included in the model. Yet, these variables are hypothesized to affect emissions. To see their possible effects, we can see if the estimated coefficients of the location dummy variables are associated with the other dummy variables. To do this, the following equation was estimated.

$$LOCINT_j = \partial_0 + \partial_1 TYPE_i + \partial_2 SIZE <500_j + \partial_3 SIZE5\text{-}1000_j + \partial_4 DATE<66_j + \partial_5 DATE66\text{-}70_j + \partial_6 OWN100\%_i + \partial_7 OWN50\text{-}99\%_i + \partial_8 PUBLIC_i + \Omega_j$$

The hypotheses here being that emissions should be different based upon the type of plant, the size and age of the plant, and the ownership characteristics of the plants. I would expect the smaller plants to emit higher levels of emissions relative to their electrical generation, that age would be a factor in increasing levels of emissions, and that 100% percent owned plants would emit lower levels

Results:

I have summarized the statistical results in tables 4.2, 4.3, and 4.4. Table 4.2 contains the results of the two-stage least squares estimation of the model. Table 4.3 represents the results of the influences of the dummy variables on the LOCINT, which is the firm-specific intercept. Table 4.4 contains the results for the estimated coefficients of the time-specific effect dummy variables. The results reveal the following information.

In table 4.2, on pages 146-147, 15 of the 23 coefficients for the lagged emission variable were significant at the 10% level or better; 20 of the 23 coefficients were also positive, the sign expected. Initial analysis indicates that once a release pattern is established for a particular facility, this pattern continues through time.

Again in table 4.2, the operational variable, net electrical generation, 7 of the 23 coefficients were significant at the 10% level or better; 14 of the 23 coefficients were positive (the sign expected), however, 9 were negative.

Again in table 4.2, on the financial side of the equation, little evidence to support the original hypothesis was found, as 8 of the 23 coefficients for the variable FIN 1 were significant at the 10% level or better. This was consistent with the findings of Feinstein.[49] Interestingly, 20 of the 23 coefficients were positive, exactly the opposite of what was expected. The lagged financial variable revealed similar results, as only 5 of the 23 coefficients were significant at the 10% level or better. When one reviews the aggregated emissions for the total fission and activation gasses, the Iodine 131 and particulates, and the mixed fission and activation gasses, one sees two of the three groupings do have a very significant relationship to profits. This relationship is positive, indicating that as profits rise relative to the financial constraints, emissions also rise. This is consistent with the following logic. As plants operate at higher levels of efficiency (in terms of higher

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[49]Feinstein, 115-154.

output levels of electricity), and, since the plants typically are used by utilities as base-line facilities, we would see per unit cost of electricity falling as economies of scale are achieved, and the higher output levels would generate higher levels of emissions. However, since corporate wide financial results were used, which include all of the operations of the firm, and not the specific financial results of the specific plants separate from other operations, this perhaps could be expected. Whether an analysis with the specific plant information would yield different results is moot, as the data, to this writer's knowledge, is not available.

Table 4.3, on pages 148-149, contains the results of regressing the estimated location coefficients from the fixed-effect model on a variety of dummy variables which were not included in the fixed-effect model because of collinearity problems (see step V). The results were surprising. For eleven of the 23 coefficients, the type of plant variable significantly affected the location intercept (or location variable). Only 7 of the 46 coefficients on the size dummy variables were significant; twenty-two of the forty-six coefficients were positive; the remaining twenty-four were negative. These results indicate that there is little difference in release behavior from the earlier, smaller plants and the later, larger ones. As to the age of the plants, 18 of the 46 coefficients were significant, with 33 of the 46 coefficients negative, indicating that in general, the age of the plant does not significantly influence emissions. Exceptions are CO 60, KR 85M, I 131, XE 133, and XE 135 in which both coefficients are negative and significant. For three of the elements (MN 54, SR 90, and CS 134), the older plants built before 1966 emitted significantly higher emissions. For four other elements (XE 135, BA/LA 140, CE 141, and M F & A), the plants built between 1966-1970 emitted significantly higher emissions than the newer ones.

The ownership criteria (percentage of stock ownership by the lead owner) results were also surprising. Only 10 of the 69 coefficients were significant at the 10% level or better, which indicates that the release behavior of the plants did not differ whether a plant was 100% owned or not. The final variable I looked at compared privately held firms with public firms. This showed only one element different at the 10% level which indicates that there is no difference between these two groupings.

A review of the significance of the coefficients on the $YEAR_t$ dummy variables in the fixed-effect model (table 4.4-page 150), where 1984 is the default year, showed for many of the elements a significant difference between the earlier years of emissions, which run in this report from 1974-1979, and the emissions from 1984, which was the default year. These results indicate that of the possible 115 coefficients (23 elements times 5 years) for the years 1975-1979, 46 (38 positive, 8 negative) were significant at the 10% or better level. Of the possible 89 coefficients (23 elements times 4 years, less F&A, I 131 &P's, and MF&A, which had no observations for 1984) for the years 1980-1983, only 23 (16 positive, 7 negative) were significant at the 10% level or better. Thirteen of the twenty-three elements tested exhibited this pattern, with tritium, Kr 85M, and xenon 133 showing a strong pattern. To further test this, one would need to create a different dummy variable which grouped the emissions from 1974-1979 instead of using the time-specific dummy variables assigned by year.

This pattern of higher emissions for some elements before 1979 and lower emissions after 1979 can be partially explained by the following. During 1979, of course, the accident at Three Mile Island, plant #2, occurred. The general public and the regulatory bodies' interest was piqued by this event. In 1979, "[A] method for assuring that occupational radiation exposures at nuclear power plants are kept as low as is reasonably achievable (ALARA) was developed and documented"[50] by the NRC. AOG equipment was being installed, and better fuel rods were being supplied to the utilities from the government facilities.[51] Finally, the NRC's acceptance of the utility's reports on the levels of emissions ended. Through mid 1979, the semi-annual reports submitted by the utilities were accepted by the NRC without independent verification (except as noted previously). After 1979, extensive monitoring procedures from the NRC and from independent bodies were implemented.

This change in behavior can also be explained by the fact that it was now in the NRC's and the utilities' best interests to contain

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[50]Nuclear Regulatory Commission, 1979 Annual Report , 238.

[51]Nuclear Regulatory Commission, Radioactive Materials Released from Nuclear Power Plants 1979 (Washington, D.C.: November 1981), 3.

emissions to a level even lower than had been previously achieved. From the NRC's viewpoint that in order to maintain their existence as a viable regulatory body, they must now demonstrate to the general public and to Congress that they indeed act as a regulatory body with the best interests of the public in mind. From the utilities' viewpoint, since the investment in the established facilities and in the plants in construction needed to be protected, their interests coincided with the NRC's interest in limiting emissions at a time when the public scrutiny of the plants was heightened by recent events. What better way to protect your current and continuing investment, and your future rate of return on those investments, than by voluntarily reducing the level of emissions which had become such a concern of the public. And, since "[N]early all of the radioactive materials reported as being released in effluents is planned and results from normal operation...."[52], then one can certainly argue that a serious conscious effort by the plants' management and technical staff (post-TMI 2) to plan fewer releases was accomplished for at least some of the elements.

Finally, I was unable to include the first years variable in the model, mainly because the lagged form of the regression equations limited the number of observations. I was therefore unable to test the learning curve hypothesis. Further analysis and interpretation will follow within chapter V.

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[52]Nuclear Regulatory Commission, Radioactive Materials Released from Nuclear Power Plants 1979 , 3.

TABLE 4.1

Excluded Observations

ELEMENT	#OBSERVATIONS	# EXCL.	% EXCL.
TRITIUM	560	0	0.0
CHROMIUM 51	474	7	1.5
MAGNESIUM 54	532	6	1.1
IRON 59	427	17	4.0
COBALT 60	561	4	0.7
KRYPTON 85	428	1	0.2
KRYPTON 85M	503	3	0.6
STONTIUM 89	483	12	2.8
STRONTIUM 90	472	41	8.7
NIOBIUM/ZIRCON. 95	456	13	2.9
SILVER 110M	308	5	1.6
IODINE 131	547	2	0.4
XENON 133	546	0	0.0
CESIUM 134	540	7	1.3
XENON 135	541	0	0.0
CESIUM 137	556	8	1.4
BARIUM/LANTH. 140	446	14	3.1
CERIUM 141	294	28	9.5
CERIUM 144	282	15	5.3
NEPTUNIUM 239	154	10	6.5
FISSION & ACTIVAT.	504	0	0.0
I 131 & PARTICUL.	500	1	0.2
MIX. FISS. & ACTIV.	482	2	0.4

TABLE 4.2

COEFFICIENTS AND STANDARD ERRORS

ELEM.	N	R2	ADJ.R2	EM T-1	NET E	FIN 1	FIN1 T-1
H3b	405	.99	.988	.555 *	1.797E-7 *	.049	.158
(se)				(.106)	(4.022E-8)	(.127)	(.135)
CR 51	319	.606	.507	.0281	.389E-7 *	.755 *	.534 *
(se)				(.03)	(5.968E-8)	(.282)	(.282)
MN 54	380	.677	.609	1.352 *	1.689E-7 *	.473 *	-.005
(se)				(.234)	(6.589E-7)	(.245)	(.233)
FE 59	260	.597	.478	-.475	1.071E-7	-.173	-.304
(se)				(.961)	(8.221E-8)	(.711)	(.275)
CO 60	413	.687	.627	1.171	*5.904E-8	.287	.196
(se)				(.222)	(4.509E-8)	(.211)	(.207)
KR 85	278	.566	.447	-.3264	.156E-9	.616	.455
(se)				(.634)	(1.462E-7)	(.683)	(.681)
KR 85M	345	.948	.936	2.596	2.573E-7	-3.591	-4.561
(se)				(2.63)	(3.133E-7)	(4.810)	(6.029)
SR 89	335	.574	.475	.936 *	2.743E-8	.584	-.014
(se)				(.561)	(1.064E-7)	(.385)	(.300)
SR 90	287	.48	.353	.341	7.332E-9	.197	.021
(se)				(.633)	(1.183E-7)	(.471)	(.263)
NB/Z95	301	.578	.468	1.767 *	-3.576E-7 *	1.456 *	-.232
(se)				(.492)	(1.843E-7)	(.565)	(.411)
AG110M	188	.714	.613	1.139	-1.618E-7	.430	-.435
(se)				(1.056)	(2.448E-7)	(.446)	(.48)
I 131	399	.59	.504	2.562 *	-2.991E-8	.43 *	-1.03*
(se)				(.561)	(3.648E-8)	(.25)	(.281)

* = SIGNIFICANT @ 10% OR BETTER

TABLE 4.2

Co-efficients and standard errors

ELEM.	N	R2	ADJ.R2	EM T-1	NET E	FIN 1	FIN1 T-1
XE 133	395	.971	.965	1.069 *	-1.157E-7	.416	.035
(se)				(.501)	(3.228E-7)	(.294)	(.279)
CS 134	392	.627	.551	.756 *	1.298E-8	.595 *	.219
(se)				(.150)	(6.832E-8)	(.279)	(.275)
XE 135	395	.954	.944	4.803 *	-1.674E-6*	. 453	-.710*
(se)				(1.616)	(6.915E-7)	(.283)	(.389)
CS 137	401	.641	.57	-16.64 *	4.350E-6*	-3.54*	5.63*
(se)				(8.789)	(2.199E-6)	(2.086)	(2.78)
B/L 140	285	.705	.626	1.52 *	1.477E-8	.692	.500
(se)				(.691)	(8.415E-8)	(.575)	(.372)
CE 141	154	.72	.611	.736	4.309E-8	.036	.736*
(se)				(.455)	(9.459E-8)	(.402)	(.410)
CE 144	149	.617	.462	2.152*	-3.065E-8	.956	-2.803
(se)				(.937)	(1.088E-7)	(.620)	(1.887)
NP 239	75	.816	.68	-.514	-2.106E-7	2.526	8.440
(se)				(5.116)	(4.274E-7)	(16.10)	(7.371)
F. & A.	353	.672	.604	.566*	1.287E-7	.339	.190
(se)				(.246)	(8.498E-8)	(.237)	(.243)
I 131/P	358	.697	.631	.544*	2.037E-8	.452*	.024
(se)				(.189)	(7.762E-8)	(.261)	(.270)
MF&A	341	.698	.632	.723*	-4.827E-7*	.583*	-.240
(se)				(.590)	(1.411E-7)	(.225)	(.200)

* = SIGNIFICANT @10% OR BETTER

TABLE 4.3

COEFFICIENTS AND STANDARD ERRORS-DUMMY VARIABLES

ELEM	R2	TYPE	SZ<5	SZ5-10	<66	66-70	OWN100	OWN5-100	PUBL
H3b	.57	1.37*	.656*	.209	-.19	-.51	-.38	-.01	.039
(se)		(.19)	(.32)	(.24)	(.41)	(.32)	(.26)	(.29)	(.28)
CR 51	.13	.38	-.84	-.47	-.68	-1.11	.62	.62	.59
(se)		(.55)	(1.02)	(.69)	(1.23)	(.96)	(.74)	(.83)	(.80)
MN 54	.24	.21	-.26	-.21	-1.27*	-.56	-.24	-.15	-.15
(se)		(.28)	(.51)	(.36)	(.64)	(.51)	(.39)	(.43)	(.41)
FE 59	.31	-.08	-.95	-.90	-1.30	-1.36	.73	-.03	.92
(se)		(.53)	(1.01)	(.64)	(1.16)	(.89)	(.79)	(.85)	(.72)
CO 60	.46	.28	.12	-.10	-1.69*	-1.07*	-.15	.24	.02
(se)		(.19)	(.34)	(.25)	(.44)	(.35)	(.25)	(.29)	(.28)
KR 85	.10	1.34	-1.26	-1.12	.78	.10	1.40	1.26	1.13
(se)		(1.18)	(1.82)	(1.40)	(2.69)	(2.16)	(1.55)	(1.73)	(1.48)
KR 85M	.49	5.20*	.95	.03	-4.73*	-3.79*	-2.49	-1.05	-.68
(se)		(1.01)	(1.82)	(1.39)	(2.37)	(1.91)	(1.60)	(1.72)	(1.48)
SR 89	.18	.18	.70*	.30	-.30	.22	.13	-.03	-.15
(se)		(.18)	(.34)	(.24)	(.42)	(.35)	(.25)	(.27)	(.27)
SR 90	.22	.001	-.75	-.59	1.53*	.79	.72*	.77*	.15
(se)		(.28)	(.54)	(.39)	(.81)	(.75)	(.39)	(.42)	(.43)
N/Z95	.21	.17	.14	.42	-2.10	-.69	-.60	-.46	-1.22
(se)		(.57)	(1.02)	(.72)	(1.37)	(1.12)	(.80)	(.86)	(.84)
AG110	.18	.22	-.55	-.24	-.66	-.39	-.03	-.16	.10
(se)		(.30)	(.55)	(.37)	(.73)	(.59)	(.41)	(.45)	(.50)
I 131	.39	1.85*	1.24	.62	-4.95*	-4.04*	-3.15*	2.07*	1.60
(se)		(.74)	(1.35)	(.91)	(1.62)	(1.23)	(1.06)	(1.16)	(1.07)

*=Significant at 10% level or better

TABLE 4.3

COEFFICIENTS AND STANDARD ERRORS-DUMMY VARIABLES

ELEM	R2	TYPE	SZ<5	SZ5-10	<66	66-70	OWN100	OWN5-100	PUBL
XE133	.48	.74*	-1.05*	-.36	-2.31*	-2.08*	-.25	-.20	.66
(se)		(.33)	(.58)	(.42)	(.72)	(.56)	(.48)	(.52)	(.48)
CS 34	.38	.57*	-.72*	-.49*	-.19	.13	.45	.47	.35
(se)		(.22)	(.39)	(.28)	(.55)	(.45)	(.30)	(.33)	(.32)
XE135	.66	14.35*	2.59	.69	-19.91*	-10.14*	-9.31*	-7.70*	.03
(se)		(2.42)	(4.15)	(2.99)	(5.20)	(4.00)	(3.65)	(3.97)	(3.44)
CS137	.19	6.98	27.53	5.63	44.02	18.46	1.97	4.90	-.83
(se)		(12.17)	(21.64)	(15.35)	(29.41)	(25.18)	(16.90)	(18.60)	(17.25)
B/L140	.41	1.19*	.47	.36	-2.85*	-1.50*	-.86	-.49	.55
(se)		(.43)	(.79)	(.58)	(1.05)	(.87)	(.67)	(.79)	(.65)
CE141	.34	-.03	-.34	-.52	1.98*	1.26	-.37	-.65	.57
(se)		(.37)	(.63)	(.55)	(.92)	(.87)	(.73)	(.80)	(.48)
CE144	.36	-2.06*	.48	.93	-4.22*	-.82	-.24	-1.64	-1.65
(se)		(1.11)	(1.89)	(1.65)	(2.26)	(1.88)	(2.79)	(3.07)	(1.27)
NP239	.56	-.44	9.13	10.53*	-9.29	-11.90*	-17.38*	-18.75*	1.44
(se)		(2.36)	(5.26)	(4.33)	(5.82)	(4.93)	(5.97)	(6.04)	(2.40)
F&A	.44	-.80*	-.40	-.03	.05	-.26	.19	.06	.71*
(se)		(.20)	(.35)	(.26)	(.52)	(.45)	(.30)	(.32)	(.29)
I131/P	.45	-.73*	-1.45*	-.47	.69	.79	1.17*	.70*	-.54
(se)		(.25)	(.44)	(.32)	(.65)	(.57)	(.33)	(.37)	(.37)
MF&A	.19	-1.76*	1.32	.98	-4.70*	-1.25	-.62	-.42	-2.00
(se)		(1.05)	(1.81)	(1.35)	(2.74)	(2.37)	(1.44)	(1.57)	(1.56)

*=Significant at 10% level or better

TABLE 4.4

YEAR COEFFICIENTS: SIGNIFICANCE AND SIGNS

ELEMENT	75	76	77	78	79	80	81	82	83
TRITIUM	C+	A+	B+	A+	A+	+	-	+	+
CHROMIUM 51	C+	A+	+	+	+	+	+	+	+
MAGNESIUM 54	-	-	-	-	+	+	+	-	-
IRON 59	C+	+	C+	B+	+	-	-	-	+
COBALT 60	A+	+	A+	-	-	+	+	-	+
KRYPTON 85	+	C+	B+	C+	C+	+	+	-	+
KRYPTON 85M	-	-	-	-	-	-	-	-	-
STONTIUM 89	+	-	+	+	+	+	-	-	+
STRONTIUM 90	+	+	+	+	+	+	+	+	-
NIOB/ZIRC 95	-	-	-	-	C-	B-	-	B-	C-
SILVER 110M	B+	-	+	+	-	+	-	+	+
IODINE 131	-	C+	-	-	-	-	B+	-	C+
XENON 133	C+	C+	C+	A+	A+	-	A+	+	+
CESIUM 134	+	A+	A+	+	-	+	+	-	-
XENON 135	+	A -	-	+	-	B-	B+	-	B+
CESIUM 137	B+	A -	B+	+	A+	B+	B+	A+	B-
BARIUM/LA 140	C+	+	C+	+	-	+	B+	B+	-
CERIUM 141	+	+	-	+	-	-	-	A+	-
CERIUM 144	B -	-	A -	A -	-	-	A-	A-	A-
NEPTUNIUM 239	+	+	+	A+	+	+	C+	+	B+
F & A	C+	A+	B+	+	+	-	+	-	NR
I 131 & PART.	C+	A+	A+	+	+	+	+	-	NR
MIXED F & A	C-	-	B+	-	A-	C+	B+	-	NR

A-significant at 10%
B-significant at 5%
C-significant at 1%
NR-No observations
+,-: sign of coeff.

TABLE 4.5

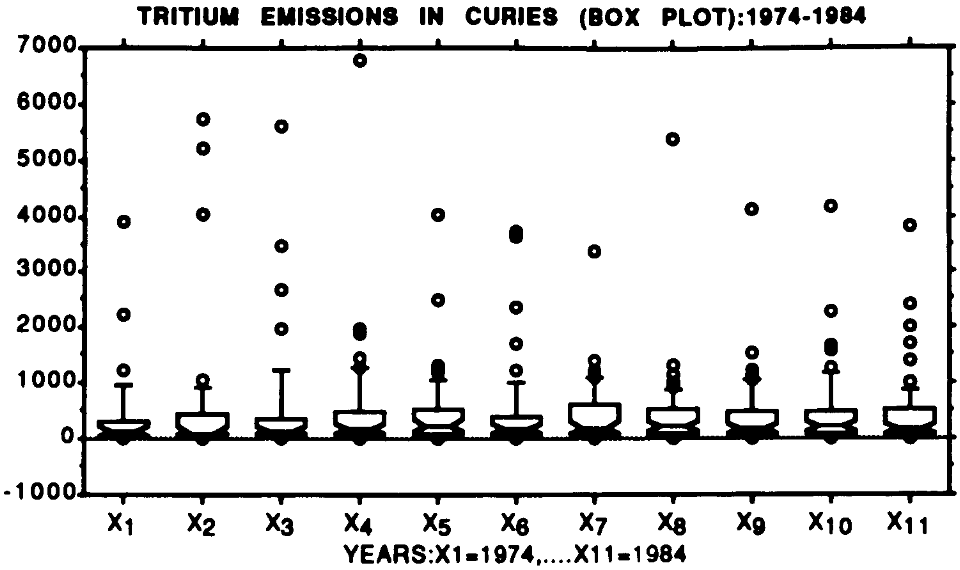
EMISSIONS: MINIMUM, MAXIMUM, MEAN AND STANDARD DEVIATION

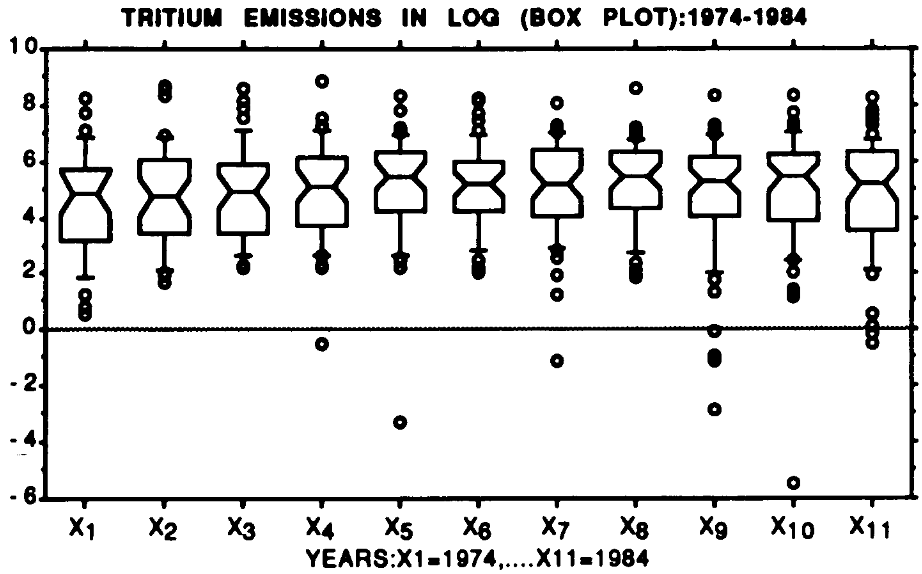
ELEMENT	MINIMUM EM	MAXIMUM EM	MEAN EM	STANDARD DEV.
TRITIUM	1.000E-5	6,789.000	435.700	806.200
CR 51	1.000E-5	9.500	0.144	0.573
MN 54	1.000E-5	49.089	0.188	2.164
FE 59	1.000E-5	0.602	0.017	0.047
CO 60	1.000E-5	165.353	0.669	7.054
KR 85	1.000E-5	161,517.300	1,493.560	10,379.840
KR 85M	1.000E-5	167,000.000	3,097.119	13,280.044
SR 89	1.000E-5	9.868	0.115	0.677
SR 90	1.000E-5	0.289	0.006	0.022
NB/ZR 95	1.000E-5	0.996	0.034	0.094
AG 110M	1.000E-5	4.512	0.038	0.264
I 131	1.000E-5	40.627	0.675	2.557
XE 133	1.000E-5	8,210,000.031	26,339.427	353,043.867
CS 134	1.000E-5	72.102	0.534	4.219
XE 135	1.000E-5	1,580,000.000	13,257.905	85,884.362
CS 137	1.000E-5	95.203	0.826	5.713
BA/LA 140	1.000E-5	11.741	0.117	0.678
CE 141	1.000E-5	0.218	0.008	0.024
CE 144	1.000E-5	1.229	0.019	0.091
NP 239	1.000E-5	0.549	0.016	0.057
F & A	1.000E-5	9,970,000.000	75,303.613	485,868.702
I 131&P'S	1.000E-5	80.047	1.536	7.123
MIXED F&A	1.000E-5	199.000	3.557	13.931

FIGURES IN CURIES(Ci)

CHARTS 4.1

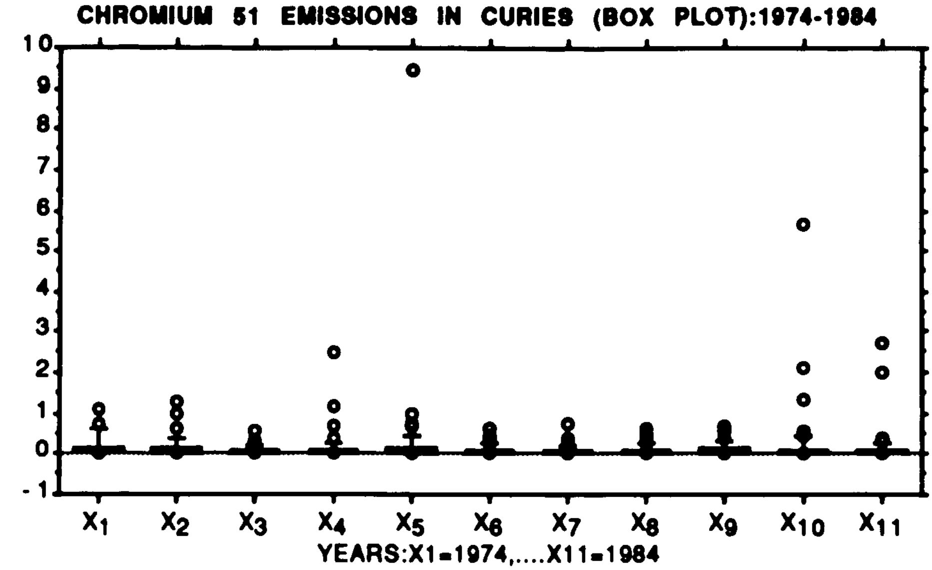
EMISSIONS DISTRIBUTION IN CURIES AND IN LOGARITHMIC FORM

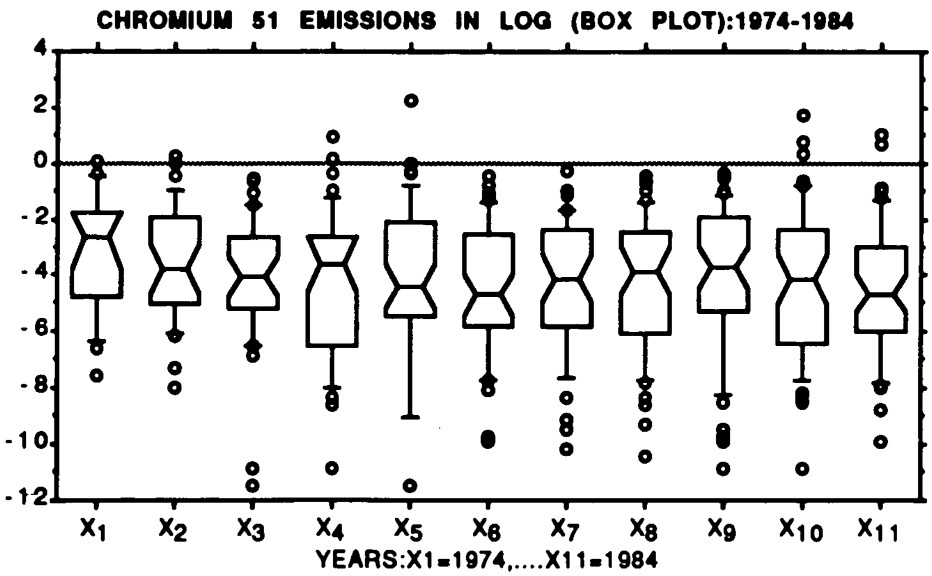




CHARTS 4.1

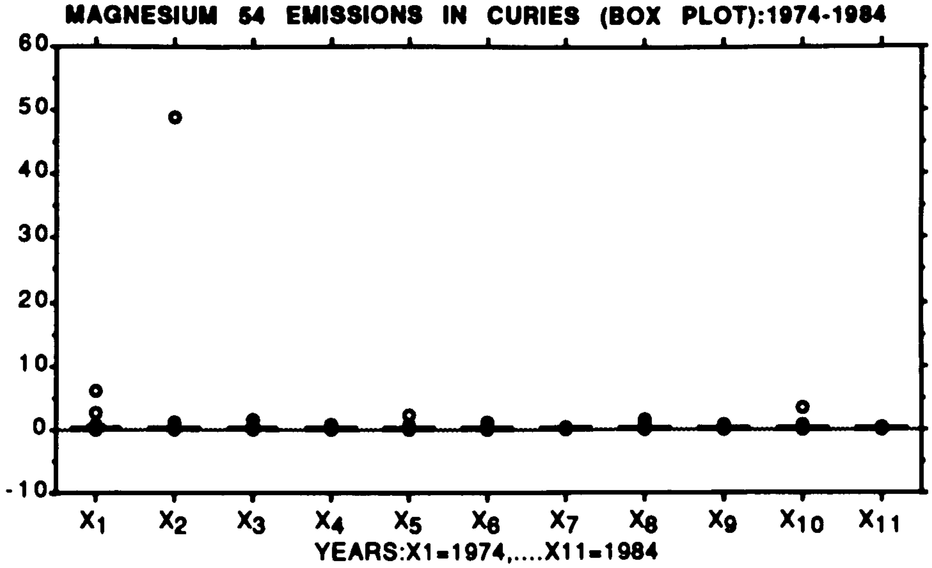
EMISSIONS DISTRIBUTION IN CURIES AND IN LOGARITHMIC FORM

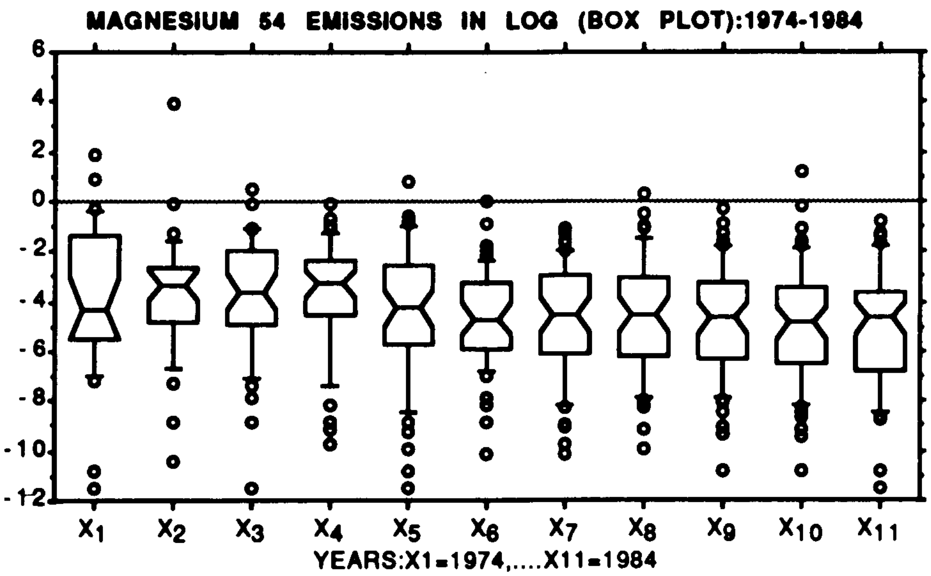




CHARTS 4.1

EMISSIONS DISTRIBUTION IN CURIES AND IN LOGARITHMIC FORM

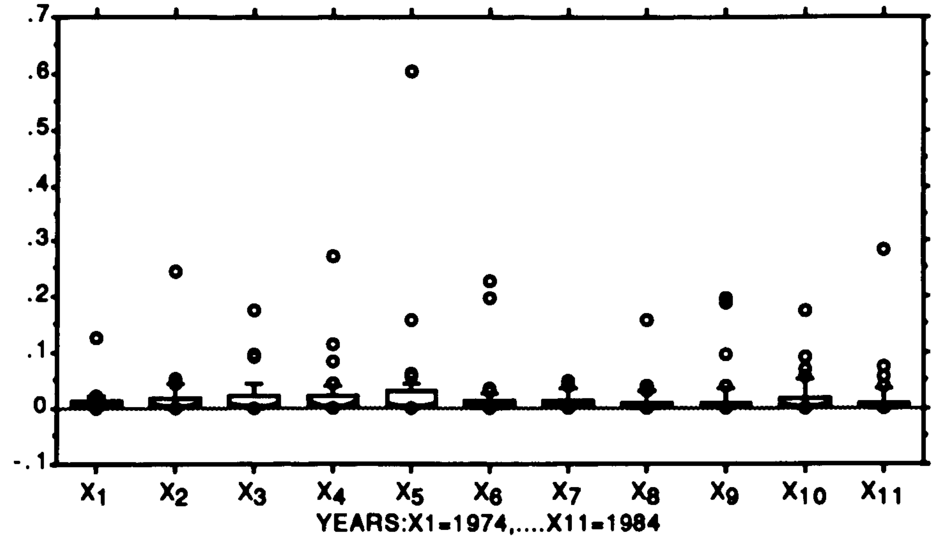




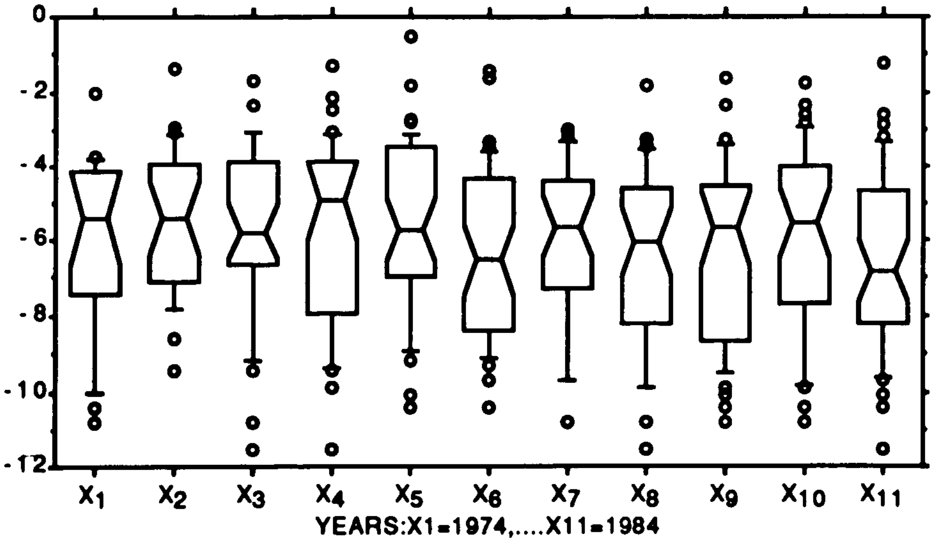
CHARTS 4.1

EMISSIONS DISTRIBUTION IN CURIES AND IN LOGARITHMIC FORM

IRON 59 EMISSIONS IN CURIES:1974-1984

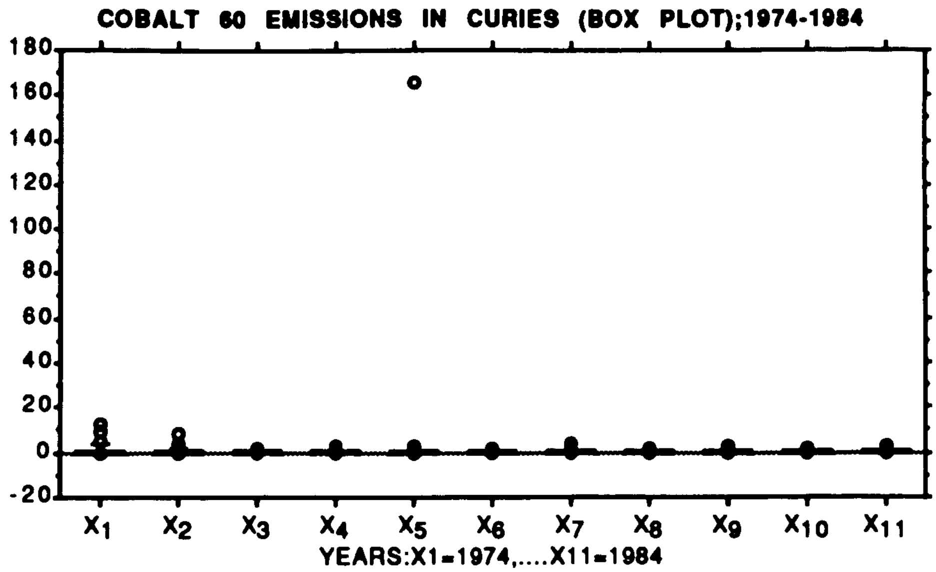


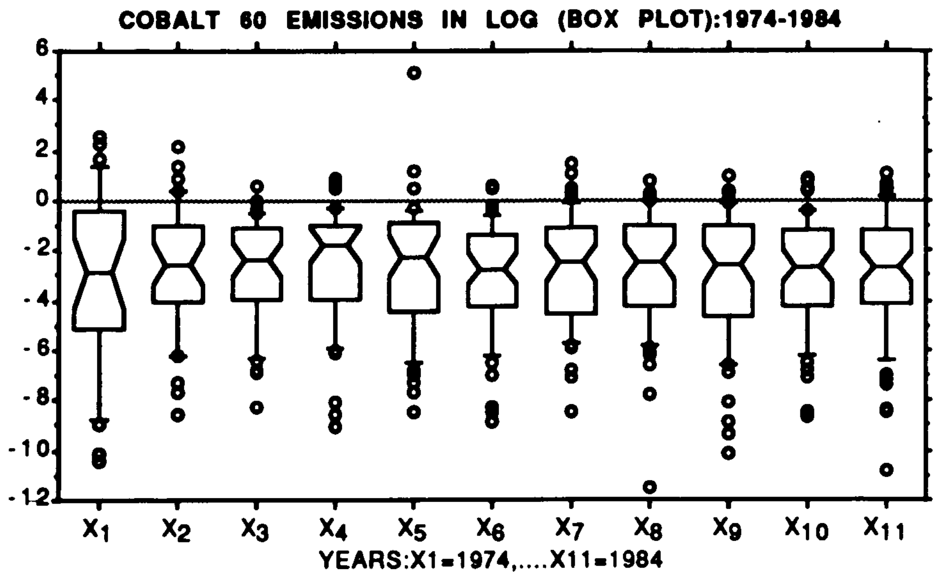
IRON 59 EMISSIONS IN LOG (BOX PLOT):1974-1984



CHARTS 4.1

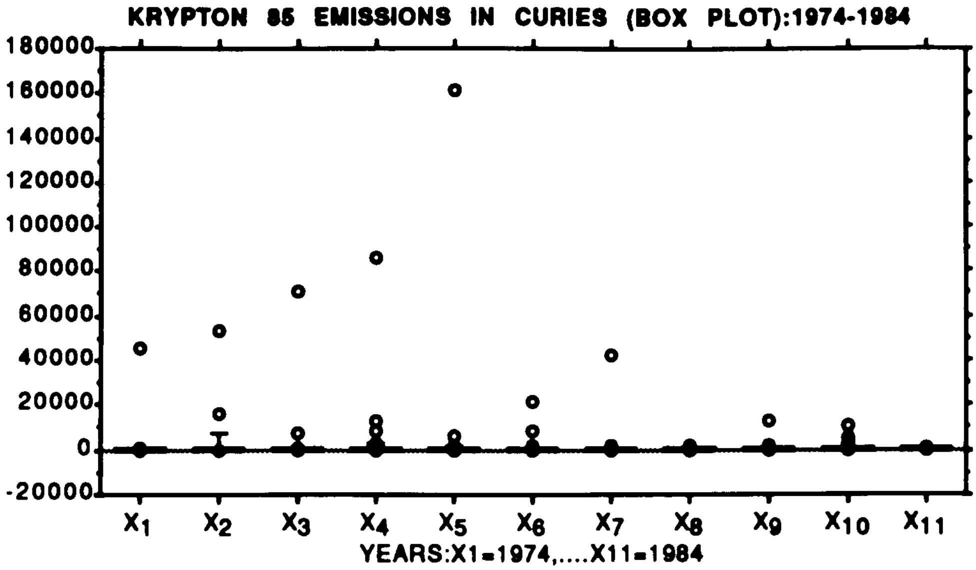
EMISSIONS DISTRIBUTION IN CURIES AND IN LOGARITHMIC FORM

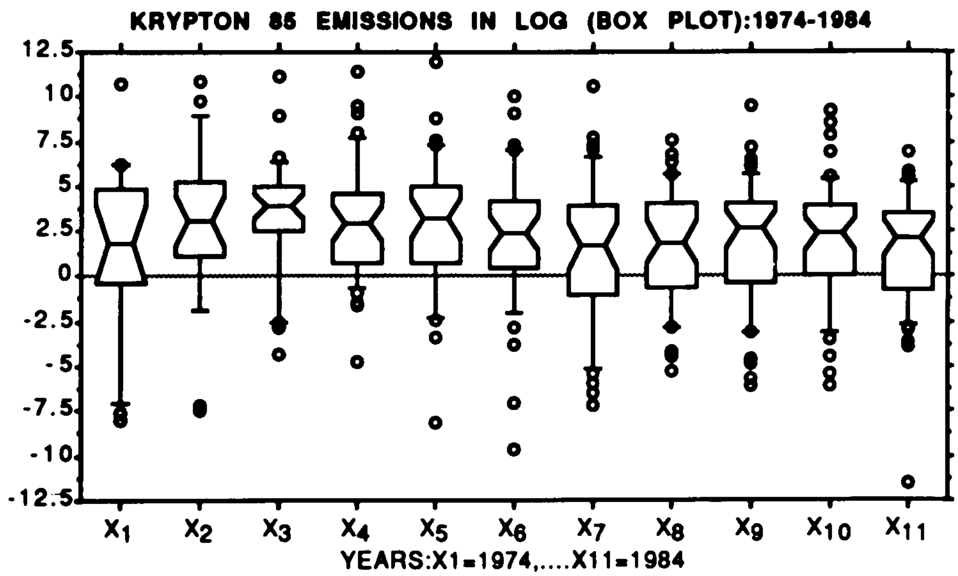




CHARTS 4.1

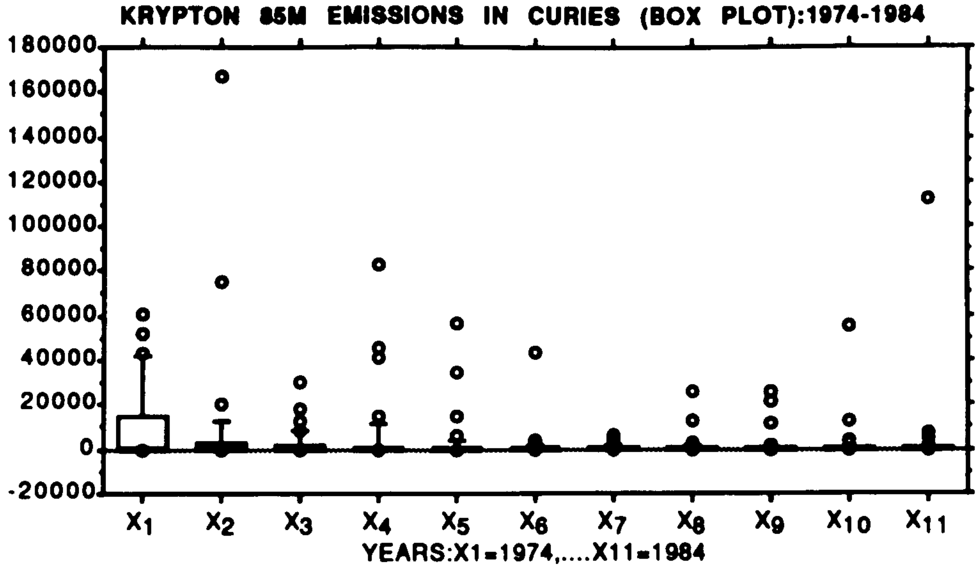
EMISSIONS DISTRIBUTION IN CURIES AND IN LOGARITHMIC FORM

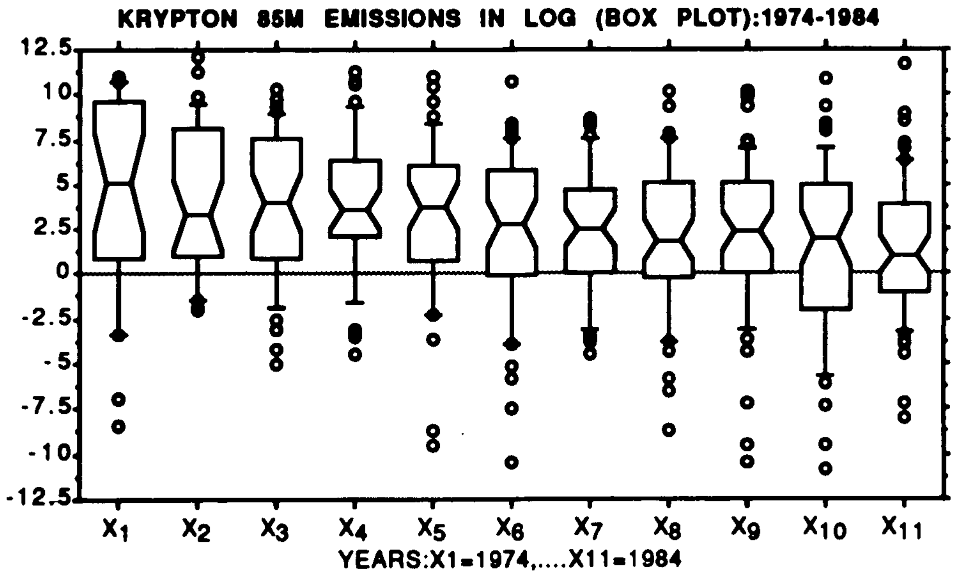




CHARTS 4.1

EMISSIONS DISTRIBUTION IN CURIES AND IN LOGARITHMIC FORM





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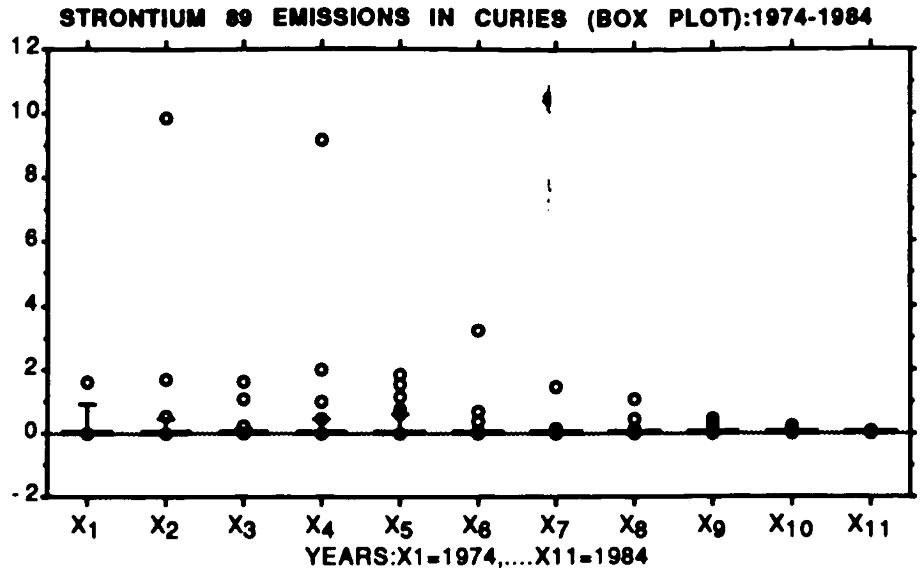

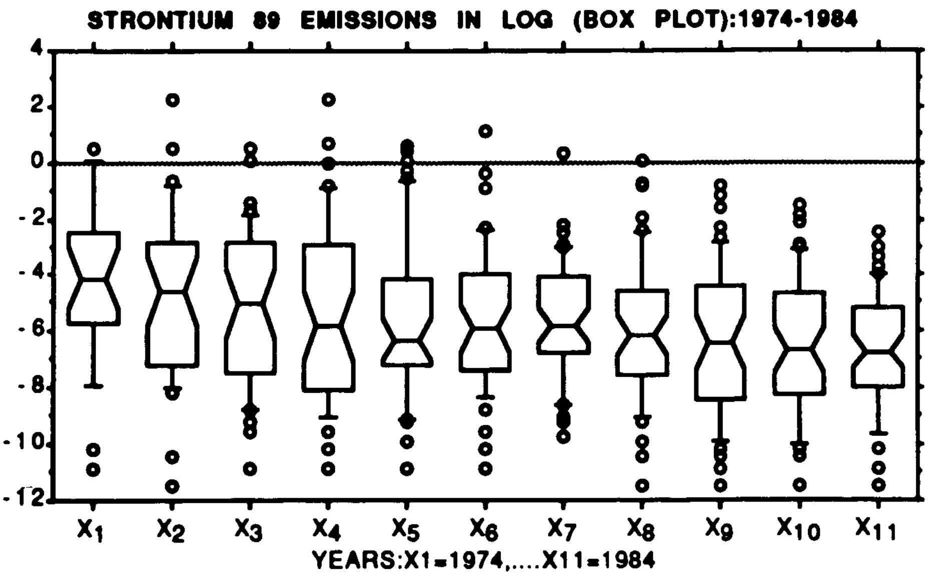

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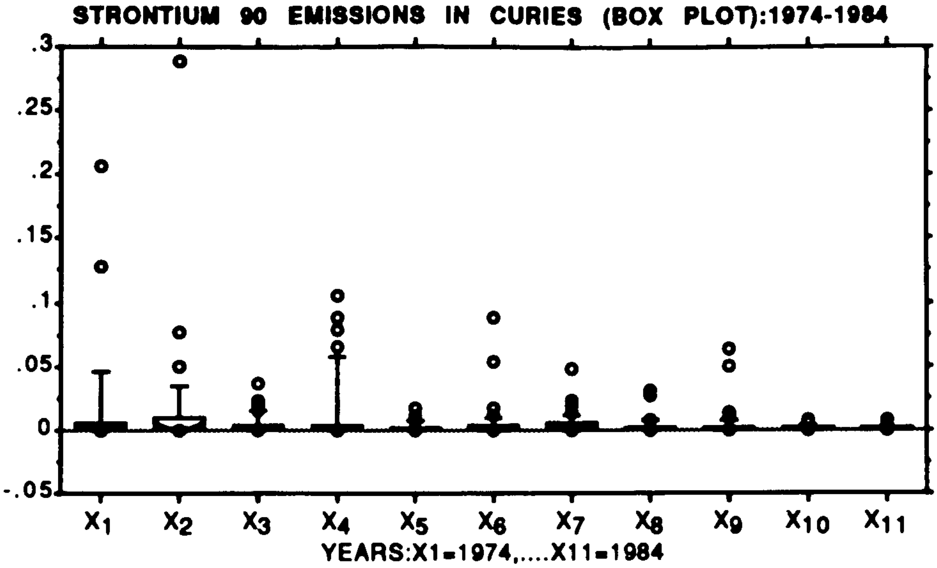

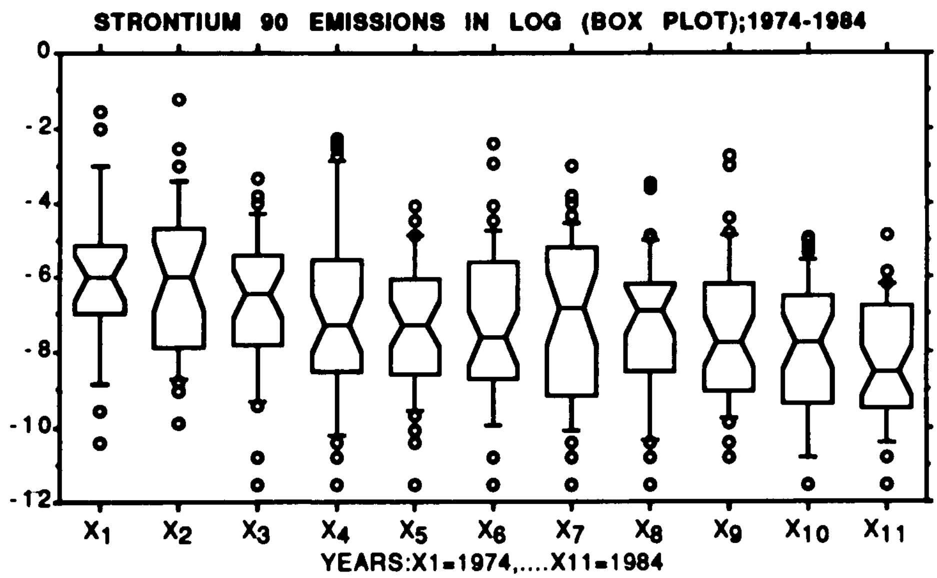

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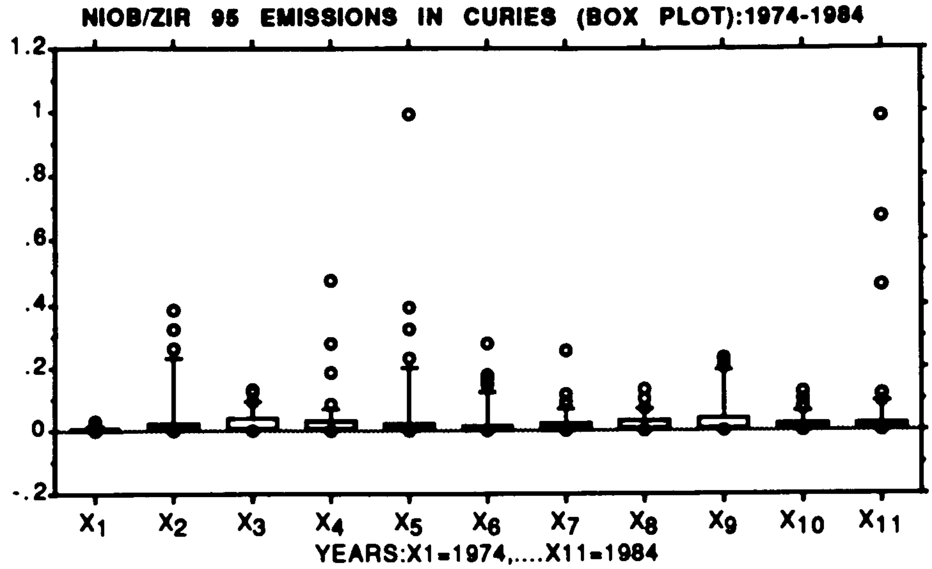

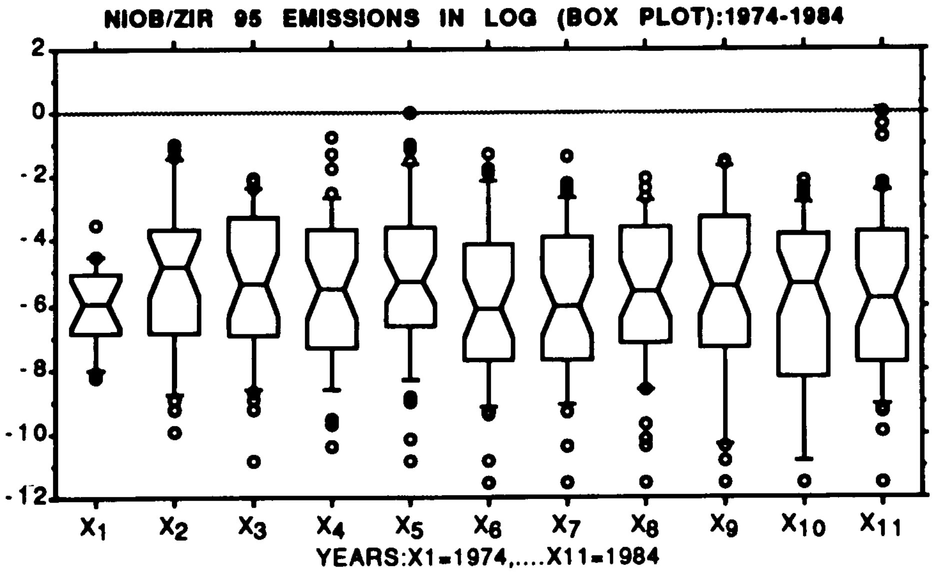

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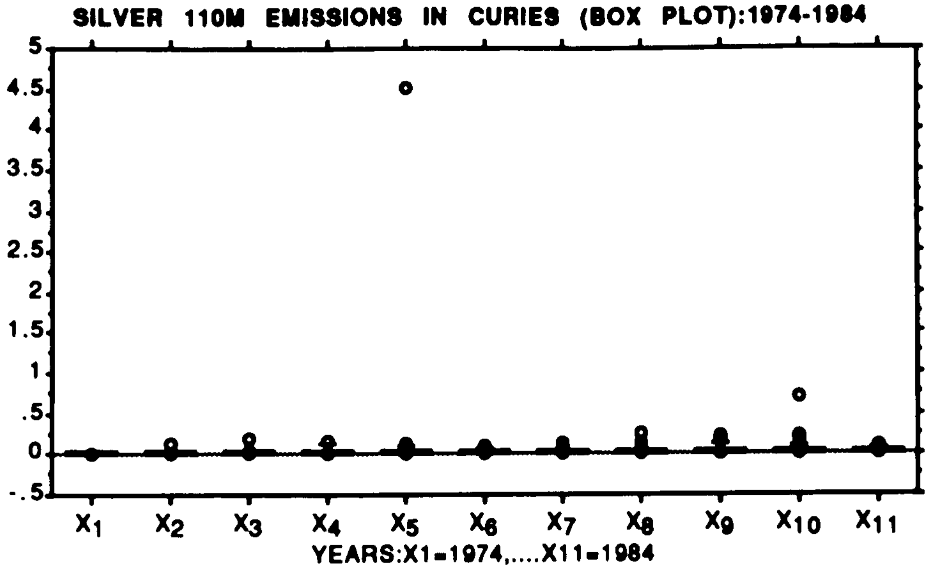

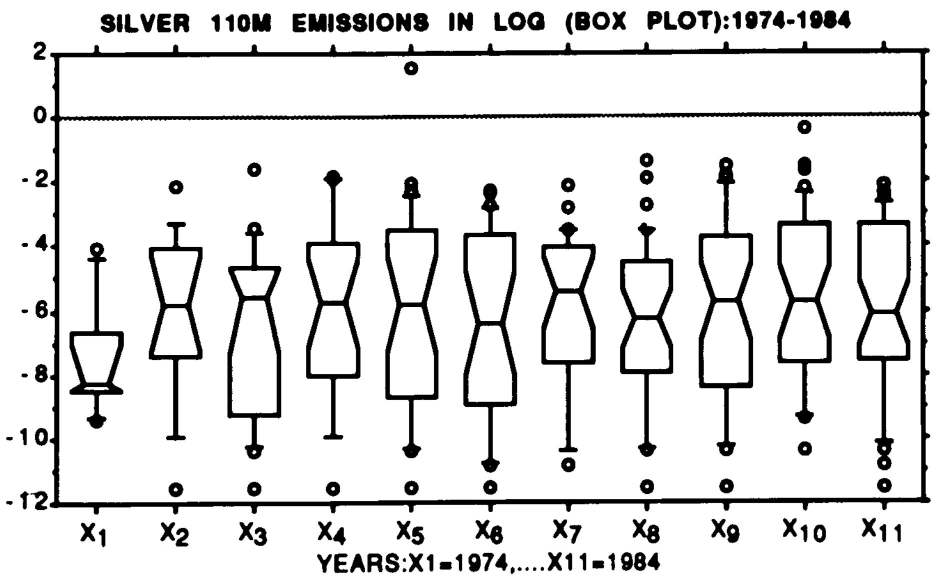

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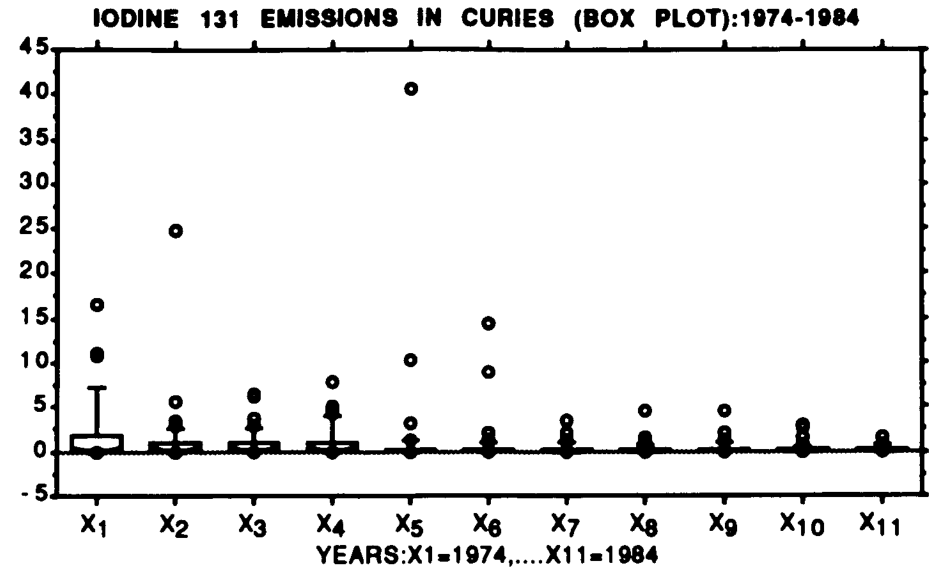

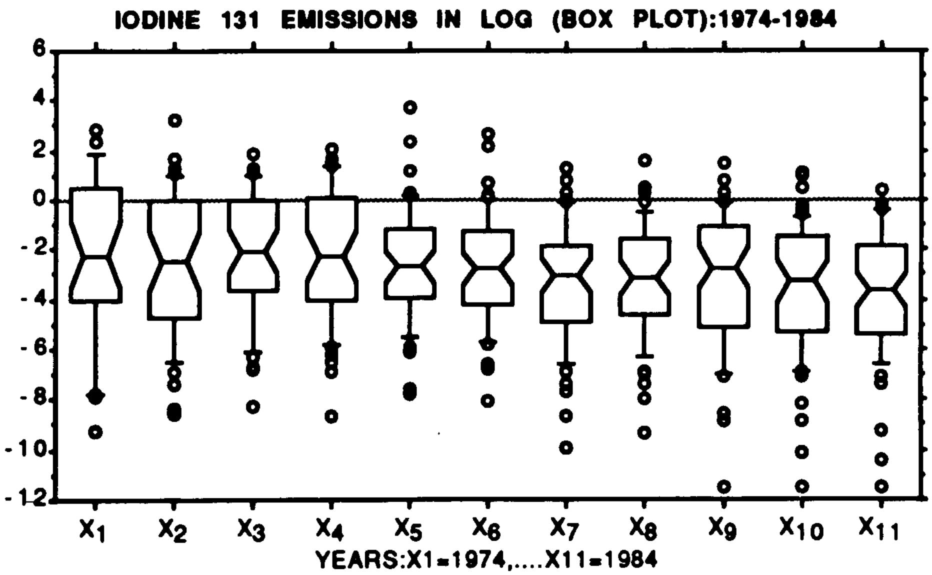

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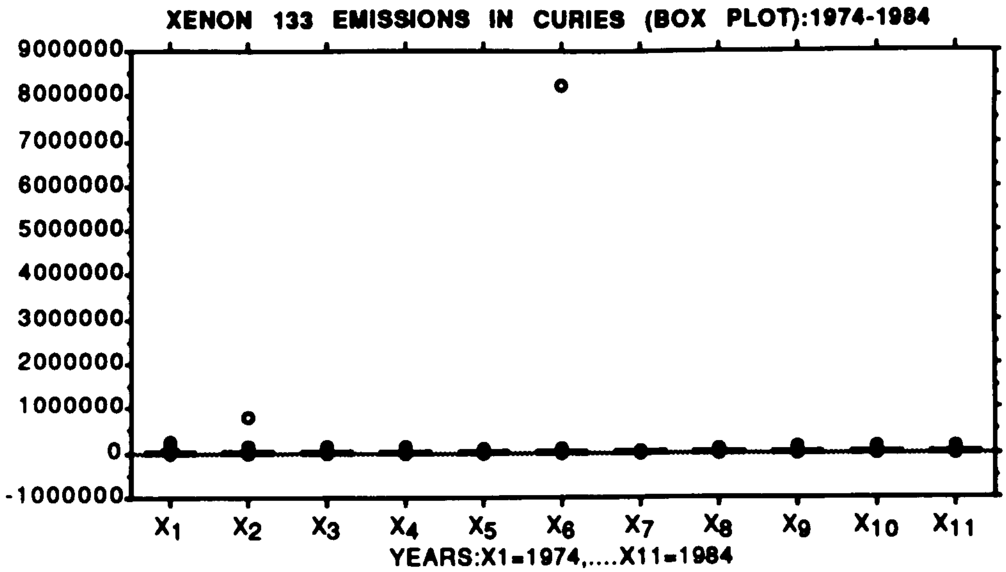

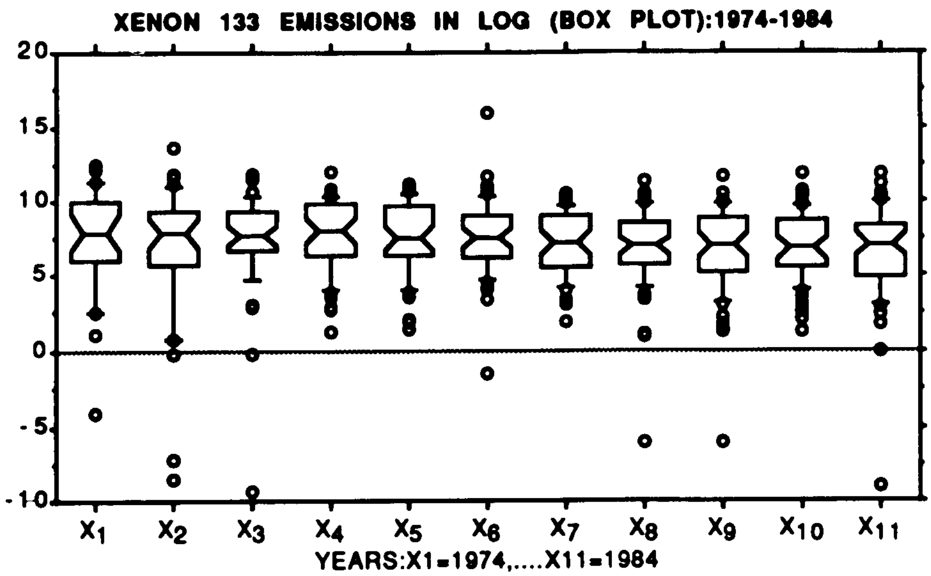

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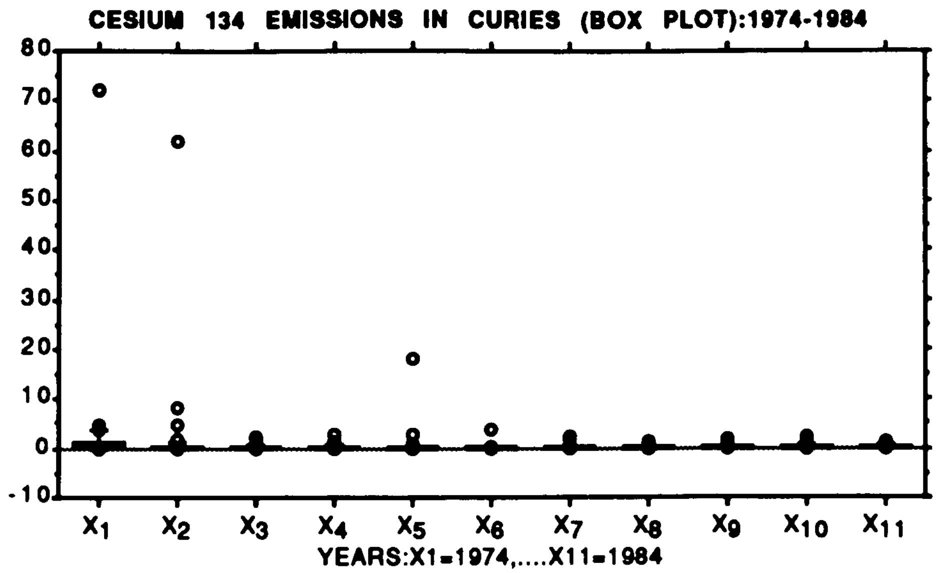

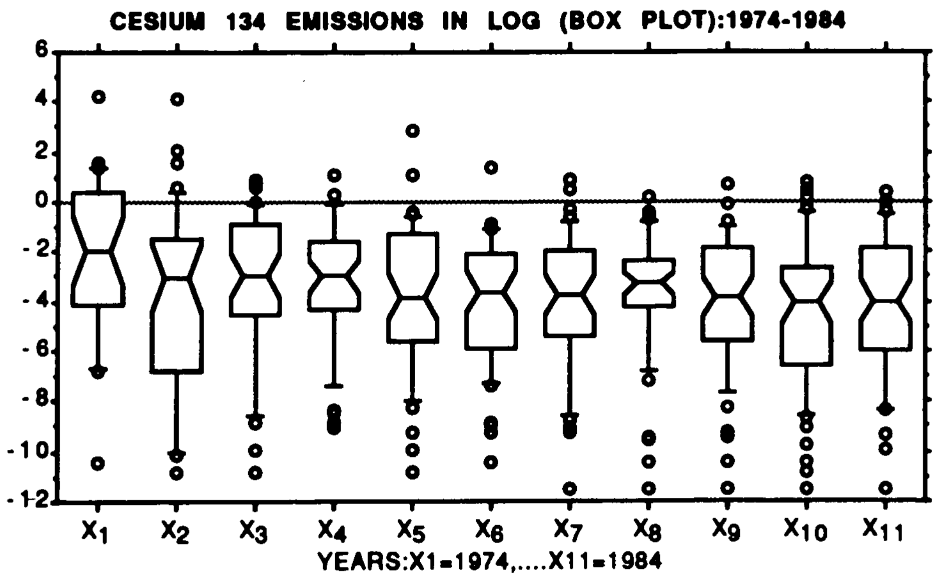

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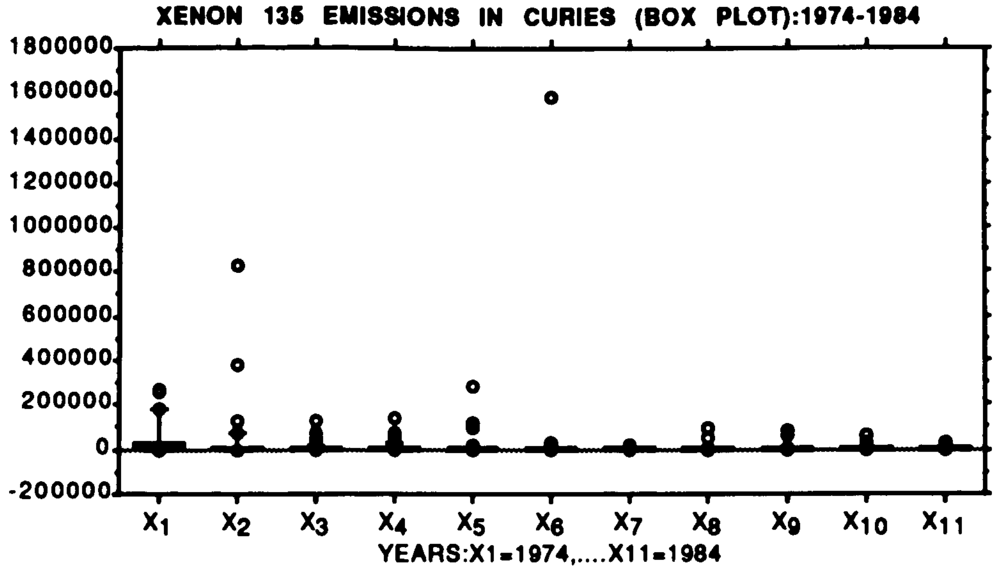

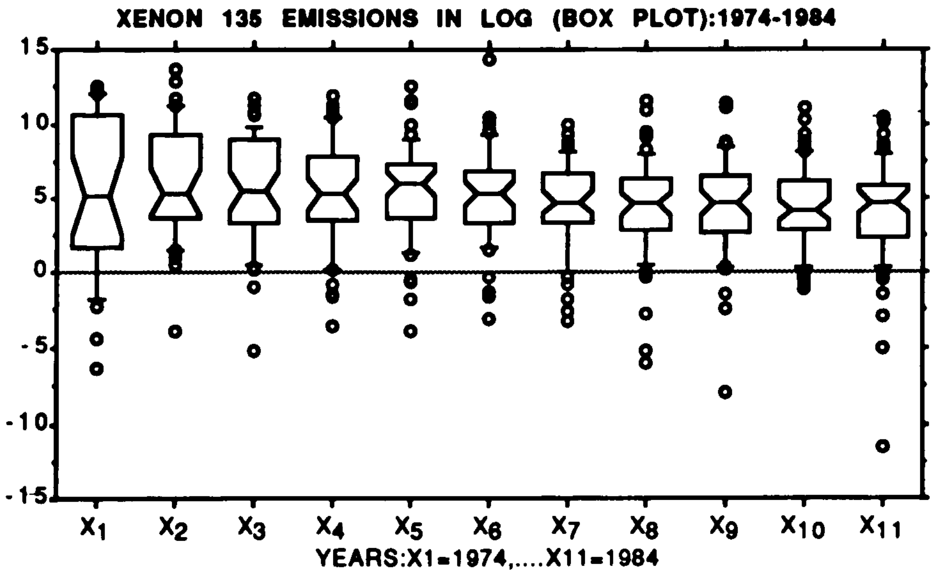

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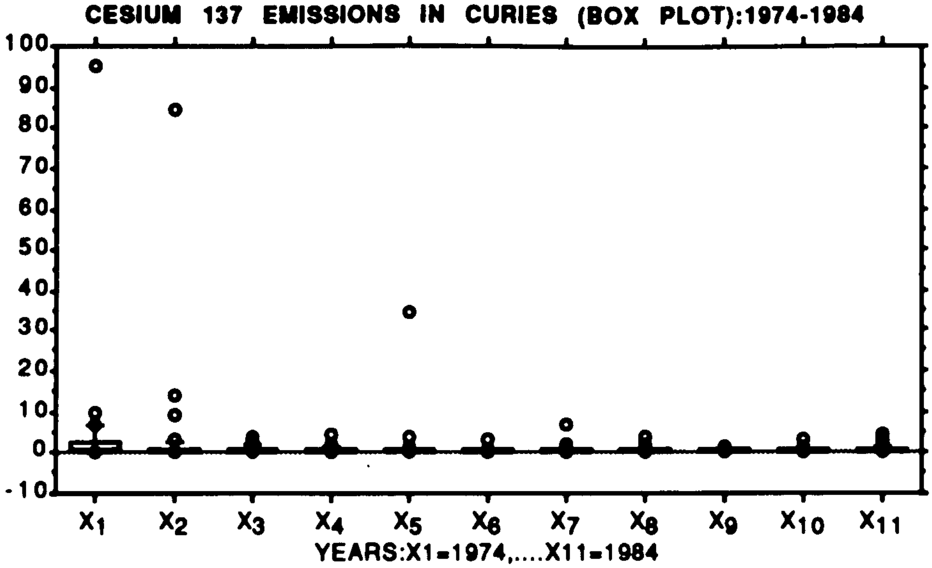

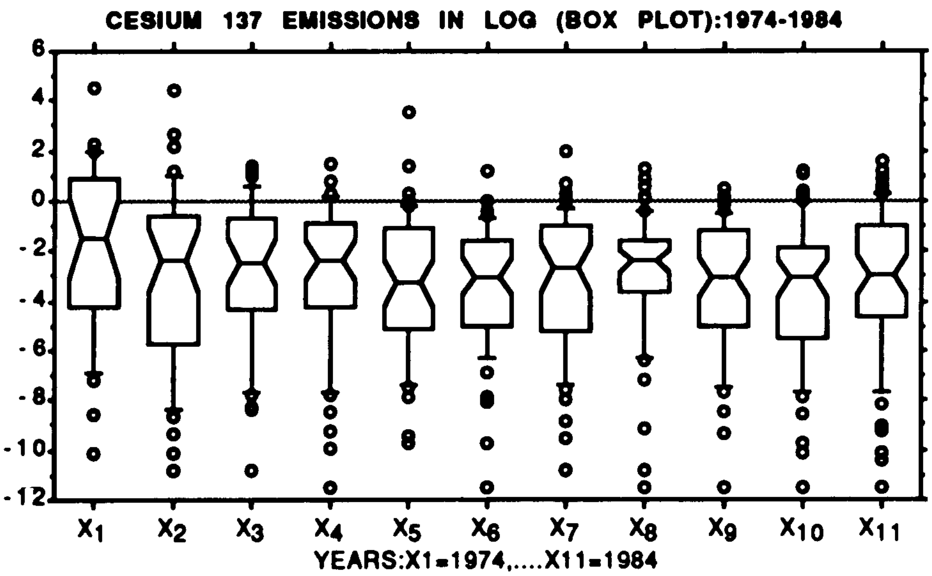

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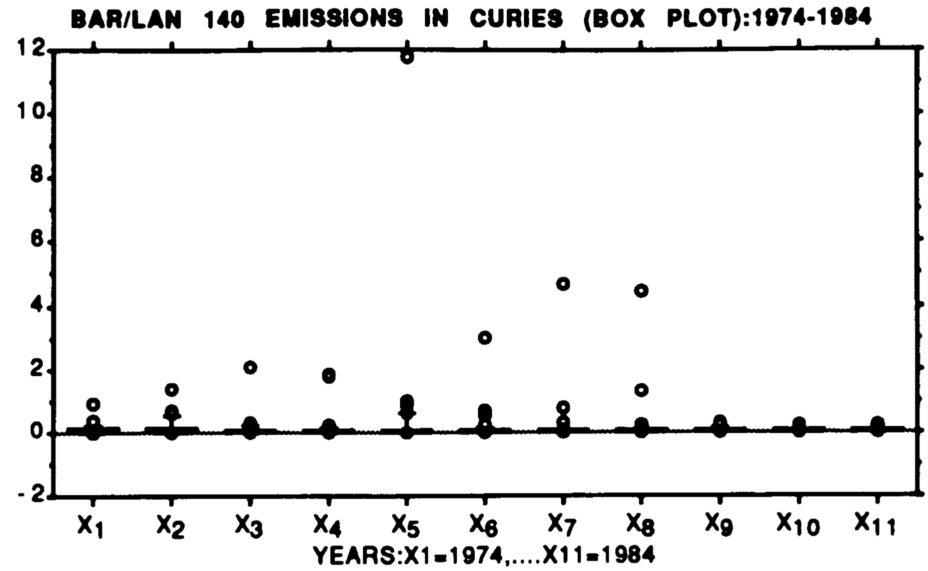

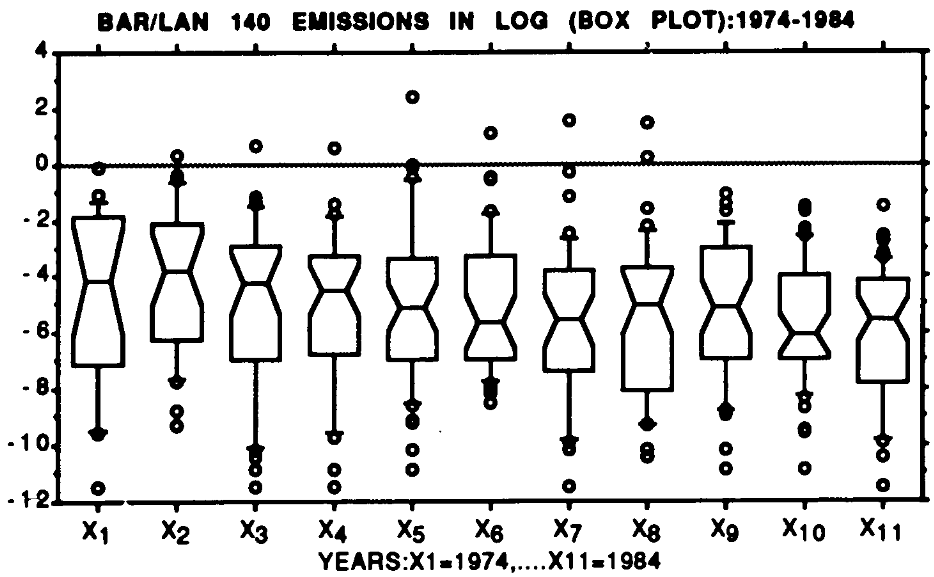

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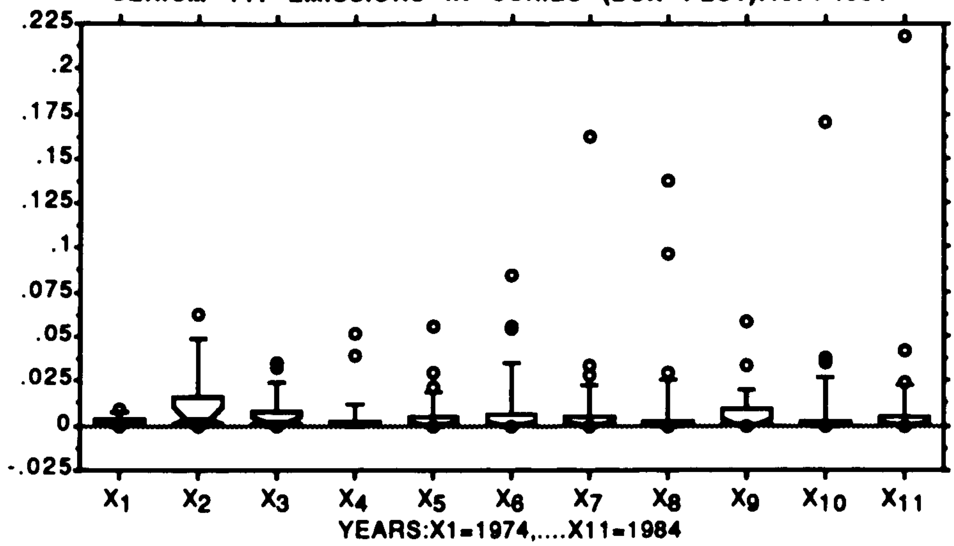

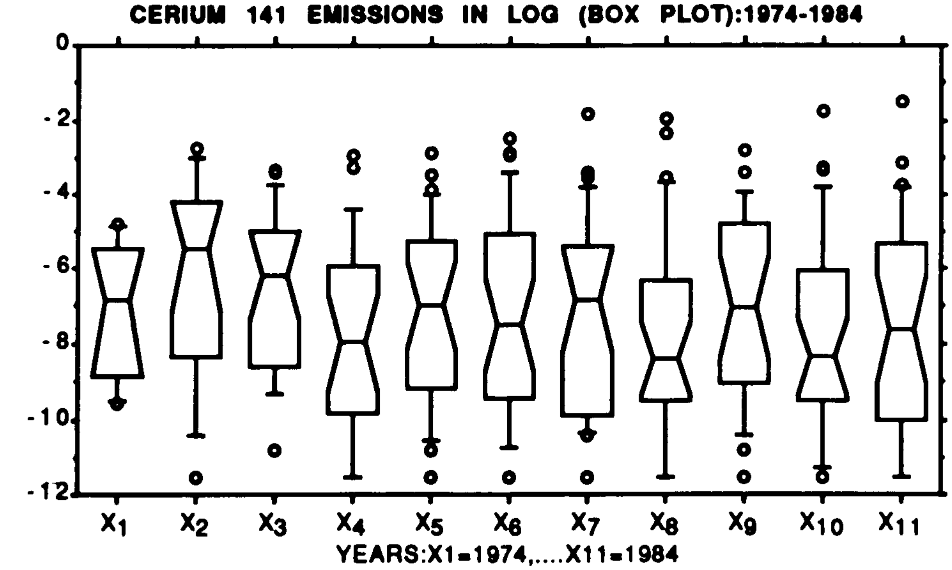

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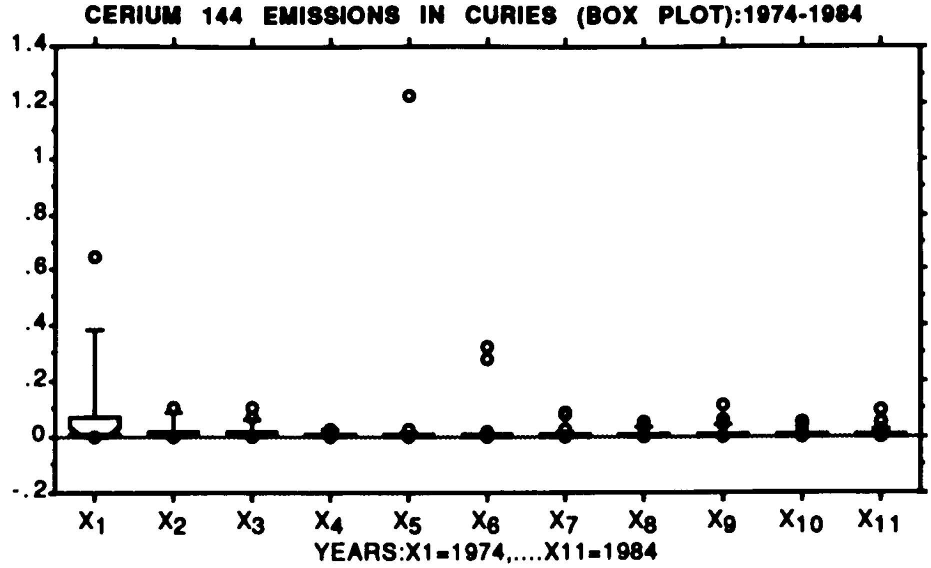

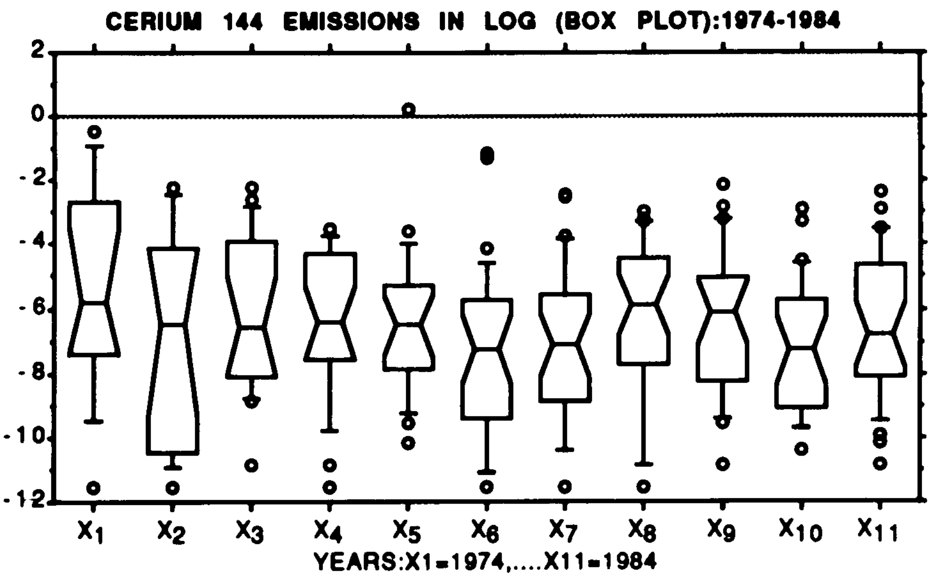

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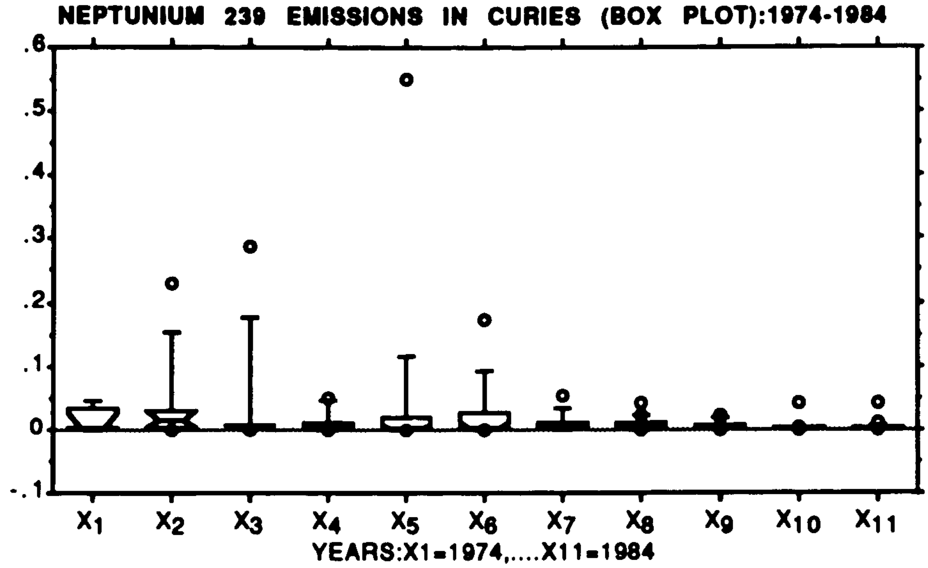

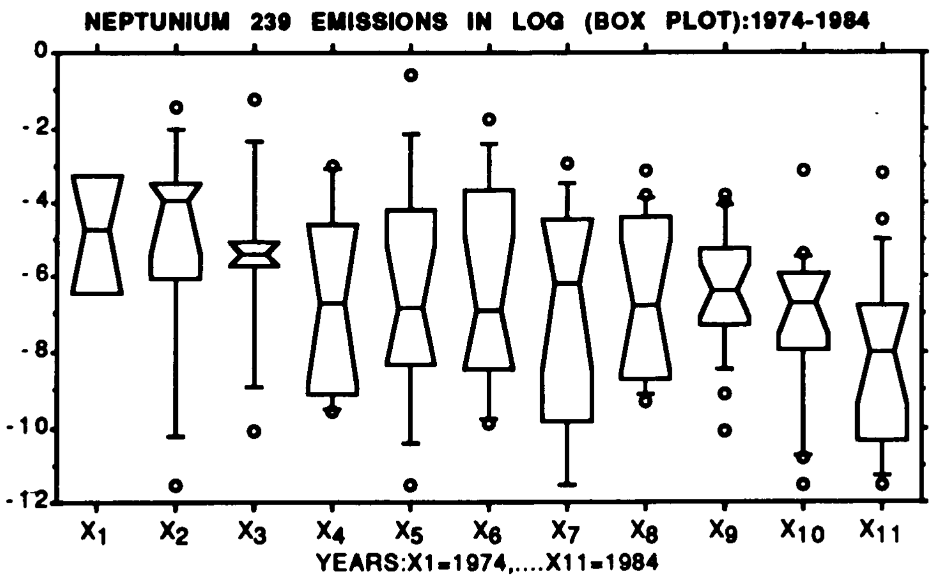

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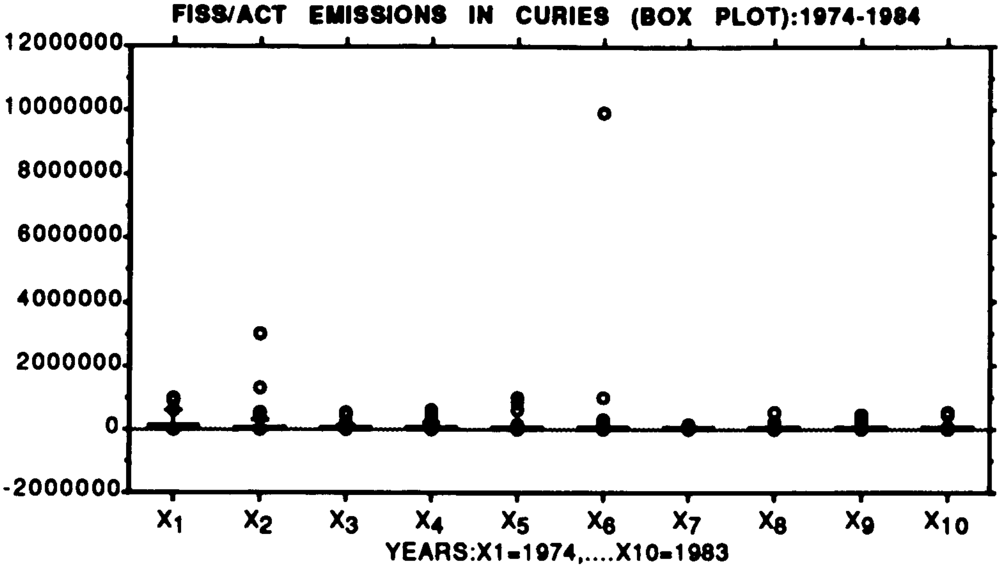

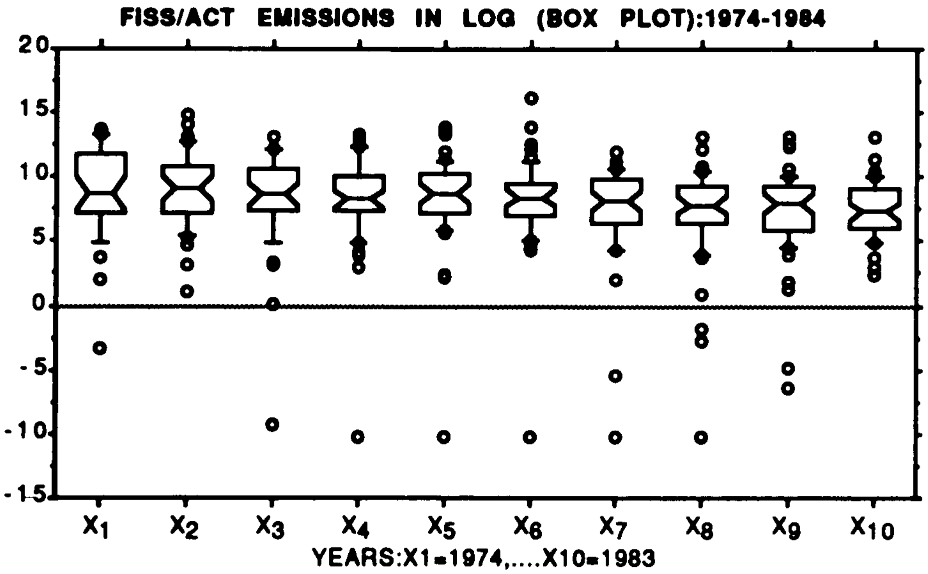

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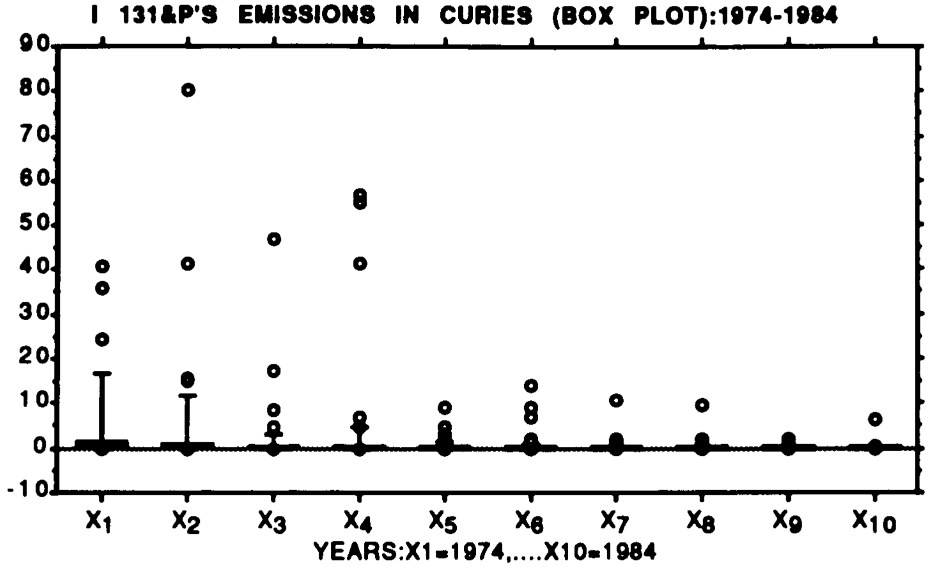

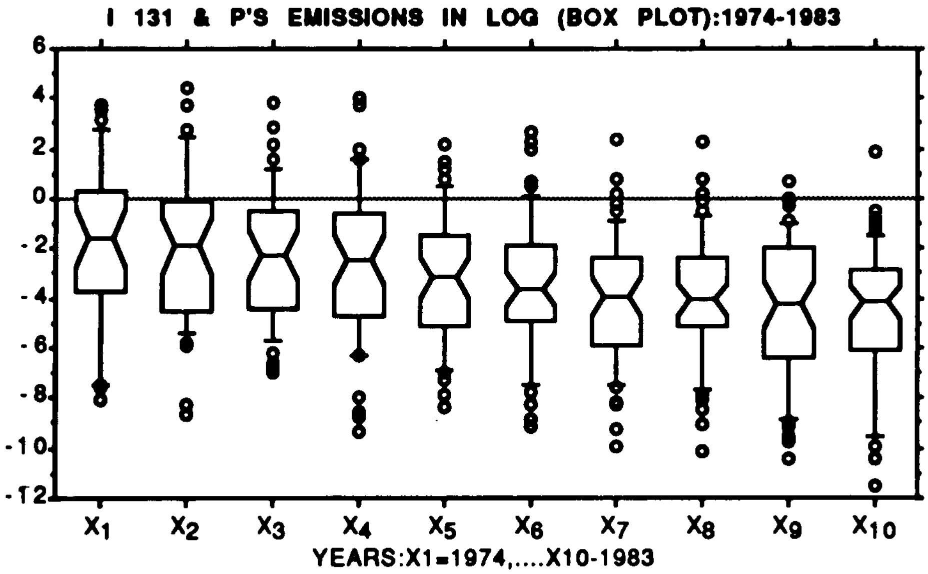

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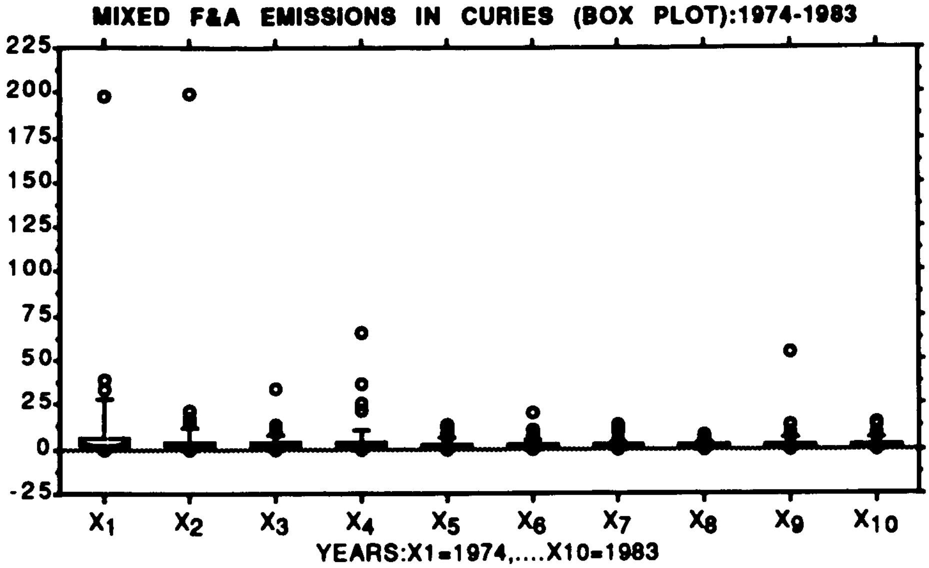

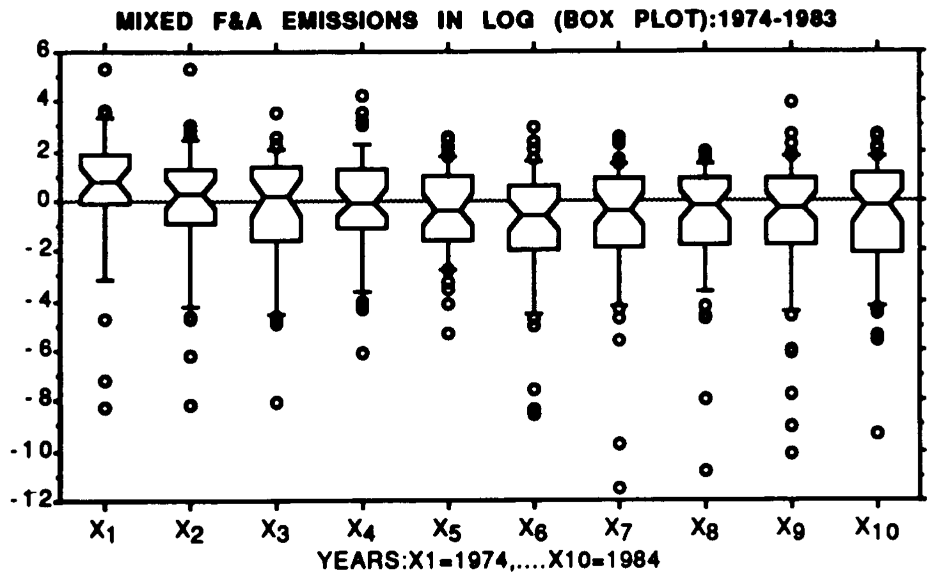

TABLE 4.6

SQUARED RESIDUALS STATISTICS

ELEMENT	MEAN	STD.DEV.	MINIMUM	MAXIMUM	#>2STD.DEV.S
TRITIUM	.785	2.256	3.9E-7	28.85	8
CR 51	2.322	4.836	1.6E-9	33.66	14
MN 54	1.752	3.682	5.0E-7	34.15	24
FE 59	2.112	3.791	3.3E-4	27.02	15
CO 60	1.627	3.645	1.4E-6	44.14	21
KR 85	4.971	10.168	3.3E-7	113.81	15
KR 85M	4.306	10.313	9.3E-6	108.85	14
SR 89	3.104	5.948	1.5E-6	49.19	24
SR 90	2.128	3.115	6.9E-7	21.86	25
NB/ZR 95	2.718	4.903	5.6E-8	39.17	21
AG 110M	2.198	4.221	6.4E-9	33.34	11
I 131	2.293	4.062	4.4E-6	37.92	32
XE 133	2.419	6.622	3.0E-6	79.96	9
CS 134	2.799	5.355	2.5E-5	43.80	23
XE 135	2.259	6.484	.001	93.31	7
CS 137	2.168	4.862	2.0E-6	55.20	24
B/L 140	2.056	3.986	0	31.29	17
CE 141	1.839	3.155	9.1E-5	20.89	8
CE 144	2.235	3.305	3.8E-5	21.34	13
NP 239	1.173	1.279	1.1E-4	5.45	11
F & A	4.308	17.617	1.6E-5	219.64	11
I 131&P'S	2.355	4.653	1.2E-6	52.94	19
MIX F&A	1.273	2.852	6.1E-6	30.48	14

CHAPTER V

CONCLUSION

"It is only by using their tools upon observed facts that economists can build up that working model of the actual world which it is their aim to construct."[1] I have attempted to do just such a thing by conducting an analysis of the nuclear industry which incorporated financial behavior, technical distinctions, operational results, and behavioral information. I have tried to use both a positivist and institutionalist approach in my analysis. For the positivist approach, I've attempted to find empirical support for the Averch-Johnson hypothesis by including profit maximizing and environmental constraints in my econometric model. For the institutionalist approach, I have tried to look beyond the statistics, beyond the theory, and into the institutional reasons for the behavior exhibited by the firms in the nuclear power plant industry. I conclude that economic analysis, in order to develop ways to interpret the economic and social world, needs to incorporate both methodologies. The concluding comments below attempt to integrate those two approaches within my analysis.

The *a priori* assumption used for the positivistic approach was that of short-term profit maximization relative to the regulatory

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[1]Joan Robinson, The Economics of Imperfect Competition (London: Macmillan and Co., Ltd., 1934), 1.

constraints set by each state's regulatory commission. Would the plants vary their emissions levels if their actual financial results varied from the financial constraint? This assumption was tested empirically for the current time period and for the previous time period as I included the actual financial results in each year relative to the emissions in that same year, and also looked at whether there was a one year lag between variability in emissions and financial results. The results of the statistical tests within the model suggest very strongly that short-term profit considerations do not impact emissions behavior, in general. This suggests that the lack of significance for the short run profits are a reflection of the high degree of regulation and the public visibility of this industry. Specifically, however, the boiling water reactor (BWR) plants within my analysis quickly adopted the requirement for the installation of augmented off-gas (AOG) equipment and greatly reduced the gaseous emissions because of the hold-up procedures implemented. These AOG's are capital equipment, and add to a utility's rate base, and thus to a firm's profit potential.

As to patterns which manifested themselves, one author has previously stated that "[A] simple analysis can only be made upon simple assumptions, and the more complicated the analysis, the more complicated the assumptions upon which it will work, and the nearer the assumptions can be to the complicated conditions of the real world."[2] Some of the complicating factors for this industry

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[2] Ibid., 2.

included different percent of ownership for the lead firm for each plant. There was no discernible difference in emissions behavior whether a plant was 100% owned by one party or not. Other aspects of the pattern model used were that I reviewed the data in detail prior to conducting the tests, or for that matter, before designing the model. This is quite contrary to Thomas Sargent who has said that:

> ....statistical theory says that you have a hypothesis with which you come to the data in advance. You estimate some regression coefficients and do the tests. It's critical that you didn't look at the data before. Acquiring priors from the data and then going back and using the same data does not seem to be right. Such objections are important to me. I think about them all the time but I don't let them stop me....[3]

The results of my total analysis support four very clear conclusions. First, nuclear power plant emissions have dramatically trended downward since 1978/1979 across most of the elements examined. This can be seen in the charts 2.2 in chapter II, on pages 57-69 and it can also be seen in my review of the $YEAR_t$ variable in table 4.4, on page 150. Both the descriptive and the statistical presentations offer support for the distinct differences in emissions behavior during the eleven year period that I studied. Second, there is little indication that variability in emissions is affected by variability in the firm's financial results. This is clearly

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[3]Thomas J. Sargent, "Thomas J. Sargent", interview by Arjo Klamer (Cambridge, Ma., July 1982), Conversations with Economists (Totowa, N.J.: Rowman and Allenheld, Publishers, 1984), 75.

evident in table 4.2, pages 146-147, within chapter IV, where the $FIN1_t$ and $FIN1_{t-1}$ coefficients are discussed. Third, the statistics reveal the very clear individual nature of the nuclear power plants in the U.S. This is evident within the step VI (see table 4.3, pages 148-149), where there is revealed no clear grouping of the plants by age, by ownership, by stock ownership, or by size of the plants, etc. The customized plants within the U.S. have customized release behavior. This is also indicated by the significance of the lagged emissions variable in the model, as discussed within chapter IV. Fourth, in spite of these dramatic declines in emissions releases, evidence was presented within chapter II that the environmental inventories of some of the longer-lived isotopes have been increasing. There are other long-lived isotopes released by these plants which weren't considered here, for example Carbon-14, which has a 5,730 year half-life, or Iodine 129, with a 17 million year half-life. One can certainly argue that their off-siteinventories would also be on the increase.

Clearly, for this one example of environmental behavior by one group of regulated monopolists, the increased vigilance of the regulatory officials within the U.S. Nuclear Regulatory Commission and the Environmental Protection Agency has indeed had its intended effects. It is also very clear that the installation of the thermoluminescent devices (TLD's) around each nuclear power plant location by the NRC after the TMI #2 accident induced each firm to alter their emissions behavior dramatically. This independent verification by the authorities of the levels and concentrations of the emissions of each nuclear facility has been a factor in dramatically reducing the emissions from each plant and thus the potential for radioactive accumulation has been decreased. This suggests that when the interests of the regulators and the regulated coincide that public regulation may be efficacious.

Thus, we have two distinct time periods and two dissimilar release behaviors within this study. During 1974-78/79, emissions in general were on the increase when the NRC wasn't independently verifying the levels; then, from 1979/80, emissions exhibited a dramatic reversal, and tended to decrease despite increased power levels and despite varied financial results. This period represented the installation of the TLD's and AOG equipment, and was of course post-TMI 2. Improved quality of fuel rods has played a role, but overall management decision making is the key. Utilities across the board, whether public or private, whether 100% owned or minority owned, whether the plants were older or newer, whether they were large or small, and in many instances, whether they were using BWR or PWR technology, have reduced their emissions from their plants. As noted within chapter II, the bulk of the emissions are planned releases, and thus an active role for improved procedures within each plant must have been implemented. As the expenditures necessary to produce these results are both fixed and variable costs, the A-J hypothesis used herein, and the broad financial statistics that I used within my model, are not adequate for a complete analysis. For future investigation, greater financial detail is necesssary. This information is required on a plant by plant basis, and not by the corporate results used here.

The interest in including financial results and financial viability into an analysis of nuclear power plant owners is not this writer's alone. At least one of the bond rating services, Donaldson, Lufkin, & Jenrette, is using safety considerations of nuclear power plant owners in the determination of credit ratings.[4] The more safety problems shown by a plant, the lower the bond rating given to the owner of the plant., This will have the effect of raising borrowing costs. Feinstein, however, used the bond ratings from another financial service, Moody's, and found the ratings were not a significant variable in his analysis on safety. He noted that, "[O]n the basis of the estimates obtained, financial distress, as measured by the power plant principal owner's bond rating, has little tendency to increase noncompliance....There is little evidence to indicate that economic incentives influence plant behavior."[5] The NRC has also included financial viability in its licensure hearings on the Seabrook, N.H. facility.

Perhaps what this tells us is that in an industry which has seen no new planned facilities since the late 1970's eventhough many new

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[4]Bill Paul, "Credit Ratings for Utilities Now Weigh Reactor Safety", The Wall Street Journal, June 9, 1988, 14.

[5]Jonathan S. Feinstein, "The Safety Regulation of U.S. Nuclear Power Plants: Violations, Inspections, and Abnormal Occurences," Journal of Political Economy 97, no. 1 (February 1989): 117,138.

plants have come on-line during those years, that short-run profit maximization is not the only motivator for these firms. What may be foremost in the owner's minds, and thus in their decision processes, is to protect what investment they have, and to minimize potential losses. The willingness of all the owners to reduce emissions despite the lack of a short-run financial incentive to do so, speaks volumes in this regard. A longer run horizon is difficult to capture empirically; one would need access to all internal meetings of each firm, and to all meetings of the NRC in order to discern management and/or industry motives.

The use of positivist and institutionalist techniques has been incorporated. Both of these, to this writer, are useful if they are realistic. The denial of one side by the other seems fruitless, at best. One can use aspects of both in a constructive manner.

> The picture of the economy which is incorporated within or emerges from the institutionalist paradigm is that of a system of power, with elements of both conflict and harmony, and with conflict as both causes and consequences of economic evolution. It is, even more fundamentally, a picture of deep cumulative causation between the market forces and institutions; of profound impacts of organization and control forces; of existential systemic diversity and openendedness; of multiple social valuation processes, including the market; of inevitable and deep legal foundations; and of individual and collective action.[6]

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[6]Warren J. Samuels, "*The Journal of Economic Issues* and the Present State of Heterodox Economics," Report to 1974 and 1976 AFEE Executive Board (Mimeo); quoted in Charles K. Wilber and Robert S. Harrison, "The Methodological Basis of Institutional Economics:

The evidence and analysis presented within this research project has suggested that the goals of the individual plant owners and the NRC have coincided in this one example. Despite one group's assertion that the NRC "fails to address the root problems such as a utility's financial ability to operate a nuclear plant"[7], the record on emissions for the period 1974-1984, at least, has indicated that the short-run financial considerations have not impacted the emissions release behavior.

There are, however, three areas within this research where I will offer self criticism. These are statistical, financial, and on the accuracy of the data that was available.

On the statistical side, previously noted in chapter IV was the exclusion of certain observations from the data base and the resultant potential for slope and intercept bias. Another statistical problem was the existence of outliers. I could treat those as observations which "correspond to an observation that occurs under unusual circumstances"[8] and within my interest about the normal operations of nuclear power plants, exclude them from the data base. Conversely, I could use

> estimators that are not sensitive to outliers....called robust estimators....a robust estimator is one whose desirable

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Pattern Model, Storytelling, and Holism," Journal of Economic Issues 12, no. 1 (March 1978): 74.

[7]Public Citizen Critical Mass Energy Project, 1984-1985 Nuclear Power Safety Report (Washington, D.C: Public Citizen Critical Mass Energy Project, August 1986), 42.

[8]Dick R. Wittink, The Application of Regression Analysis (Boston: Allyn and Bacon, Inc. 1988), 198.

properties are insensitive to departures from the assumptions under which it is derived. The most common of these alternative "robust" estimators is the LAE (least absolute error) estimator, the estimator obtained by minimizing the sum of the absolute values of the residuals.[9]

These two techniques certainly should be explored in future projects.

On the emissions side, the NRC noted that uncertainties about measurement accuracy were that:

> [I[t is not possible to generalize about uncertainties in the reported data. The errors vary with the spectrum emitted by the individual isotopes, the concentration of the isotope in the sample and the particular methods used for detection and analysis......Procedures and equipment in use should yield assay precisions in the range +-10-50% for the more significant isotopes. In the case of those isotopes produced in much lower abundance and lacking prominent gamma-rays, the uncertainties typically range from a factor of 2 to as much as a factor of 10 or more.[10]

Thus, while the quality of the data collected on emission improved over the time period used in this report, there remains a degree of uncertainty. In a hypothetical situation, suppose that the actual amount released of a particular isotope was exactly one curie in two

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[9]Peter Kennedy, A Guide to Econometrics, 5th ed., (Cambridge, Ma.: The MIT Press, 1984), 24.

[10]Nuclear Regulatory Commission, Summary of Historical Experience With Releases of Radioactive Materials From Commercial Nuclear Power Plants in the United States (Washington, D.C.: March 1985), 16.

successive years. Given the measurement error expected above, that could translate, in the first period with a -50% error, to a reported release of .5 curies and in the second period, with a +50% error, to 1.5 curies. Thus, the variation from one period to the next is a magnitude of three. If, in continuing with this hypothetical example, the financial results were such that the firm in question attained its allowed rate of return, one would then have variability in emissions without any variability in financial results. This would of course, expand the standard error of the estimated coefficient and thus reduce the test for significance. One can also do this analysis for the low gamma-ray elements, and, given their degree of variability in calculation of a factor 2 to 10, see a similar result occur. An actual one curie release of a gamma ray element may in fact have been listed as small as 0.5 curies, or as high as 20 curies. If one assumes minor variations in financial and operational results, this wide range of variability between the actual and the measured release would bias the the coefficient and the standard error of any variable used. In that regard, it is therefore not surprising that the R^2's were low, as were the number of statistically significant coefficients estimated in all of the steps within the model. The technical characteristics may have captured the individual nature of each plant without proving to be significant as the individual nature of each plant (age, size, type) did not impact the emissions as I had hypothesized.

The financial information used in the model was corporate wide results. What may be necessary in order to conduct a more fruitful analysis would be the internal financial report of each company for each plant.

The NRC is partially correct, therefore, in ascribing emissions behavior to the technical specifics of the plants. I am partially correct in including financial considerations as a causal variable. The positivist approach to the analysis helped to support hypotheses developed by the "pattern analysis" review I conducted. None of the three reviews fully explains why emissions levels are what they are. This indicates that further research may be necessary. Any future research in this public policy arena will need to consider how the uncertainty about any future negative impacts that may develop alters the decision making processes of the affected firm today.

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