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FEDERAL SUBSIDIES TO NUCLEAR POWER: REACTOR DESIGN AND THE FUEL CYCLE

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ABSTRACT

This paper analyzes selected Federal subsidies to nuclear power including subsidies to reactor design and to reactor exports, subsidies to uranium producer's subsidies provided via government pricing of enrichment services and subsidies provided via government control of waste management.

Chapter two presents the implicit rationale for subsidies to nuclear power in the context of a broader discussion of subsidies. The following chapters discuss the history of each of the subsidy types and present quantitative estimates in constant dollars of each subsidy type.

Each of the subsidy types has reduced the cost and/or uncertainty to private firms of investing in nuclear power. The result has been that current production of electricity from nuclear power is substantially larger than it would have been in the absence of such subsidies.

PREFACE

This paper is one of a series of papers reporting the results of the Energy Information Administration study of energy policy. The study was requested by the Subcommittee on Energy and Power of the U.S. House of Representatives and is being conducted under the direction of David L. McNicol, Director of the Office of Economic Analysis. The paper was prepared under the supervision of John Mitrisin. The author would like to thank Andrew Reynold, Dave Agro and Dan Nikodem for reviewing the paper and providing useful comments, and Ann Doster and Sherre Washington for typing the paper.

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EXECUTIVE SUMMARY

This paper is part of a series that will assess the economic impacts of the entire set of governmental actions that differentially affect energy markets. The paper discusses selected Federal subsidies to nuclear power including subsidies to reactor design and to reactor exports, subsidies to uranium producers, subsidies provided via government pricing of enrichment services and subsidies provided via government control of waste management.

Chapter two presents the implicit rationales for subsidies to nuclear power in the context of a broader discussion of subsidies. The rationale normally used to justify subsidies is market failure. Such failure may occur when the costs and benefits accruing to private investors diverge substantially from the costs and benefits of a project from the point of view of the public. This divergence may result from the presence of external economies or from differences in the ability to bear risk between the public and private sectors.

Both rationales underly historical and continuing subsidies to nuclear power. A prominently cited external economy associated with investment in nuclear power is that nuclear electricity can reduce U.S. reliance on imported oil. This benefit is probably not as significant as frequently suggested, primarily because the base-load electricity supplied by nuclear plants cannot substitute for oil in many of its uses.

The second situation in which subsidies may be justified occurs when firms are less able to bear risk than society as a whole.

This argument is applicable only to projects which impose financial risks rather than health and safety or environmental risks, for example. This type of market failure provides only limited justification for subsidies because much of the risk associated with nuclear power is nonfinancial or derives from nonfinancial sources.

The remaining chapter present the details of the selected nuclear subsidy programs. The Federal Government has provided substantial research, development and demonstration (RD&D) funds to develop nuclear power since 1948. These expenditures were critical to the development of the private nuclear power industry and continue to be critical to its development.

The Federal Government has provided a variety of subsidies to uranium producers. The subsidies include production incentives, exploration assistance and an embargo on foreign uranium. These subsidies were initially designed to encourage the development of a uranium industry and later, to ensure a smooth transition from AEC fuel ownership to commercial ownership.

The waste disposal program of the Federal Government has also provided a subsidy to the nuclear power industry. Direct expenditures on RD&D were and are essential to finding a solution to the problem of waste disposal upon which the viability of the nuclear industry depends.

The enrichment stage of the nuclear fuel cycle is owned by the Federal Government. The government provides a subsidy to the nuclear industry through the mechanism of enrichment pricing policy. The government pricing formula does not include provision for a rate of return, for state and local taxes, for insurance, for federal income taxes, for interest on the uranium inventory required for enriching, or for eventual decommissioning of the enrichment plants.

Each of the subsidy types has reduced the cost and/or the uncertainty to private firms of investing in nuclear power. The result has been that current production of electricity from nuclear power stations is substantially larger than it would have been in the absence of such subsidies.

1. INTRODUCTION

This paper will present the details of and rationale for selected federal subsidies to nuclear power including subsidies to reactor design and sales, subsidies to uranium producers, subsidies provided via government pricing of enrichment services, and subsidies provided via government control of waste management. This paper provides estimates of the dollar value of these subsidies by sector from their inception to the present.

2. SUBSIDIES

Definition

Subsidies are defined here as economic assistance from the Federal Government to producers and/or consumers in the private sector, which are intended to promote a change in the supply of or demand for a particular good.[1] This is a relatively broad definition of subsidy. It includes all economic assistance which is intended to affect the market for a good, regardless of whether it is successful. For

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[1] For a review of definitions of subsidies see: U.S. Congress, Joint Economic Committee, The Economics of Federal Subsidy Programs. 92nd Congress, 1st session: GPO, 1972.

This section draws heavily on an earlier study: Bowring, Joseph, "Selected Federal Tax and Non-Tax Subsidies to Energy Use and Production", Department of Energy, Energy Information Administration, January 1980, DOE/EIA-020116.

example, it includes expenditures to promote research and development activities, although the effects of such programs are not always clearly ascertainable. Government procurement programs are also included, even when purchases are made at the market price, because such programs provide a reduction of uncertainty for producers which can best be analyzed in the same framework as more direct subsidies.

Most forms of government "assistance" or incentives can be dealt with in the context of this broad definition. The primary form of such assistance that is explicitly excluded from this definition is the welfare payment. A welfare payment is intended only to raise the income of the recipient and is not intended to have a particular effect on their market behavior.

Rationale

The case for subsidies generally rests on an argument that there are flaws or imperfections in the private markets which are normally relied upon to allocate resources. In perfect markets, this allocation is driven by investors who make decisions about where to invest their funds on the basis of individual profit maximization. However, the costs and benefits accruing to the private investor may diverge substantially from the costs and benefits of a project from the point of view of the public. It is this divergence which government actions of various types, including subsidies, are designed to remedy.[2]

Subsidies may be appropriate where external economies exist and where there are differences in the ability to bear risk between the public and private sector.

External economies exist when a particular investment is beneficial from the public's perspective but not equally beneficial for a private firm. This divergence between the benefits flowing to the public and to the private sector arises when a firm cannot capture all the benefits of a project. This often means that the rate of profit is too low from the firm's perspective to justify the invesment. In this case, a subsidy may be justified in order to encourage firms to invest. Ideally the subsidy would equate the additional costs to the public, in the form of subsidy payments and external costs, with the additional benefits to the public, i.e., the external economies.[3]

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[2] Break, George F., "Subsidies As An Instrument For Achieving Public Economy Goals", in The Economies of Federal Subsidy Programs, Joint Economic Committee, U.S. Congress, 1972.

[3] See for example: Musgrave, Richard A. and Musgrave, Peggy B. Public Finance in Theory and Practice. New York: McGraw-Hill Book Company, 1973, Chapter 3.

The exact rationale for subsidies to nuclear power is not clear. Certainly, no detailed analysis of external economies and/or costs preceded the initial decision to develop nuclear power. The Federal Government made a decision to fund R&D on nuclear reaction for the simple reason that benefits in some broad sense, despite their uncertainty, seemed to outweigh the costs.[4] In addition, no such analysis has been made subsequently despite continuing high levels of subsidy.

While this report does not present such a detailed cost-benefit analysis, the implicit rationale for these subsidies can be examined within the general analysis of subsidies. The most basic rationale is that there are external economies associated with the use of nuclear power as an energy source. A prominently cited external economy is that nuclear electricity can reduce U.S. reliance on imported oil. This benefit is probably not as significant as frequently suggested, primarily because the base load electricity supplied by nuclear power cannot substitute for oil in many of its uses.[5]

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[4] Allen, Wendy, Nuclear Reactors For Generating Electricity: U.S. Development From 1946 to 1963. Rand Corporation, June 1977, p. 5, 28-34.

[5] Taylor, Vince, "Energy: The Easy Path", report to the U.S. Arms Control and Disarmament Agency, 1979.

The second general situation in which subsidies may be justified occurs when firms are less able to bear risk than society as a whole. For a project with a given degree of risk there may be a divergence between its evaluation by a firm and its evaluation by society. This divergence arises because society may be able to spread the risk associated with a project to such an extent that risk becomes irrelevant in the evaluation process.[6] In contrast, individual firms must bear most of the risk by themselves. As a result they veiw the potential benefits more conservatively than society.[7] An appropriate subsidy would insure the individual firm(s) against financial loss. Firms could then evaluate a project in the same fashion as society, i.e., as if the risk did not matter.[8]

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[6] This is the case because of imperfections in the capital markets. In particular, the absence of perfect contingent claims market means that the risks of private investments cannot be distributed in optimal fashion. For an elaboration see: Arrow, Kenneth J. and Lind, Robert C. "Uncertainty and the Evaluation of Public Investment Decisions", American Economic Review, June 1970.

[7] Vickery, William "Discussion", American Economic Review Proceedings, May 1964.

[8] This result also depends on the assumption that the outcome of individual projects is not correlated with national income or with the outcomes of other projects. Op. cit. Arrow and Lind.

However, this argument is applicable only to projects which impose financial risks rather than health and safety or environmental risks, for example. Financial risk can be easily spread across all taxpayers while non-financial risks tend to have localized effects which cannot be spread.[9] In addition, these financial risks must be insubstantial for any single taxpayer. In the case of non-financial risk, government risk-spreading is ineffective because individuals bear substantial risk. As a result, the benefits of such projects must be appropriately discounted by the government as well as private firms.

Much of the risk associated with nuclear power is nonfinancial. The health and safety risks associated with low-level radiation, with long-term waste disposal strategies, and with the potential for a serious accident are all prominent examples of nonfinancial risk. The danger of nuclear weapons proliferation based upon the nuclear fuel cycle is another such risk. In addition, many of the financial risks which face utilities investing in nuclear plants derive from the underlyng nonfinancial risks. For example, utilities face the risk that substantial changes in plant design will be mandated both during and after construction.

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[9] Ibid. Bailey, Martin J. and Jensen, Michael C., "Risk and the Discount Rate for Public Investment", in Studies in the Theory of Capital Markets, Michael C. Jensen (ed.). New York: Praeger Publishers, 1972.

The potential costs pose a serious financial risk. These requirements, however, are the outcome of a social decision designed to reduce safety costs imposed on society by increasing the safety of plant design. The risks are not inherently financial, but derive from the health and safety risks of nuclear powerplants.

Costs

The costs to society of subsidies fall into three basic categories: direct costs, external costs and opportunity costs. Direct costs are actual budget outlays made for a program. These cash outlays range from the actual budget figures for a cash subsidy to an amount for loan guarantees which depends on the level of loans and uncertain default rates. Government subsidized projects, like private projects, may impose external costs on society. These external costs are not borne by the producers in either case and thus do not enter into the producers' investment decisions. Since the goal of a subsidy may be to equate the costs and benefits to society from a project, external costs must be weighted when a subsidy is granted. It is the net benefits of a project, i.e., the social benefits minus the social costs, which should be considered. Ideally a subsidy would equate the subsidy payments with the net benefits to the public.

Opportunity costs are the value of the alternative investments that could have been made with the same funds in the absence of the subsidy. One way of assessing the opportunity costs of a subsidy is to consider alternative programs the government could have funded with the same funds. The second way is to assess what private investments could have been made with the funds, if the government has not used them to finance its subsidy.

In the latter case, with a limited total amount of capital available in the economy, using some part of it to stimulate the production of nuclear power, for example, means that some other uses must be foregone. The exact amount of these other uses depends both on the nature of the supply of capital and on how fully employed the economy is.

Government expenditures, or expenditures stimulated by government subsidies, will increase the demand for capital and put upward pressure on interest rates. As a result, some investments which were profitable before the government action may not be at the new interest rates and may not be made. The amount of investment which is "crowded out" in this way depends on how the supply of capital responds to the increase in demand. If the amount of capital supplied increases significantly, the total amount of other investments crowded out will be less than if the supply is not so responsive. The amount of capital supplied in response to an increase in demand will be greater as more resources are unemployed in the economy.[10]

In the case of nuclear power the costs of the subsidies examined here are primarily direct costs and external costs. Research and development expenditures impose direct costs. External costs are imposed by the as yet unpaid costs of waste disposal for example. Opportunity costs are not explicitly addressed but they include alternative energy supply strategies that could have been, and could be, financed with the resources now going to the nuclear option.

Workings

Subsidies are designed to affect firms' investment decisions in several ways. Subsidies provide incentives to firms to expand production, by allocating resources to them which they might not otherwise receive. This can be done by reducing the cost of production or by reducing the risk involved in production.[11]

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[10] See for example: Haveman, Robert H. "Evaluating Public Expenditures Under Conditions of Unemployment", in op. cit. Public Expenditures and Policy Analysis.

[11] For a general discussion see: Shoup, Carl S. "The Economic Theory of Subsidy Payments", in The Economics of Federal Subsidy Program, Part 1, General Study Papers. Joint Economic Committee, U.S. Congress, 1972.

The expected rate of return on a project can be affected by subsidies which reduce costs or by subsidies which increase prices. Cost reduction can be provided by grants to producers by provision of some factor of producton at less than the market price. Cost reductions raise the revenues from an investment, and can increase the expected rate of return to a point where it exceeds the required rate of return and makes the investment attractive.

The risk premium element of the required rate of return can be reduced by subsidies which remove some of the risks of production. Such risk reduction can be provided by government ownership of risky parts of the production prices, by government procurement policies or by government guarantees. Risk reduction decreases the required rate of return for the firm and may make a project attractive even if the expected costs and revenues, and consequently the expected rate of return, are unaffected.

Subsidies to nuclear have affected both the required and expected rate of return accruing to members of the nuclear industry. Specific reductions in cost as a result of R&D expenditures or enrichment services priced below the market level, have increased the expected rate of return on an investment in nuclear power. Similar cost reductions have resulted from the postponement of payments for decommissioning and waste disposal.

Perhaps more important than specific cost reductions have been the reduction in uncertainty to the nuclear industry and the financial community, provided by the Federal government. The clear government commitment to the nuclear option has created a general reduction in uncertainty. The industry has been assured that the government will supply acceptable solutions to serious outstanding problems. The result has been a decrease in the rate of return required by nuclear investors, and a substantial amount of investment.

The actual impact of a subsidy, intended to affect the expected rate of return, may be quite different from its intended impact. Such a subsidy will have effects on both the price and quantity of the subsidized goods and services. The nature of these effects depends upon the elasticities of supply and demand.[12]

The elasticity of demand for subsidized energy supply technologies depends on whether the technologies are close substitutes for existing energy sources. High elasticity of demand for a product implies that consumers have readily available substitutes. In other words, price changes will have a significant impact on the quantity of a product consumed because consumers are easily able to substitute

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[12] For a more extended discussion with graphical analysis, see: op. cit. The Economics of Federal Subsidy Programs.

the product for others depending on which is cheaper. For example, a high price for nuclear generating stations relative to substitutes like coal or gas plants, will mean that very few are actually purchased. If the price of nuclear units falls below that of conventional systems, however, the quantity purchased could rise significantly. Thus, in order to be effective, subsidies must reduce the price of nuclear electricity to the prevailing price of electricity which is currently determined largely by the price of coal-fired power.

Even with a very highly elastic demand the quantity of a good sold in the market will not increase unless supply also responds to price increases, i.e., unless supply is also elastic. Relatively high elasticities of supply require that resources flow to the production of the good in response to an increase in price. Firms already in the market will increase production and new firms will enter the market if the rate of return is higher than that which can be earned elsewhere.

Except under unusual circumstances, low elasticities of supply would also occur only in the short run. It takes time to enter a new market or to expand production significantly, and producers may be uncertain about the long run prospects for profitability in the industry. As new production facilities are built and the market situation becomes more clear, supply will respond to price changes.

From the outset, government policy was directed at creating a viable private nuclear industry. Research and development subsidies and other assistance were intended to bring the industry to a point where it could respond to increase in demand, or in other words, to create an elastic supply.

Increased consumption of nuclear generated electricity in response to subsidies will also affect the consumption of traditional energy supply technologies which coal, oil, or natural gas, as well as the consumption of emerging energy technologies. The effects depend on the responsiveness of the demand for these sources to changes in the price of the new ones, or the cross elasticity of demand. The responsiveness in turn depends on how fully nuclear electricity can substitute for other sources. For example, nuclear electricity cannot substitute for oil in many important uses including transportation and chemical feedstocks. The effect of any change in demand for oil and other sources will depend on the elasticities of supply and demand within their particular markets. For example, although the demand for oil might fall if the price of nuclear electricity fell, the quantity of oil consumed would be unaffected if the supply curve for oil were perfectly inelastic.

3. RESEARCH AND DEVELOPMENT SUBSIDIES

Introduction

Expenditures on nuclear power research and development constitute a subsidy because they are economic assistance from the Federal Government intended to promote an increase in the supply of nuclear energy. Historically, government R&D expenditures have reduced the private expenditures required on a nuclear project. This made it more likely that a private firm or group of firms would undertake a project both because the direct costs were lower and because the total potential losses were less. In other words, the expected rate of return was increased.

Over the longer run, government R&D subsidies also improved nuclear technology and produced information about it. This increase in technical information reduced some aspects of the uncertainty associated with the technology. There was a cumulative effect from the R&D subsidies which was probably more important than the incremental impact of any single subsidized project. The sequence of experiments and research projects succeeded finally in demonstrating that light water nuclear reactors could be operated successfully in a configuration compatible with power generation. Research and development subsidies were oriented towards what was a relatively narrow goal in the context of the requirements of a full nuclear supply system, i.e., that reactor technology could be made to work. The success of the effort was similarly narrow.

The form of subsidies to support research and development of nuclear reactors has changed since the introduction of subsidies in the late 1940's. The essentials of the program have remained constant, however. Federal subsidies were provided in two stages. The first stage began with the birth of the AEC itself and ended with the contract for the first non-subsidized light water nuclear plant in 1962.[13] The first stage culminated in the commercialization of the light water technology. The second stage was intended to repeat the first except that its goal was to be the development of a breeder reactor.[14]

The Atomic Energy Act of 1946 created the Atomic Energy Commission (AEC) and the Congressional Joint Committee on Atomic Energy (JCAE). The AEC was mandated to develop civilian nuclear power by encouraging private research and

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[13] This plant, Oyster Creek in New Jersey, was non-subsidized only in the sense that it was not built with plant-specific subsidies.

[14] This is not intended to imply that the AEC's goal from the outset was development of light water technology. In fact other reacter types, including breeders, received substantial support during the first stage of nuclear R&D subsidies.

development (R&D), by conducting R&D itself, and by controlling the required flows of fissionable materials. Early AEC reactor R&D was divided into civilian and military components. In the early stages, both military and civilian reactor R&D were critical to the development of light water reactors.[15]

The military and civilian reactor programs of the AEC were closely related. The military program used information and expertise developed in the more experimental civilian program. Further, the reactor prototype developed in the military program became the foundaton for some of the AEC's later civilian reactor work as well as the basis for the commercial light water reactor.

Initial civilian R&D followed three lines of development.[16] The Materials Testing Reactor, the Experimental Breeder

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[15] "The most important AEC R&D effort between 1947 and 1953 was aimed at developing reactors for submarine and aircraft propulsion."

"The submarine propulsion program was successful and formed the most important factor in the selection of light water reactor for commercial electricity generation in the U.S.", op. cit., Allen, p. 13.

See also: Hewlett, Richard G., and Duncan, Francis, Nuclear Navy. Chicago: University of Chicago Press, 1974, pp. 380-5.

[16] The historical discussion of research and development subsidies relies heavily on Wendy Allen, op. cit. and on Robert Perry et al., Development and Commercialization of the Light Water Reactor, 1946-1976. Rand Corporation, June 1977.

Reactor and the Intermediate Power Breeder were pursued simultaneously in the early years of the AEC. The first was designed to test construction materials under high temperature and radiation conditions. Results of these tests were useful both for LWR and breeder designs. The second and third were to examine the potential of different breeder concepts. Early research and development for non-military applications was clearly oriented towards a breeder reactor. The combination of technical problems with the breeders and the successful development of the light water technology in the military program eventually led to a reorientation of the civilian program towards LWRs.

The AEC's military program was divided into two types of activities, those involved with weapons production and those related to power reactor development. Only the latter will be considered to have contributed towards development of the civilian nuclear industry.

The military reactor development program in turn included a range of subactivities. Only those which contributed most clearly to the development of civilian reactor technology are considered to have provided subsidies. These were the naval propulsion reactor program and the aircraft reactor program. Army power reactor development is excluded because these reactors were a specialized design for remote applications without direct relation to commercial power development. Also excluded are expenditures in the categories special classified projects, operation of service facilities, general, special nuclear materials consumed and merchant ship reactor development.

AEC research and development on military reactor applications was designed to produce reactors suitable for submarine, aircraft, and aircraft carrier programs resulted in working reactors. The submarine propulsion program was probably the most important of the AEC's early R&D efforts. It culminated in a system based on a light water reactor which was first demonstrated in 1953. The success of the light water reactor at this early stage contributed greatly towards its eventual acceptance as the AEC's technology of choice. The development process of the naval reactor contributed directly to designs later adopted for civilian commercial use.

The development of a nuclear aircraft carrier propulsion system, begun in 1952, led directly to the first civilian nuclear power plant at Shippingport, Pennsylvania. The aircraft carrier system was also based on a light water reactor as a result of the successes enjoyed to that time in the submarine program. The shipping port project was in fact developed and managed by the same group which had developed the submarine reactor.

The AEC's efforts relied heavily on several private firms, primarily General Electric and Westinghouse, especially in the submarine and carrier programs. These relationships gave the firms superior capability in nuclear technology and assured their place in future reactor development and commercialization. It was a relatively short step for these companies to pursue civilian research, with government subsidies, in an area which held some potential to become a significant private market in the future.

The naval propulsion reactor program went through two stages. The intensive effort from 1948 to 1955 culminated in the successful testing of a nuclear-powered submarine. The second stage, from 1956 to 1962, encompassed the building of a nuclear fleet, including both surface ships and submarines. While both contributed significantly to the successful development of civilian nuclear power, their contributions differed. The first stage developed reactor technology from scratch and demonstrated its inability. This process was an integral part of the AEC's overall RD&D program and was probably the most important part of it.[17] The importance of the second stage was in its establishment of a broad technical

[17] op. cit., Nuclear Navy, p. 381.

base in private industry which would be critical to the later development of commercial nuclear power.[18]

The selection of a proportion of the relevant expenditures on military reactor development which constituted a subsidy to commercial nuclear power was based on the two stages of the military program. Thus, one hundred percent of military expenditures for the naval propulsion reactor system and the aircraft propulsion reactor system are considered to be a measure of the subsidy between 1948 and 1955. In the second stage, fifty percent of the military expenditures on naval propulsion reactor is considered to have provided a subsidy. Given that a substantial proportion of military reactor-related expenditures were deleted at the outset (see above), that only research and development expenditures (i.e., construction expenditures were excluded) are included after 1959, and given the importance of the second stage to private industry's development of nuclear capacity, fifty percent is considered a conservative figure. (See Table 1 for exact figures by year.)

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[18] "Just as much of that technology [LWR technology] came directly from the naval propulsion project, so did the laying of a broad technical base in industry depend in large measure upon the techniques devised in building the nuclear fleet."

"The first effect was to help create the nuclear equipment industry upon which the later rapid expansion of nuclear power plant construction depended." "The second effect was to set new and unprecedented standards of precision and quality in the fabrication and assembly of nuclear equipment." "The third effect was to provide the technical manpower base for the nuclear industry in the United States."

op. cit., Nuclear Navy, p. 382-384.

Industrial Participation

The AEC needed to involve private industry in order to attain its goal of commercial nuclear power. As government funded reactor development proceeded from the submarine reactor to Shippingport, the AEC pursued another line of development in the civilian area. In 1951 the AEC began its Industrial Participation Program designed, as its name suggests, to encourage the participation of private industry in reactor development. The program solicited studies from groups of private firms as to suggested types of reactors, technical aspects of the development process, non-technical barriers to development and required levels of government support.

These studies as well as AEC analyses indicated that there were serious barriers to active private involvement. Technical information derived from earlier government funded research was not widedly available. Much of it was classified. In addition, substantial risks faced any potential investor. Technical risks derived from the preliminary state of knowledge and uncertainty about whether the technology would ever be commercially viable. Related to these risks were financial risks. There was substantial uncertainty about when the payoff to an investment in R&D might occur, if ever. A key conclusion of the private studies was that private industry could not handle the projected capital costs of nuclear power plants in light of the risks involved.

An amended Atomic Energy Act (The Atomic Energy Act of 1954, PL 83-709) was passed in an effort to facilitate industry's involvement. The revised Act allowed ownership by private firms of nuclear facilities and their use but not ownership of nuclear materials; provided better access to the AEC's technical information; and promised AEC services and materials to private firms. These incentives, however, did not directly affect the risk component of nuclear investment. As a result, they evoked no perceptible response from industry. In response, the AEC instituted a new set of incentives under its Power Reactor Demonstration Program, announced in early 1955.

The Power Reactor Demonstration Program (PRDP) was developed over three "rounds". Each employed a somewhat different approach to relieving private investors of risk. In general, there were two options for private firms. The first was a package which included AEC performance of requested R&D work without charge, lump sum R&D grants, and the waiver of fuel use charges to utilities. The second option was for private companies to sign an R&D contract under which the AEC would build the reactor and would become the owner of the reactor. The private firms would contribute some portion of operating and construction expenditures, a site, would contract to buy the steam, and would own the conventional part of the system. In return for its investment, the AEC was allowed to disseminate the resulting technical information. The latter option was included primarily to make it possible for small utilities to be involved.

The first option made a nuclear investment more attractive to private investors primarily by reducing the cost rather than by directly reducing the risk. In other words the subsidies increased the expected rate of return on the investment rather than reducing the required rate of return. The second option directly reduced the risk to private participants. By owning the reactor the AEC directly bore the risks associated with its construction and operation. Private investors' risks were limited to their investment in the site and the conventional portion of the generating plant. In this case the subsidy directly reduced the rate of return required by investors.

These early subsidies were intended primarily to generate technical information about the design and performance of various reactor types. The benefit received from subsidy expenditures was the information required in order to proceed towards commercially viable nuclear power. However, private firms overwhelmingly preferred the first option precisely because they retained control of the information produced. This limited the direct benefits to society from the subsidy. The costs were those expenditures required to induce private companies to invest despite considerable uncertainties about the technology and about potential commercial viability.

First round assistance was aimed primarily at reducing the cost rather than the risk to investors. Only four proposals were submitted for the first round and of these only two received direct AEC assistance on the terms of the first round. The two projects which received direct AEC assistance and the one built without such assistance were financed by groups of firms. In the absence of significant risk sharing by the AEC, investors spread the risk among the frequently numerous members of their group. Each member received the benefits of the project in technical information but restricted their potential liability to an acceptably small amount.

The second round of the Power Reactor Demonstration Program was announced in September 1955. It was designed to encourage the participation of publicly-owned utilities and to demonstrate small (<40Mw) reactors for export and for small-scale application in the U.S. In order to do this, the AEC offered to provide the funds for construction of the plants and to retain ownership of them. The utilities agreed to provide sites and entered into five year contracts to purchase the steam for generating electricity. The investors were forced to bear some risk however, because the AEC agreed to pay only a predetermined fixed amount. Any cost overrun would be paid by the utility or by the reactor vendors. Cost overruns were almost guaranteed, given the infant status of nuclear reactor technology.

Of seven proposals received in the second round, only two resulted in completed reactors. Most of the cancellations resulted from failure to agree on a division of risk between the AEC, utilities and reactor manufacturers. The completed projects resulted in financial losses to the reactor manufacturers. In each case the small utility involved successfully limited its contribution to a fixed amount. In addition, indirect subsidies to the projects were received because of the small utilities' status. One was a rural electric cooperative and one was a municipal utility. Such utilities have access to low-cost capital as a result, respectively, of Rural Electrification Administration loan guarantees and the tax-exempt status of muncipal bonds.

The goal of the third round of the PRDP was to support the construction of larger reactors which were closer to commercial prototypes than those of the second round. The emphasis on reactor design which had already undergone substantial R&D meant that technically based risks were reduced. AEC subsidies for the third round again emphasized cost reduction rather than risk sharing. The subsidies included the waiver of fuel use charges; the loan of heavy water; the provision of technical information; and grants for R&D work.

Five reactors were completed as a result of third round contracts. Again, the plants were built by groups of firms, including utilities and manufacturers, in order to reduce the risk for any single firm to manageable proportions. The three light water reactors, representing the most advanced of the reactor types, provided the most successful experience.

The modified third round was intended to encourage the building of large, base-load plants which could demonstrate the commercial reliability of nuclear power. This round, begun in 1962, was the only one which could take full advantage of lessons learned in the three previous rounds. Again because of the AEC's goals, only light water reactors were eligible for support. The AEC limited its role to 10 percent of pre-construction R&D and the waiver of fuel use charges. Two plants were ordered with AEC assistance: Haddam Neck - Connecticut Yankee and Corral Canyon in California. Only the Haddam Neck plant was completed.

These two plants were the last light water reactors to receive direct government subsidies oriented to specific plants. In 1962, reactor manufacturers began to offer

A New Strategy

Subsidies for R&D from the government, however, continued. The AEC began its second stage of R&D subsidies. The post-1962 surge of utility orders led the AEC and others involved in LWR development to assume that the technology was mature.[19] The AEC altered its priorities in reactor development and began to move towards what it hoped would be the second generation of nuclear powerplants. Two design concepts emerged from the five considered by the AEC for subsidization. A debate between backers of the high temperature gas cooled reactor (HTGR) and backers of the liquid metal fast breeder led to a choice of the breeder. For the next 15 years, the bulk of the AEC's and ERDA's R&D budget went to breeder development.

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[19] The problem with AEC's strategy of developing second generation reactors was that significant problems remained with light water technology. Light water reactors were technically immature. Industry, with the AEC support, had built commercial prototype reactors rather than a finished design. In 1962, there were only five operating power plant prototypes, with an average capacity of less than 160 MW. The problems of scaling up to plants as large as the 800 MW plants which some utilities order during the turnkey era and the 1000 MW plants order shortly thereafter, were immense. Design, materal and construction problems plagued these plants. Despite some technical progress, ubiquitous and chronic cost overruns were a symptom of the continuing problems.

In addition, the AEC gave low priority to safety research on LWR's and paid little attention to problems with the nuclear fuel cycle. The AEC failed to develop independent R&D capability and was forced to rely on the industry for data and standards.

See: Bupp, Irvin C. and Derian Jean-Claude, <u>Light Water</u>. New York: Basic Books, 1978.

The current program of fission energy research and development, under DOE, includes breeder reactor systems and converter reactors.[20] In April 1977 reprocessing and the commercialization of the fast breeder were postponed primarily because of their implications for the proliferation of nuclear weapons. Substantial R&D work continues on the breeder, although at lower than historical levels. The converter reactor program is a joint government-industry program designed to improve the operating characteristics and the safety of current reactors. This return to subsidies to light water reactors is in recognition of the continuing problems which plague their operation.[21]

After the AEC was disbanded in 1974, the Nuclear Regulatory Commission (NRC) was given the regulatory functions of the AEC while the Energy Research and Development Administration (ERDA) was given the promotional and other functions. While ERDA was merged into the Department of Energy in 1977, the NRC retains its independent status. The NRC's programs are also directed primarily towards the current generation of reactors. The goal of the NRC is to ensure the safety of nuclear power plants and the associated fuel cycle.

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[20] Converter reactors are those which consumes fissile material faster than they generate it. In other words, all the commercial nuclear power plants now operating in the U.S. are converter reactors.

[21] Fission Energy Program of the U.S. Department of Energy, Deputy Assistant Secretary for Nuclear Reactor Programs, U.S. Department of Energy, Janary 1980.

Nuclear Regulatory Commission expenditures are subsidies to commercial nuclear power because they represent external costs, imposed by the industry and absorbed by society, which are unavoidably associated with production. Further, society chooses to say these costs explicitly via government expenditures. The alternative is that society simply absorbs the costs, e.g., society absorbs some of the health and safety costs imposed by the industry without trying to mitigate them. No effort will be made here to include this last form of costs, the unpaid external costs, in the total government subsidy to nuclear power.

Total Expenditures

Table 1 summarizes the data on Federal research and development subsidies. Expenditures are included for civilian fission reactor development, military reactor development where appropriate and for fusion reactor development. The total expended since 1948, in constant 1979 dollars is $20.9 billion.

In addition, following Battelle's analysis, several other categories of expenditures are included.[22] These categories are biology and medicine; education and training; physical research; and program management. They are included because

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[22] An Analysis of Federal Incentives Used to Stimulate Energy Production, PNL-2410 Rev., Battelle Memorial Institute, December 1978, pp. 110-112.

expenditures in each of these areas provided direct support to both military and civilian reactor development. The actual proportions of expenditures used follow Battelle. The total additional expenditures, in 1979 dollars, is $2.5 billion. This raises the total expenditures on research and development to $24.7 billion.

Table 1. Research and Development Subsidies (millions of dollars)

	Fission a/ Civilian	Military b/	Fusion a/	Total Current $	Total c/ Constant $ (1979)
1950	3.1	5.1		8.2	25.3
51	5.1	17.7		22.8	66.1
52	6.3	24.5		30.8	87.8
53	10.1	38.8		48.9	137.4
54	18.9	35.5		54.4	150.7
1955	29.9	32.8		62.7	169.9
56	55.1	51.4	7.2	106.5	280.1
57	97.5	99.0	11.6	196.5	501.1
58	148.1	103.6	19.9	251.7	631.8
59	184.7	96.5	36.0	281.2	688.9
1960	243.8	79.3	32.1	323.1	778.7
61	282.5	82.3	30.1	364.8	871.9
62	271.8 d/	47.7	25.0	319.5	747.6
63	265.4	54.5	26.2	319.9	739.0
64	295.8		22.9	318.7	733.0
1965	298.9		23.4	322.3	709.1
66	277.9		24.1	302.0	664.4
67	285.7		25.1	310.8	652.7
68	334.6		27.7	362.3	724.6
69	302.8		30.1	332.9	632.5
1970	280.7		31.6	312.3	562.1
71	301.0		32.5	333.5	567.0
72	356.1		36.1	392.2	666.7
73	417.4		42.5	459.9	735.8
74	600.3 e/		59.0	659.3	923.0
1975	739.1		95.0	834.1	1,084.3
76	959.3		164.0	1,123.3	1,348.0
77	1,217.0		236.0	1,453.0	1,743.6
78	1,237.7		277.0	1,514.7	1,666.2
79	1,266.4		349.0	1,615.4	1,615.4
				Total Constant Dollars	20,904.7

FOOTNOTES TO TABLE 1

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[a] All figures include operating and construction expenditures.

[b] Includes operating and construction costs through 1959. After 1959, military expenditures exclude construction costs. These numbers are 50 percent of relevant expenditures. See text for explanation. Excludes classified projects, operation of service facilities, general, special nuclear materials consumed, and merchant ship reactors.

[c] Current dollars adjusted to 1979 dollars by applying GNP deflator.

[d] For 1962 to 1975, construction and equipment costs are from Battelle, PNL-2410 Rev.

[e] After 1974, figures include NRC budget obligations.

Sources: Atomic Energy Commission, Financial Report, 1955 to 1974.

Department of Energy, Office of Budget, Energy Technology Branch.

"An Analysis of Federal Incentives Used to Stimulate Energy Production," PNL-2410 Rev., Battelle Memorial Institute, December 1978.

Nuclear Regulatory Commission, Budget Estimate, FY 75-80.

4. SUBSIDIES TO FOREIGN REACTOR SALES

The United States, through several government agencies, has provided and continues to provide susidies to foreign use of U.S. reactor technology. These subsidies were instrumental in aiding penetration of the European market by light water reactors produced by domestic manufacturers. The subsidies provided direct and indirect assistance to these manufacturers. They helped to sustain the momentum of nuclear development when it slowed in the U.S., both in the late 1950's, and in the 1970's. According to some expert observers, direct U.S. government support for light water reactors in Europe became substantial precisely when it was flagging in the U.S.[23]

U.S. subsidies to the foreign construction of U.S. light water reactors or U.S. designed reactors have included: loans; grants; gifts; the supply of nuclear materials and the waiver of fuel use charges; loan guarantees; research contract grants; and the financing of international training courses, schools, symposia and conference. Such subsidies also include the sale of enrichment services at below the market price. This subsidy form will be addressed in section 6 below.

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[23] op. cit., Bupp and Derian.

The Atoms for Peace Program provided research reactor grants and research equipment grants to 27 countries, between 1953 and 1962. Total aid was $29.1 million in constant 1979 dollars.[24]

The Agency for International Development provided financial assistance including a $72 million loan to build the Tarapur nuclear power plant in India as well as $4.97 million in grants for technical assistance to a number of countries.[25]

The Atomic Energy Commission agreed to sell nuclear materials and services to foreign countries with bilateral nuclear agreements with the United States. The AEC also assisted countries in obtaining nuclear fuel under long term, deferred payment contracts. The AEC facilitated the construction of the three reactors under the Joint U.S.-European Atomic Energy Community program by deferring fuel payments for 10 years. The AEC also waived fuel-use charges of $342,000 on foreign contracts.[26]

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[24] "U.S. Financial Assistant in the Development of Foreign Nuclear Energy Programs", U.S. Government Accounting Office, May 28, 1975.

[25] Ibid.

[26] Ibid.

The Export-Import Bank has been the largest source of U.S. Government financing for foreign nuclear projects. The Export-Import Bank has provided loans for constructing and fueling nuclear powerplants,for nuclear training centers, engineering studies, heavy water purchases and research reactors. The loans are tied to the purchase of nuclear equipment, materials and services from U.S. companies. Through September 1979, 77 such loans have been made,with a total value of $4.677 billion. The Export-Import Bank provides loans at terms which are substantially more favorable than those obtainable on the open market. Interest rates are lower and the repayment periods in general are longer than those obtainable from private sources. Private U.S. sources, including reactor manufacturers, have participated in a large proportion of the Ex-Im Bank's loan agreements. The Ex-Im Bank provided has loan guarantees to these private sources which total $1.894 billion to date.[27]

The United States contributed resources in support of foreign nuclear power development through its participation in the International Atomic Energy Agency. The U.S. has provided about one third of the regular budget plus additional cash contributions, gifts in kind, voluntary gifts of special nuclear material and research contracts. The U.S.

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[27] "Authorization for Nuclear Power Plants and Training Centers", Export-Import Bank of the United States, 1979.

also conducts research on areas identified by the International Atomic Energy Agency, through the Arms Control and Disarmament Agency. U.S. contributions to date total $174.3 million.[28]

The U.S. has provided support for a number of other activities to encourage the wider use of nuclear power. These include: a joint U.S.-European Atomic Energy Community research program to improve light water reactor performance; U.S.-Canadian research on heavy water reactors; international nuclear training and educational programs; and international conferences and exhibits. The total documented contribution was $34 million through 1974.[29] These programs are subsidies because they provide or did provide economic assistance to the producers of nuclear power plants in order to promote an increase in the supply of nuclear reactors. These subsidies were designed to increase foreign demand for U.S. reactor technology. They do so in two ways. Aid like research reactors and training courses build familiarity and expertise with a technology. They contribute towards creating and

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[28] op. cit., "U.S. Financial Assistance".

Office of Nuclear Affairs, Assistant Secretary International Affairs, U.S. Department of Energy.

[29] op. cit., "U.S. Financial Assistance".

maintaining the basic technical infrastructure that is required in order to maintain nuclear generating stations. Thus they contribute a critical ingredient to foreign demand for nuclear plants and substantially reduce the uncertainty of such a venture.

Aid like loans from the Export-Import bank, loan guarantees and the provisions of nuclear materials at advantageous terms serve a different but related function. These provide financial and physical resources that might not otherwise even be available, at below market cost. The availability of these resources both lowers the cost of constructing a plant and reduces the uncertainty connected with such an investment.

Overall, the effect of subsidies to foreign reactor purchases is to lower the required rate of return through reducing the risk premium and to increase the expected rate of return by lowering costs. Together, these effects serve to increase foreign demand for U.S. produced reactors and thus benefit the domestic reactor industry.

These subsidies to foreign demand are a complement to domestic subsidies. Domestic subsidies helped to establish a nuclear supply industry and to create a demand for its output. Thus, these subsidies served both to increase the long run elasticity of supply and to shift to the demand curve for nuclear components. Foreign subsidies were in theory a useful complement because domestic demand was relatively limited compared to productive capacity. They could further shift out the demand curve for domestically produced components and thus contribute to the viability of U.S. manufacturers.

Many of the subsidies to foreign reactor sales are not quantifiable. Table 2 summarizes those that are. The total subsidy equals $237.4 million in constant 1979 dollars.

Table 2. Subsidies to Reactor Sales

($M)	1979 $'s
Atoms for Peace	29.1
IAEA/ACDA	174.3
Other	34.0
Total	237.4

Source: "U.S. Financial Assistance in the Development of Foreign Nuclear Energy Programs," U.S. Government Accounting Office, May 28, 1975.

Office of Nuclear Affairs, Assistant Secretary International Affairs, U.S. Department of Energy.

5. SUBSIDIES TO URANIUM PRODUCTION

The Federal Government, primarily through the Atomic Energy Commission, has provided a variety of key subsidies to uranium producers. The subsidies include production incentives, procurement policy, exploration assistance and an embargo on foreign uranium. These subsidies were initially deigned to encourage the development of a uranium industry and later, to ensure a smooth transition from AEC fuel ownership to commercial ownership.[30]

The AEC in 1948 established a set of incentives to encourage the exploration for and production of domestic uranium. Prior to 1948, U.S. uranium needs, primarily military, were met from foreign sources. The incentives included a ten-year guaranteed price for selected high-grade ore; a $10,000 bonus for new discoveries of high-grade ore; a three-year guaranteed price for ores from the Colorado plateau where significant exploration had already taken place; payment of haulage and development allowances; provision of access to certain public lands; and a guaranteed price for vanadium, a mineral which was frequently associated with uranium ore. In 1951, the price guarantees were extended through 1962 and a production bonus was declared for the first five tons of uranium dioxide extracted from any new property.[31]

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[30] Dawson, Frank G., Nuclear Power. Seattle: University of Washington Press, 1976, pp. 150-163.

[31] "Chronology of Raw Materials Program", Grand Junction Office, U.S. Department of Energy, 1966.

In 1956 the procurement program was extended for the 1962 to 1966 period. It included a guaranteed price and a limit, to be used at the AEC's discretion, on total uranium dioxide bought from any operation. In 1955 the U.S. was already the world's largest producer of uranium. By 1957 the AEC's stockpile was much larger than required. The AEC announced that "it was no longer in the interest of the Government to expand the production of uranium concentrate." As a result, in 1958 the AEC announced a cutback in the planned procurement for the 1962-1966 period.[32] Price guarantees for the 1962 to 1966 period were restricted to uranium from ore deposits developed prior to 1958. Further, no new contracts would be signed in the interim 1958 to 1962 period. The AEC made it clear that in the future, new contracts for uranium would be entered into only as needed.

It was initially hoped that commercial demand would be high enough in 1966 to obviate the need for any further AEC purchases. In 1962, the low probability that adequate commercial demand would materialize by 1966, led to the announcement of a stretchout program. It deferred purchase of a portion of the uranium already covered by purchase agreements for the 1962 to 1966 period, and spread the purchases over an additional two years. The stretchout

[32] Ibid.

(op. cit., Dawson.)

program also provided for the purchases of additional uranium equal to the deferred amount, between 1968 and 1970 when the program would end.[33]

The Private Ownership of Special Nuclear Materials Act of 1964 mandated the end of the AEC monopoly over the ownership of nuclear reactor fuel. Private ownership of nuclear fuel was permitted immediately upon passage of the Act. However, it was in many utilities' interest to continue to lease the fuel from the AEC at a charge substantially below what it would have cost them to own the fuel. The Act provided for termination of the AEC's leasing program as of the end of 1970 and terminated all outstanding lease agreements as of 1973. In 1971, at the end of the leasing program, the AEC had a stockpile of 50,000 tons of excess uranium dioxide.[34]

The second component of the subsidies to uranium producers was the exploration program. This exploration was carried out by contractors to the AEC, by AEC staff, by the U.S. Geological Survey and by the U.S. Bureau of the Mines. The program included airborne radiometric surveys, geological investigations and exploration drilling.[35] Exploration

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[33] Ibid.

[34] Op. cit., Dawson.

[35] Op. cit., "Chronology of Raw Material Program".

activity between 1948 and 1955 was carried on primarily by the government. Private activity picked up in 1956, and the AEC discontinued most of its exploration activities. However, the AEC again began to undertake substantial exploration activities in the early 1970's which were continued by ERDA and DOE. The AEC also built access roads to mines and constructed and operated uranium ore-buying stations. In addition, the AEC developed new methods to process raw ore and improved sampling and assaying techniques through contractor and staff work in a program which ended in 1958.[36]

The current program of uranium exploration under DOE, the National Uranium Resource Evaluation program, or NURE, was begun in 1974 by the AEC. The stated goals of the NURE program are to assess the uranium and thorium resources of the United States; to reduce uncertainty about the extent, availability and economies of the resources; and to make technology and resource information available to industry for use in exploration, development and production.[37]

The NURE program consists of data collection, data evaluation and resource assessment. The data collection program includes the national aerial radiometric survey and the national hydrogeochemical and stream-sediment reconnaissance survey

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[36] Ibid.

[37] National Uranium Resource Evaluation Interim Report, Grand Junction Office, Assistant Secretary for Resource Applications, 1979.

In addition, other data collection efforts are being pursued including studies of high-cost, nonconventional resources, subsurface geologic investigations, and the improvement of data collection methodologies.

The final component of subsidies to uranium producers was the uranium embargo imposed by the Private Ownership of Special Nuclear Materials Act of 1964. The Act prohibited the import of foreign uranium for use in domestic reactors, although the U.S. was allowed to enrich foreign uranium for re-export. The embargo served to maintain domestic prices above world prices and helped the domestic uranium industry survive the slack period in world demand.

In 1975, the AEC instituted a policy of allowing uranium imports on a gradual basis. In 1977, 10 percent of the uranium enriched by the U.S. for domestic use could be of foreign origin and by 1984, no restrictions will apply.

The three major programs of intervention in the uranium market were and, where they continue, are subsidies to uranium producers. Uranium production incentives provided a guaranteed market and a stable price. The AEC intervention was unprecedented among natural resource industries. The AEC constituted, with only minor exceptions, the entire market for uranium until commercial nuclear reactors began operation in the late 1960's. AEC demand created and sustained uranium producers for almost twenty years. The program substantially raised the expected profits to producers. In addition, it reduced uncertainty about future prices, which reduced the risk premium associated with uranium production which in turn reduced the producers required rate of return.

AEC actions increased the demand for uranium and allowed uranium producers to earn a profit. The secondary effect was to create a uranium supply industry, which in turn meant increased elasticity of supply. The creation of an industry capable of expansion, i.e., an industry with relatively elastic supply, was critical to the later development of the entire nuclear industry. Producers were in a position to expand output without large price increases when demand from commercial sources picked up. Thus, fuel-supply was assured at a price which did not threaten nuclear's cost competitiveness with coal. Although the precise effects are unclear, the embargo on uranium imports complemented the production incentive. It prevented imports of lower price world uranium and contributed to both the level and stability of domestic uranium prices. The embargo maintained the profit expectations of producers and reduced their required rate of return by reducing uncertainty about future prices.

Exploration assistance from the AEC, ERDA, and DOE was and is another production incentive. Active AEC involvement contriuted to knowledge about the location and extent of uranium resources. The early exploration program reduced the cost of uranium exploration and production to private industry and thus increased their expected profits. It also reduced uncertainty about the viability of domestic uranium resources and production and thus reduced firms' required rate of return. The current program has a similar effect. It reduces costs and uncertainty to uranium producers. Their required rate of return is reduced and their expected rate of return is increased. As a result, given adequate demand, production is expanded.

In order to estimate the value of Federal subsidies to uranium production, several assumptions were made. Data are available on the total value of uranium procured by the AEC from 1950 to 1970, when the program was terminated. These expenditures include those on foreign and domestically produced uranium. Expenditures on foreign uranium procurement are excluded although foreign uranium was also available for the domestic reactor program. From 1950 to 1962, the uranium procurement program served both to provide uranium for military uses and to sustain the domestic uranium industry. For this period, the proportion of domestic procurement costs attributable to the needs of civilian power development is approximated by the proportion of total AEC reactor development costs (excluding construction) which were spent on civilian reactor development over the same period. The proportion is twelve percent.[38]

The original uranium purchase program, which was intended to support both military and civilian needs, was initially scheduled to end in 1962. The purpose of the new program and subsequent stretchout was to ensure a smooth transition to a uranium market based on commercial demand.[39] In 1970 the AEC estimated that it held 50,000 tons of uranium in excess of government needs.[40] This surplus resulted primarily from the AEC's purchases in support of domestic uranium producers between 1962 and 1970. The 50,000 ton surplus represented sixty three percent of all uranium purchased by the AEC during this period.[41] From 1962 to 1970, sixty three percent

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[38] This proportion is probably conservative. For example the 1955 AEC Financial Report says in reference to the procurement budget "A large proportion of these costs have been to acquire inventories which can be made available for peaceful as well as military uses." p. 4.

[39] Atomic Energy Commission, <u>Financial Report</u>, 1969, pg. 1.

[40] Op. cit., Dawson.

[41] <u>Summary, The Domestic Uranium Program</u>, Grand Junction Office, U.S. Department of Energy, 1966.

of domestic uranium procurement expenditures were attributed to the civilian program on the grounds that the primary purpose of the procurement program in those years was to ensure that uranium supply would not inhibit civilian nuclear power development.

Table 3 summarizes the Federal subsidy to uranium production from 1950 to 1979. The total subsidy, in constant 1979 dollars is $2.5 billion.

Table 3. Subsidies to Uranium Production
(Millions of Dollars)

	Current $	Constant $ (1979)
1950	3.8	11.8
51	4.3	12.5
52	6.4	18.6
53	9.1	25.5
54	12.6	35.3
1955	17.9	48.3
56	12.1	31.5
57	19.7	49.3
58	23.8	59.5
59	34.2	85.5
1960	35.8	85.9
61	36.7	88.1
62	34.0	78.2
63	156.2	360.8
64	127.3	290.2
1965	114.7	255.8
66	102.7	222.9
67	92.0	192.3
68	78.1	156.2
69	63.0	120.3
1970	32.1	58.1
71	0.0	0.0
72	0.0	0.0
73	0.0	0.0
74	2.9	4.1
1975	6.8	8.8
76	16.9	20.3
77	34.9	41.9
78	54.8	60.3
79	71.8	71.8
Constant Dollar Total		2,493.8

Sources: Atomic Energy Commission, Financial Report, 1955 to 1971.

Office of Uranium Resources and Enrichment, Assistant Secretary for Resource Applications, U.S. Department of Energy.

6. ENRICHMENT SUBSIDIES

Introduction

The enrichment stage of the nuclear fuel cycle is owned by the Federal Government. Originally built to supply highly enriched uranium for manufacturing nuclear weapons, the capacity is now almost completely available for civilian nuclear power plants. The three currently operating U.S. uranium enrichment plants are located in Oak Ridge, Tennessee; Paducah, Kentucky; and Portsmouth, Ohio. They utilize gaseous diffusion technology in which uranium hexaflouride gas (UF6) is forced through a permeable barrier. The gas initially contains only about .7 percent of the desired fission uranium isotope, U-235. The remainder is U-238. A larger proportion of the lighter U-235 passes through the barrier and after thousands of repetitions, the gas contains about four percent U-235, which is suitable for use in light water reactors.[42]

The annual capacity of the three DOE plants is about 17.1 million kilogram separative work units (SWU's). A SWU is a measure of the work required to separate the two uranium isotopes.[43]

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[42] Office of Uranium Resources and Enrichment, Assistant Secretary Resource Applications, U.S. Department of Energy.

[43] Ibid.

There are currently two programs designed to increase enrichment capacity. The cascade improvement plan (CIP) will incorporate recent advances in diffusion technology into current plants. Capacity will be increased by about 5.5 million SWU's per year. The cascade uprating program (CUP) allows the current plants to use more electrical power in the enrichment process. The result will be a further increase in capacity of about 4.6 million SWU's per year.[44]

Finally, a plant using the new and as yet unproven gaseous centrifuge enrichment technology is being built in Portsmouth, Ohio near the existing diffusion plant. The gas centrifuge enrichment plant (GCEP) will add a further 8.8 million SWU's per year of enrichment capacity when it is fully operating by 1993. Increments of 1.1 million SWU's will be brought into production between 1988 and 1993.[45]

The DOE engages in an active contracting and marketing program in order to promote U.S. enrichment services. DOE also maintains an industrial participation program which supports the transfer of centrifuge technology to industry.[46]

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[44] Ibid.

[45] Ibid.

[46] Ibid.

The government owned enrichment plants provide a subsidy to the nuclear power industry through the mechanism of enrichment pricing policy. The government charges for enrichment have been consistently lower than the prices which would be charged by a private supplier. The government's pricing formula does not include provision for a rate of return, for state and local taxes, for insurance, for federal income taxes, for interest on the uranium inventory required for enrichment, or for eventual decommissioning of the enrichment plants. The government buys power at a price well below the price that a commercial enrichment facility could expect to pay. This lower price is passed on directly to the users of enriched uranium. Finally, the price of enrichment services includes a depreciation charge based on construction costs incurred between 25 and 35 years ago and which are spread over a 50 year period. Depreciation charges would be substantially higher for a commercial firm operating an enrichment plant today. In other words, the government makes enrichment services available to the industry at substantially less than the market price.[47]

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[47] "Fair Value Enrichment Pricing: Is It Fair", EMD-78-66, General Accounting Office (GAO), April 19, 1978.

"Comments on Proposed Uranium Enrichment Pricing Legislation", EMD-77-73, GAO, September 27, 1977.

"Comments on Proposed Legislation to Charge Basis for Government Charge for Uranium Enrichment Service", RED-76-30, GAO, September 22, 1975.

The subsidy provided through low-cost enrichment services lowers the cost of fuel to utilities which operate nuclear power plants and thus lowers the cost of nuclear generated electricity. For a non-regulated firm, the subsidy would increase the expected rate of return from producing nuclear power. However, since the firms in this case are electric utilities with a regulated rate of return, the expected rate of return would not change. The decreased cost of nuclear electricity relative to other forms of electricity will make it more attractive to utilities interested in minimizing the cost of service of their customers. The effects of the subsidy is to increase utilities' demand for nuclear plants and thus to increase the supply of nuclear electricity.

The enrichment pricing subsidy is supplied to foreign purchasers as well as domestic. Approximately one half of current enriched uranium sales are to foreign buyers.[48] The effect of this subsidy to foreign buyers is to increase the demand for nuclear electricity in the purchasing countries. More importantly, as a result of this increased demand for nuclear electricity, the demand for U.S. produced nuclear plants is increased. Thus the enrichment subsidy increases both domestic and foreign demand for nuclear power plants.

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[48] Op. cit., Office of Uranium Resources and Enrichment.

Fair Value Pricing

The pricing rule established in the Private Ownership of Special Nuclear Materials Act of 1964 was that enrichment prices should be such as to provide "reasonable compensation to the government". At the end of 1970, the basis for pricing was changed to "recovery of the Government's costs over a reasonable period of time". (PL 91-569) This remains the rule although ERDA and DOE have made several attempts since then to alter the basis for pricing to "fair-value" pricing. The fair-value price is the price that would obtain if DOE charged for enrichment on the same basis as a private firm. The difference between fair-value price and the price actually charged is one measure of the subsidy.[49]

The fair value price would probably be about thirty percent higher than current and historical charges, according to detailed estimates made by ERDA's Division of Uranium Resources and Enrichment in 1978.[50] Official estimates from the General Accounting Office are in the same range.[51]

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[49] See footnote 47.

[50] Op. cit., Office of Uranium Resources and Enrichment.

[51] Op. cit., "Fair Value Enrichment Pricing: Is It Fair?", pp. 5, 11.

This 30 percent figure is probably on the low side. A number of the additional costs of commercial pricing were estimated conservatively by ERDA. These include assumptions about the rate of return on equity, the cost of debt, and the ratio of debt to equity.[52]

However, if these additional factors are ignored, and the 30 percent price discount figure is assumed to be approximately correct, the subsidy from this source of underpricing of uranium enrichment services since 1970, can be calculated. This was done by simply taking thirty percent of the annual revenues from the sale of enrichment services. (See table 4.)

Power Costs

A second portion of the subsidy provided through uranium enrichment pricing derives from the cost of electricity to the enrichment plants. Operation of the enrichment plants requires a substantial amount of electric power. In fiscal year 1979, the three enrichment plants used 33,939,781 kwh's of power. Three sources supply this power. The Tennessee Valley Authority provides much of it while Electric Energy Incorporated (EEI) and Ohio Valley Electric Corporation (OVEC) provide the balance. Both EEI and OVEC were formed by privately owned utilities in order to build plants designed solely to provide power for the enrichment facilities.[53]

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[52] Op. cit., RED-76-30.

[53] Op. cit., Office of Uranium Resources and Enrichment.

For a complex set of reasons, all three sources sell power to the enrichment plants at a price substantially below the average price paid in the industrial sector. The price to typical industrial customers includes higher cost electricity generated by new plants rolled in with cheaper power from old plants. Thus, the market price for electricity is determined by the historical average cost of producing it rather than the cost of the most recent plant. A private enrichment company could be expected to pay the full average cost of electricity. As a result, an appropriate measure of the subsidy provided by low cost electricity available to government enrichment plants is the difference between the average industrial price and the actual price paid, multiplied by the number of units consumed, since the toll enrichment plan began in 1969. Because government costs are passed through to customers this amount would also have been reflected directly in the price of enrichment services.

Depreciation

Finally, there is an aspect of subsidies to the enrichment of uranium which predates the toll enrichment plan. The government built these plants and provided enrichment services for research and development purposes, and for civilian reactors, prior to the introduction of toll enrichment. The current method of treating depreciation provides a subsidy in that it results in depreciation charges substantially below those that would be charged by a commercial operation. The depreciation charges are based on a low historical investment cost which was incurred in the late 1940's and early 1950's. Original investment in the three enrichment plants was about $2.8 billion while estimates of the current cost of building a gaseous diffusion plant range from $5.6 to $7.5 billion in 1983.[54] In addition, the government plants are effectively being depreciated over a 45 to 50 year period which is about twice as long as the period for comparable commercial equipment.[55] Finally, at the beginning of toll enrichment in 1969 more than half of the original investment had already been depreciated by the AEC. The remainder is depreciated, using a straight-line method, from 1969 to 2000 and charged to enrichment customers on that basis.[56]

Only a limited attempt will be made to estimate the quantitative impact of this subsidy. Some of the unrecovered depreciation prior to 1969 represented costs incurred to support the development of civilian nuclear power. A pro-

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[54] Miller, Saunders , The Economics of Nuclear and Coal Power. New York: Praeger, 1976, p. 78-79.

[55] Op. cit., Office of Uranium Resources and Enrichment.

[56] Financial Statement, Uranium Enrichment Activity, U.S. Atomic Energy Commission, 1972.

portion of these costs will be imputed to civilian nuclear development as a subsidy.

The subsidy is calculated in the following manner. Total capital expenditures on enrichment plants were totalled from 1946 through 1968. Net investment in the plants as of the beginning of 1969 was subtracted in order to arrive at the total depreciation charged over the period. This total depreciation was then spread evenly over the 23 year period in accordance with AEC and DOE accounting practices.[57] It was then assumed that all depreciation prior to 1960 can be charged against military programs while all subsequent depreciation can be charged to the civilian program. Forty percent of the total depreciation between 1946 and 1968 is charged to civilian nuclear power. The result is an annual depreciation charge.

This method attempts only to assign a portion of the historical depreciation to commercial nuclear power. No attempt is made to estimate what depreciation charges would be in the case of a recently constructed commercial plant. Such an estimate would involve both a higher plant cost and a shorter depreciation period. While the method used here does not provide a full adjustment it does provide a partial correction to the method currently used to calculate the depreciation charge in the price of uranium enrichment.

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[57] Ibid.

When each of the thre adjustments to the price are calculated and converted to constant 1979 dollars, the total subsidy is $7.1 billion. (See table 4.)

Table 4. Enrichment Subsidy
(Millions of Dollars)

	Pricing	Power Cost	Depre-ciation	Total (Current $)	Total (Constant $)
1960			76.1	76.1	183.4
61			76.1	76.1	181.9
62			76.1	76.1	178.1
63			76.1	76.1	175.8
64			76.1	76.1	173.5
1965			76.1	76.1	169.7
66			76.1	76.1	165.1
67			76.1	76.1	159.0
68			76.1	76.1	152.2
69	9.0	20.7		29.7	56.7
1970	25.2	54.8		80.0	144.8
71	66.9	128.0		194.9	335.2
72	55.2	104.8		160.0	265.6
73	86.1	133.9		220.0	343.2
74	216.3	507.4		723.7	1,034.9
1975	168.9	278.8		447.7	582.0
76	200.7	237.1		437.8	542.9
77	254.4	431.1		685.5	802.0
78	268.8	372.5		641.3	699.0
79	365.1	352.4		717.5	717.5
				Total	7,061.6

Sources: "Statistics of Privately Owned Electric Utilities in the United States," U.S. Department of Energy, 1978.

<u>Monthly Energy Review</u>, U.S. Department of Energy, February 1980.

Office of Uranium Resources and Enrichment, U.S. Department of Energy.

7. WASTE DISPOSAL SUBSIDIES

Introduction

Substantial quantities of radioactive waste were first generated by the Manhattan Project in the successful effort to produce nuclear weapons. Military applications continued to generate the bulk of such wastes through the late 1960's. Defense-related wastes still comprise more than half of the total existing wastes, when measured by volume.[58] Beginning in the late 1950's, however, government supported, commercially oriented, R&D, and later commercial applications, began to generate radioactive waste. The rate of production of such commercial waste has increased since then. When measured in terms of cumulative radioactivity, total commercial wastes now exceed total defense produced wastes.[59]

Systematic efforts to develop a viable reactor were not parallelled by efforts to find an adequate method for radioactive waste disposal until the late 1950's. A 1957 study by the National Research Council and The National Academy of Sciences indicated that disposal in bedded salt formations was probably feasible subject to the resolution of certain problems. Subsequent AEC waste disposal efforts

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[58] Report to the President by the Interagency Review Group on Nuclear Waste Management, Washington, D.C., March 1979, pg. 11.

[59] Ibid., pg. 8

were based on the use of bedded salt until 1975. The waste research program, however, was not a high priority effort. The President's Interagency Review Group on Nuclear Waste Management indicated that after the bedded salt study was completed, "Attempts to develop methods (for disposal in salt formations) continued sporadically and at low funding levels through 1975."[60]

The waste disposal situation was further complicated in April 1977 when President Carter announced the deferral of commercial nuclear fuel reprocessing. In October 1977, President Carter announced that the U.S. Government would offer to take title to and store spent nuclear fuel from commercial nuclear power plants. The government would charge a one-time usage-based storage fee for this service. The intent of the policy is to relieve the pressure on the limited storage capacity at utilities, while research on disposal is pursued.

The waste disposal program of the U.S. Government as it has evolved has provided a subsidy to the private nuclear power industry in several ways. The government has reduced the overall uncertainty associated with waste disposal, has pursued research and development, has paid for uranium mill tailing cleanup and has avoided the imposition of charges for spent fuel disposal and decommissioning.

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[60] Ibid.

Research and Development

There has been a subsidy provided by direct expenditures on research, development and demonstration work designed to provide permanent storage. These expenditures were and are required in order to avoid the imposition on society and future generations of substantial environmental costs. High level nuclear waste, of which spent fuel is one type, poses a serious threat to health for more than 250,000 years after it is generated.[61] This external cost of nuclear electricity generation has not been absorbed by the producers of that electricity. However, the principle that this cost should be borne by the producers and users of this power is widely supported by those involved with nuclear power, including industry, government and interested citizens.[62]

The federal waste disposal research, development and demonstration effort also provides indirect but probably more important subsidies. Government responsibility for ultimate waste disposal removes significant uncertainties from those investing in nuclear power production. To be a viable source of power, nuclear generation must be able to dispose of its wastes in a socially acceptable manner. If all the costs of

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[61] Ibid.

[62] Nuclear Waste Management Program Summary Document, Office of Nuclear Waste Management, Assistant Secretary for Energy Technology, U.S. Department of Energy, April 1979.

nuclear power (including external and internal costs) are to be paid by current producers, then waste must be permanently and completely isolated from the biosphere. Since there is not, now, a technology which meets these criteria,[63] substantial uncertainty faces producers of nuclear power.

Corporations which manufacture nuclear plants and utilities which purchase and operate them do not have to ensure that nuclear wastes will be dealt with in a socially acceptable manner. As a result, they make investment decisions without taking that uncertainty into account. The subsidy reduces their required rate of return by reducing their risk premium. As a result, they are more likely to undertake such an investment. Thus, the subsidy increases both the supply and demand for reactors because it reduces the uncertainty which faces both utilities and manufacturers. This, in turn, ensures that the supply of nuclear electricity also increases.

The generation of electricity with nuclear power produces waste of several types. These include high-level waste, low-level waste, uranium mine and mill tailings and waste from the decontamination and decommissioning of obsolescent power plants. Each type of waste requires different treatment if it is to be successfully isolated from the biosphere, and each has different costs associated with it.

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[63] Op. cit., Interagency Review Group.

Commercial high-level waste consists primarily of spent fuel assemblies from power plants. Current policy calls for the eventual permanent storage of high-level waste in geologic repositories. These spent fuel assemblies are currently stored by utilities at the site of nuclear plants. However, because the earliest date at which an acceptable geologic repository could be ready is now projected to be the mid 1990's, an interim storage capacity is required. This will be provided, pending legislative action, by away from reactor (AFR) storage sites, owned and operated by the Federal Government.

Subsidies provided by the Federal Government in support of high level waste disposal are the reduction of uncertainty and expenditures on research and development. The reduction of uncertainty is not a quantifiable subsidy. Research and development expenditures on waste management and disposal have been provided by the AEC, ERDA, DOE, and NRC. Expenditures have been made on R&D for both civilian and military waste. The total expenditure is considered a subsidy to civilian nuclear power. Substantial overlap has and continues to characterize the civilian and military waste programs. Although there is some difference of form in the high-level waste, a satisfactory solution for the storage of high-level military waste will be a solution for high-level civilian waste and vice versa.[64] This basic confluence of goals is reflected in President Carter's recent policy statement on nuclear waste disposal.[65] The total expenditures to date on nuclear waste management in constant 1979 dollars are $2.3 billion. (See Table 5.)

Spent Fuel Disposal Costs

There is an indirect measure of the subsidy received by utilities in the area of spent fuel disposal, in addition to direct R&D expenditures. This measure is an estimate of the costs which utilities have avoided to date, for disposal of high-level waste already generated. The estimate is, in effect, an estimate of the costs which have been incurred but not paid by utilities which own nuclear plants. The estimate represents part of the subsidy which the government contributes to nuclear power by assuring utilities that a solution will be found and by allowing the continued generation of waste in the absence of such a solution.

Utilities now have on hand a substantial quantity of spent fuel. Estimate of the cost of disposal for this fuel are available from a number of sources. These estimates provide an indication of the cost in current dollars of the most likely scenario for the disposal of the waste. In order to

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[64] Ibid., pg. I-6.

[65] Press Release, Office of the White House Press Secretary, February 12, 1980.

Table 5. Waste Disposal Subsidy
(Millions of Dollars)

	R&D (Current $)	(Constant $)
1967	206	432.6
68	21	42.0
69	26	49.4
1970	28	50.4
71	32	54.4
72	46	78.2
73	50	80.0
74	61	85.4
1975	94	122.2
76	158	189.6
77	235	282.0
78	362	398.2
79	483	483.0
Spent Fuel		2,115.0
Mill Tailings		283.4
Decommissioning		1,742.4
Constant Dollar Total		6,488.2

Source: Report to the President by the Interagency Review Group on Nuclear Waste Management, Washington, D.C. March 1979, p. 4.

Office of Nuclear Waste Management, Assistant Secretary Energy Technology, U.S. Department of Energy.

estimate the total value of the subsidy to utilities, the estimated cost per kilogram of spent fuel is multiplied by the total amount of spent fuel now held by utilities.

The estimated costs of waste storage and disposal in geologic repositories range from $232 per kilogram[66] to $1129/kg in 1979 dollars.[67] The estimate used here is in the conservative range.[68] It is $352/kg, which when adjusted for current lower projections of nuclear capacity and thus total waste, is $399/kg. When this figure is applied to the 5300 metric tons of spent fuel discharged by U.S. reactors to date,[69] the total cost not paid through 1979, is $2,115 billion.

Low-level waste from reactors is currently disposed of by shallow buraial at three state-owned commercial burying grounds. Ongoing R&D activity in low-level waste provides a subsidy to this waste form. These expenditures are included in the overall R&D figures

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66 "Preliminary Estimates of the Charge for Spent-Fuel Storage and Disposal Services", Assistant Secretary for Energy Technology and Director of Energy Research, July 1978.

67 "Spent-Fuel Disposal Costs", MHB Technical Associates, August 1978.

68 It is derived from the MHB report, using their Low Financial case which assumes a low rate of inflation and a high discount rate.

69 Op. cit., "Spent Fuel Disposal Costs".

for nuclear waste. Utilities pay a charge to site owners to cover the costs of current disposal techniques.[70]

Mill Tailings

The milling of uranium produces large quantities of waste tailings which contain high levels of radium. This radium can and has polluted water supplies and the food chain. In addition, tailings emit significant quantities of radon gas which decay into radon daughters. Both pose health hazards. In addition, mill tailings have been used in housing construction, both as fill and as a substitute for sand in mortar. This also poses substantial hazards.[71]

Attempts at government control of mill tailings date from 1959 when the U.S. Public Health Service and the AEC limited the dumping of radioactive tailings into streams. In 1972, Public Law 92-314 was enacted to provide remedial action on buildings in Grand Junction, Colorado where mill tailings had been used in construction. In 1972, this bill was amended and extended by the "Uranium Mill Tailings Radioactive Control Act of 1978," PL 95-604. The law provided for the funding of clean-up operations at 25 abandoned mill sites. The Federal share of the costs is 90 percent and the affected

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[70] Op. cit., "Preliminary Estimates."

[71] The Nuclear Fuel Cycle, prepared by the Union of Concerned Scientists. Cambridge: MIT Press, 1975, pg. 41-69.

State pays the remainder. The bill does not provide for similar actions related to active mills.[72]

The subsidy here includes to elements. The Federal Government make direct expenditures for the mitigation of effects from priate uranium mills, and for ongoing R&D on the health effects of mill tailings. In addition, the owners of active mills, although subject to some restrictions, are still allowed to impose health costs on the public. No attempt will be made to quantify the latter.

The total projected expenditures on the remedial mill tailings program are $283.4 million.[73]

Decommissioning

The decontamination and decommissioning of nuclear reactors will produce large quantities of radioactive waste. In light of President Carter's recent policy statement on waste disposal,[74] and the NRC's current position,[75] decommissioning will probably require the total dismantlement of nuclear plants.

72 Annual Status Report on the Inactive Uranium Mill Tailings Sites Remedial Action Program, Office of Environmental Compliance and Overview, Assistant Secretary for Environmental, December 1979.

73 Ibid.

74 Op. cit., Press Release, February 12, 1980.

75 "Assuring the Availability of Funds for Decommissioning Nuclear Facilities", Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, July 1979.

Current policy, however, does ot require that utilities make any provision for the costs of decommissioning. In order to be consistent with Federal policy on other waste forms, the cost of decommissioning should be borne by those who receive the benefits of the electricity generated by the plant.

A subsidy is provided by the failure to require utilities to recover the costs of decommissioning from their current customers. The value to date of this subsidy is determined by the proportion of the reactors' plant life which has been used as well as by the per plant cost of decommissioning. Each reactor is expected to produce electricity for 30 years.[76] The current estimated cost for the dismantlement of a typical nuclear plant is $110 million in real 1979 dollars.[77] The 72 currently operating nuclear power plants have used up an average 22 percent of their useful operating lives.[78] The value of decommissioning charges that should have been allocated to the electricity produced during those years is thus $1.7 billion in real 1979 dollars.

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[76] Nuclear Power Analysis Division, Energy Information Administration, U.S. Department of Energy.

[77] Nikodem, Z. D., Reynolds, A., and Clark, G., "Nuclear Power Regulation", Department of Energy, Energy Information Administration, February 1980.

[78] Data from Nuclear Reactor Data Base, Nuclear Energy Analysis Division, Energy Information Administration.

8. CONCLUSIONS

This paper has presented an analysis of selected subsidies to nuclear power. In each case the historical details of the subsidy and an estimate of the total subsidy were presented. The total constant dollar value of these subsidies is just over thirty-seven billion dollars.

Several additional calculations may help to put this overall subsidy figure in perspective. Subsidies contributed to the growth of the nuclear power industry which in turn has supplied nuclear electricity since 1957. It is possible to estimate what the cost of nuclear power would be in the absence of government subsidies, i.e., if all expenditures had been incurred directly by private firms. In order to do this the subsidy costs must be spread across the total output to date of nuclear electricity.

An immediate problem is that there is no currently accepted method for treating expenditures on research and development within a business accounting framework.[79] However, by using two extreme possibilities for treating such expenditures, the range of per kilowatt hour subsidy can be established.

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[79] See: Leopold A. Bernstein, Financial Statement Analysis. Homewood, Illinois: Richard D. Irwin, Inc., 1974, pg. 246-251, 548-551.

One alternative is simply to treat R&D outlays as current expenses and to charge them against current output.[80] This results in a per kilowatt hour subsidy of 2.5 cents. In other words a kilowatt hour of nuclear electricity would cost about 2.5 cents more than its current cost in the absence of government subsidies.

The other extreme alternative is to amortize all the R&D costs over some future period in order to more closely associate the expenditures with the benefits derived from them.[81] If the period chosen for amortization is the same as the period over which a nuclear plant itself is depreciated[82] then the subsidy is calculated to be 1.66 cents per kilowatt hour.[83]

The cost of nuclear generated electricity in 1979 was 2.22 cents per kilowatt hour.[84] Thus, in the absence of subsidies nuclear electricity would probably range in cost from about one and one-half to twice its current cost.

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[80] Ibid.

[81] Ibid.

[82] The depreciation life of a nuclear power plant is typically 16 years.

[83] It was assumed that on average a plant's total historical output is directly related to the time since it began commercial operations.

[84] Office of Nuclear Reactor Programs, U. S. Department of Energy.

An equally important result of the subsidies to nuclear power is non-quantifiable. The subsidies in particular, and the government commitment that they represent in general, have dramatically reduced the uncertainty surrounding the development and ultimate commercial applications of nuclear power. Early research and development subsidies demonstrated the technical viability of nuclear reactors at a time when private firms were reluctant to pursue the technology. Subsidies to uranium production virtually created the industry and sustained it until the commercial demand was adequate. Continued and growing subsidies for waste disposal contribute perhaps the greatest reduction in current uncertainty about the viability of commercial nuclear power. They promise a solution to what is one of the larger barriers to the expansion of nuclear power.

Both quantifiable and non-quantifiable aspects of the subsidies examined have made a substantial contribution to the current status of commercially generated nuclear electricity.