THE DEVELOPMENT OF NUCLEAR ENERGY

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The next 25 years will undoubtedly see the large-scale entry of nuclear energy into a variety of applications as a consequence of substantial progress in nuclear technology for peaceful uses. This period will also see substantial economic growth in the United States, accompanied by a major rise in energy consumption as a whole. In the rest of the world, growth in economic activity and particularly energy is likely to be even more rapid.

The United States supply of conventional energy, including overseas oil sources, seems generally adequate to meet projected demands on it, if foreign demands could be ignored. But the combined requirements of all countries may tax the world supply to a relatively greater degree, with inevitable consequences for the United States supply situation. This, too, will influence the rate of entry of nuclear energy. In these circumstances it may be useful to analyze the likely magnitudes of future energy demand and supply, including the scale and scope of nuclear energy, as a background for considering the basic problem before this panel, Federal expenditures for atomic-energy development.

The first section of this paper presents projections of United States energy supply and demand over the next quarter century (nominally, to 1980) and indicates some of their implications. The second section considers the problems of policy criteria in regard to public expenditures on atomic energy for peaceful uses.

Energy Projections and Economic Growth

Nuclear energy "needs"

In seeking to establish a frame of reference for the present projections, we may usefully begin with the following classification of nuclear energy "needs." As suggested subsequently, we are here concerned mostly with domestic "needs."

1. Military, including weapons and reactors for propulsion, power, and heat.

[1] The views expressed are those of the authors and not necessarily those of the organizations with which they are associated. The authors were formerly on the staff of the National Planning Association project on the productive uses of nuclear energy. This paper is based, in part, on the research and publications of the NPA project. Mr. Teitelbaum takes primary responsibility for the first section on energy projections and economic growth, and Mr. Mullenbach takes primary responsibility for the second section on nuclear energy expenditures and national policy. The authors gratefully acknowledge the cooperation of the staff of the National Planning Association and of the Division of Finance, AEC.

2. Foreign relations, based on intangibles associated with foreign policy, such as prestige derived from technical leadership, and the tangibles of foreign markets.

3. Domestic, including power, heat, propulsion, and radiation.

In the past, almost all of the United States investment in nuclear research and development, and in physical plant and equipment has been directed toward military applications. Progress toward nonmilitary applications has been largely a byproduct. This situation has been slowly changing in the past few years, although expenditures for military applications still represent an overwhelming proportion of the total. In future periods, considering the already high level of weapons production and stockpiles that undoubtedly exist, and the ever-broadening economic potentials for peaceful uses of nuclear energy, strictly military applications may account for successively smaller, although still substantial, fractions of public and private expenditures. Determination of a suitable balance by the Federal Government between outlays for military and nonmilitary applications will mostly depend on factors peculiar to each; only to the extent that military applications yield byproducts for other applications need they be considered together.

There is also a "need" to maintain technical leadership in nuclear science and technology as an adjunct of United States foreign policy. In the present juncture of world affairs, great importance is attached to achieving preeminence in this field. Such leadership may also be instrumental in securing suitable international control of the atom for peaceful purposes.[2] Some consideration must therefore be given in any policy deliberations to maintaining this leadership.

Related to the foregoing foreign policy considerations, but susceptible of separate treatment, are the economic opportunities for United States industry to supply foreign demands for nuclear fuels, reactors, and related goods and services. While no systematic overall analysis of the United States share of this "market" has as yet been undertaken, it is possible that many opportunities will exist in the next few decades. Table 1 below indicates the general order of magnitude of these foreign demands. Since these data refer exclusively to electric power generation, they would be substantially enhanced if nuclear energy becomes significant in industrial heat and propulsion applications.

The foreign market may also represent a useful "crutch" for a domestic nuclear industry to lean on during its early years: The higher competitive cost thresholds for nuclear power and heat in foreign markets as compared with those in the United States will offer domestic producers of nuclear fuels and hardware an opportunity to "earn while they learn" during the next decade, at least, so that the experience gained could yield improvements in nuclear technology with resulting cost reductions which may permit a subsequent large-scale entry into the United States market.

[2] See Summary of Findings—Policy Suggestions for the Future, Reports on Productive Uses of Nuclear Energy, National Planning Association, Washington, September 1957, ch. VI, for a fuller discussion of this question.

TABLE 1.—*Range of free world requirements for nuclear power, 1956 and about 1980*

[Thousands of kilowatts, at high plant factor]

Free world	1955 conventional power capacity	Nuclear power capacity	
		1965	1980
Western Europe:			
Euratom	47,688	2,000- 8,000	60,000- 75,000
United Kingdom	27,250	5,000- 6,000	50,000- 66,000
All others	26,269	500- 1,000	5,000- 15,000
Total	101,207	7,500-15,000	115,000-156,000
Asia:			
Japan	14,512	500- 1,000	9,500- 15,000
India	3,221	100- 500	1,500- 3,000
All others	2,940	200- 500	500- 1,500
Total	20,673	800- 2,000	11,500- 19,500
Africa	5,510	200- 500	1,500- 3,000
North America:			
United States	130,896	1,500- 4,000	60,000-227,000
Canada	12,678	500- 1,000	5,000- 15,000
All others	3,299	100- 500	500- 1,000
Total	146,873	2,100- 5,500	65,500-243,000
South America:			
Brazil	2,970	100- 500	2,000- 3,000
All others	4,987	100- 500	2,000- 3,000
Total	7,957	200- 1,000	4,000- 6,000
Oceania	4,459	200- 500	1,000- 3,000
Free world total	286,679	11,000-24,500	197,500-430,500

Source: Summary of Findings, ibid., table V-1, p. 45.

From the viewpoint of the domestic economy, nuclear energy can most usefully be thought of as an energy source which will acquire significance by preempting energy markets or applications based on its unique characteristics. In some cases, particularly in regard to radiation energy and some applications of high temperature furnace heat in industry, both of these developments will occur simultaneously. The present projections are concerned largely with the entry of nuclear energy into the domestic fuel and energy economy and they ignore other possible nuclear markets. To the extent that this "partial" analysis is valid, policymakers are free to alter the stated projections and implications to introduce the influences of the broader issues of military and foreign policy and of foreign markets for nuclear energy.

Specific underlying assumptions

Generally speaking, the present projections assume a continuation of the essentially full employment conditions which have characterized the United States economy in the post-World War II decade. They also assume that the cold war will continue, with continued heavy outlays for defense and foreign military and economic aid; that population growth will be rapid; and, based on the full employment assumption, that industrial technological progress will proceed at a more rapid pace than in the past.[3]

[3] The present projections are taken from a staff study prepared by Perry D. Teitelbaum for the National Planning Association project on the productive uses of nuclear energy.

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The following assumptions were made regarding fuel and energy prices and costs:[4]

1. Nuclear energy costs: These can be best illustrated in the case of electric power generation. (See table 2.)

TABLE 2.—*Nuclear power cost assumptions*

Cost item	Large plants		Small plants	
	Short term (1965)	Long term (1980)	Short term (1965)	Long term (1980)
Plant cost, per kilowatt	$225	$150	$350	$190
Generating costs at a 50 percent lifetime plant factor (in mills per kilowatt-hour):				
Fixed charges [1]	6.9	4.6	10.8	5.9
Operating and maintenance	2.0	.5	2.5	1.5
Fuel costs [2]	3.0	.8	4.7	2.5
Total	11.9	5.9	18.0	9.9

See footnote 3.

[1] At 13½ percent, consisting of: Interest, 1.5 percent; equity return, 4 percent; Federal income taxes, 4 percent; other taxes and charges, 2.2 percent; insurance, 0.2 percent; and replacement and amortization, 1.6 percent. These figures assume a 50–50 bond-equity private financial structure with an average 8 percent equity return. Federal income taxes were figured at 50 percent, other taxes at about the national average. The amortization and replacement component reflects a 25- to 35-year plant life on a sinking fund basis.

[2] Includes fuel inventory.

2. Coal: At most, an average rise in delivered prices of 15 to 20 percent is envisaged by 1980, based on ample reserves, an increasingly alert and aggressive management, substantial progress in mining techniques, a decreased tendency for coal miners' wages to continue to rise more rapidly than those in other industry groups, and lowered transportation costs. (See 5 below.)

3. Oil: Increased dependence on ample overseas sources (assuming no drastic changes in the Middle Eastern situation), the low ceiling on United States crude oil price rises imposed by shale oil, and the continued availability of United States sources of supply, assuming improved techniques of finding and drilling for new-oil reserves and of producing oil, all suggest only a moderate oil price rise at most.

4. Natural Gas: Domestic supplies are deemed ample to support projected demand, although average well prices may increase substantially. The domestic supply may also be augmented by Canadian and Mexican gas and by the development of tankers carrying natural gas liquefied under pressure and at low temperature.

5. Fuel transportation: Through a variety of developments, fuel and energy transportation real costs are expected to continue their long-term downward trend. These developments include increased use of barges, conveyor belts, and pipelines for coal; supertankers for oil; larger pipelines and tankers for natural gas; and improved long-distance transmission techniques for electric energy.

Other underlying assumptions include the following: In constant 1955 prices, gross national product in 1980 is projected to rise by about 1.3 times above 1955 levels. This yields a figure of around $900 billion (or $960 billion in 1957 prices). The industrial production

[4] All references to prices or costs should be understood to be in real, or constant dollar, terms.

index is projected to 324 (1956=143); steel ingot production is estimated at 225 million tons (117 million tons in 1955); and electric power generation is projected to 1,795 billion kilowatt-hours (629 billion in 1955).[5]

Energy supply and demand in 1980

Based on the foregoing assumptions (and on other related assumptions), we have projected domestic primary energy consumption to double between 1955 and 1980, from 40.3 to 80.9×10^{15} b. t. u. Table 3 summarizes this projection in terms of supply by primary fuels:

TABLE 3.—*Domestic energy consumption by primary source, 1955 and 1980*

Primary energy source	1955			1980		
	Conventional units	10^{15} B. t. u.	Percent of total	Conventional units	10^{15} B. t. u.	Percent of total
Bituminous coal and lignite (million tons)	423.4	11.1	27.2	735	19.2	23.7
Anthracite (million tons)	23.6	.6	1.5			
Liquid petroleum products [1] (billion barrels)	2.81	16.3	41.1	5.8	33.6	41.5
Wet natural gas (trillion cubic feet)	10.1	10.9	26.7	17.4	18.7	23.1
Hydro (billion kilowatt-hours)	118	1.4	3.4	271	2.4	3.0
Nuclear energy (10^{15} B. t. u.)					7.0	8.7
Total		40.3	100.0		80.9	100.0

[1] May include liquid fuels in 1980 derived from shale oil and coal, as well as from crude oil, although no allowance is made for this in the coal projection.

Source: See footnote 3.

Table 4 summarizes the energy consumption projections and their nuclear shares in applications liable to nuclear competition. The overall nuclear share of these components is approximately one-sixth. Comparison of the total for these applications (39.6×10^{15} B. t. u.) with the total for all energy in table 3 (80.9×10^{15} B. t. u.) demonstrates that roughly half of total energy consumption in 1980 will not be affected directly by nuclear energy.[6]
nuclear energy.

[5] 1980 was chosen as the target date for the projections solely as an analytical expedient. It should more properly be considered to represent a convenient way of saying "the next 2 or 3 decades."

[6] It may be noted that tables 4 and 5 include estimates of energy consumption for military purposes. These estimates are introduced solely to have a complete account of the domestic energy budget and represent rough approximations of the appropriate components. The figure for the U. S. Navy is largely based on publicly announced plans for nuclear naval capacity as applied to total capacity of naval vessels on active duty. The figure for the Air Force is essentially an arbitrary estimate. These estimates have no significance, however, in regard to current or future outlays on military or civilian applications of

TABLE 4.—*Potential nuclear share of energy consumption in competitive applications, 1980*

Energy consuming category	Installed capacity, 10^6 kilowatts (heat)		Energy consumption, 10^{12} B. t. u.		Nuclear share of total (percent)
	Total	Nuclear	Total	Nuclear	
Steam electric generation	732	192	14,798	4,307	29
Industrial process and furnace heat	(1)	53	20,740	1,454	7
Ship propulsion	122	23	2,064	491	24
Railroad locomotion	169	8	1,000	96	10
U. S. Navy	60	60	450	450	
U. S. Air Force	(1)	40	500	110	
Other military	(1)	17	(1)	100	
Total		393	39,552	7,008	[2] 16

[1] Not estimated.
[2] Civilian categories only.

Source: See footnote 3.

Table 5 summarizes significant aspects of the competitive interfuel struggle derived in conjunction with the projections in tables 3 and 4: the projected displacement of fossil fuels and hydro by nuclear energy in particular applications.

TABLE 5.—*Projected displacement of conventional energy by nuclear energy, by consuming sectors, 1980*

[In 10^{12} B. t. u.]

Energy consuming sector	Added—nuclear energy	Displaced—			
		Coal	Oil	Gas	Hydro
Electric power generation	4,307	2,260	884	276	51
Industrial process and furnace heat	1,454	765	408	281	
Ship propulsion	491		491		
Locomotives	96		96		
U. S. Navy	450		450		
U. S. Air Force	110		110		
Other military	100		20		
Total, in 10^{12} B. t. u.	7,008	3,025	2,459	557	51
Total, in conventional units	[1] 270	[2] 116	[3] 410	[4] 538	[5] 5.6
Percent of total in 1955	17	26	15	5	5

[1] Million tons coal equivalent.
[2] Million tons.
[3] Million barrels.
[4] Billion cubic feet.
[5] Billion kilowatt-hours.

NOTE: Totals do not balance because a higher thermal efficiency is assumed in conventional than in nuclear electric-power generation. In addition, the conventional energy losses in the "other military" category, except for an estimated substitution for oil by package power reactors, cannot be soecified because of its miscellaneous nature.
Source: See footnote 3.

Because of their long-run nature and because of their dependence on assumptions that are subject to varying degrees of uncertainty, the foregoing projections must be considered to offer no more than an estimate of the relevant orders of magnitude. Nevertheless, the nuclear projections are more likely to be too low than too high: first, because generally conservative assumptions were introduced at various stages in their derivation; second, because we cannot make any allowances for applications of nuclear energy that are as yet undiscernible. The potential pervasiveness of such applications may be appreciated, however, by considering as an analogue the impact that electric energy has had on the pattern of energy consumption during the past quarter century, in terms of its direct substitution for other energy forms and of new uses that were unknown in 1930.

Others have undertaken more detailed considerations of the potential impacts of nuclear energy on specific energy-intensive industries.[7] To a large extent, these analyses concern applications of nuclear electric energy, exclusively; hence they ignore the possibilities (considered in the present projections) of either low or high temperature nuclear-based heat in industrial applications. They are also based on energy-cost comparisons which may since have shifted slightly in favor of nuclear energy, at least for the long run. The present projections of nuclear energy in industry, which thus cover a wider range of possibilities, may therefore on this score appear more optimistic than would be indicated by these other studies.

Implications for public policy and economic growth

The primary implications of these projections for future economic growth and for emerging questions of energy policy are these:

First, potential supplies of fossil fuels available to the United States appear sufficient to meet projected demands at no more than moderate increases in real costs over the next quarter century. Nuclear energy can be expected to become competitive in the United States only as the result of substantial progress in technology and cost reduction.

Second, the growth of total energy demand required to sustain economic development is rapid, with total energy consumption expected to double and electric power consumption expected to triple in 25 years. All forms of energy supply will be called on to meet this growth. As a supplementary source, nuclear energy can help in meeting a part of growing boiler fuel needs, in providing a restraint on price increases of fossil fuels, in reducing the disparity between energy cost differentials in various regions of the United States, and in providing stimulus to the economic growth of such regions as New England and the upper Mississippi Valley where energy costs have constrained the development of energy-intensive industrial activity.

Third, nuclear energy alone cannot solve the problem of the steadily growing dependence of the Nation's energy economy on fluid fuels, secured in part from lower cost foreign sources that seem vulnerable to interruption. Aside from the contribution of nuclear energy in special applications such as ship propulsion, the United States economy will have to look mainly to a domestic synthetic liquid fuels industry, from shale or coal, to lessen the dependence on foreign sources of petroleum.

Finally, owing to the close interrelations existing between different energy sources and between domestic and overseas supplies, the Nation for many years has needed and still needs an overall energy policy. While recognizing that nuclear fuel has already multiplied the Nation's energy potential, such an overall policy should be concerned with broadening the energy base and assuring supplies at minimum cost, consistent with considerations of national security.

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[7] See, for example, Economic Aspects of Atomic Power, S. H. Schurr and J. Marschak, Princeton University Press, 1950; and Atomic Power, W. Isard and V. Whitney, Blakiston Co., 1952.

The economic growth of other advanced industrial nations of the free world has already been seriously affected by the constraints imposed by inadequate and assured energy sources at reasonable costs. With proper management of our resources—including the technology of synthetic liquid fuels and of nuclear energy—there need be no similar problem here. We can therefore meet the expanding energy needs implied by the rapid economic growth foreseen in the United States during, and far beyond, the next generation.

Nuclear Energy Expenditures and National Policies

Development of nuclear energy in the United States, we have seen, will be one of several technical advances that will help to broaden the energy base of the economy, restrain the tendency toward rising cost of energy sources and hence contribute to longtime economic growth. Yet, the influence of nuclear energy on resource development is unlikely to be large in the short term. Federal expenditures for nuclear energy could depart substantially from present levels without producing immediately discernible effects upon resource development and economic growth.

The connection between development expenditures now and the Nation's future growth, while remote in time, is nonetheless real. Indeed, the wide range of nuclear energy applications, not merely in electric power, but also in ship propulsion, radiation, and process heat, seems certain to result in long-term economic benefits here and abroad. Moreover, large public and private investment undoubtedly will be necessary to achieve the long and difficult transition from technical to economic feasibility of all these applications.

Applications receiving the largest investment support in the development phase may not prove to be the ones contributing the most to longer term growth. The nonpower uses, such as radiation processing, may prove more productive, in terms of increments in national product per dollar of research and development expense, than may reactor-produced electricity.[8] But the economic effects of nuclear energy's wide application—and particularly electric power—should be assessed not alone by cost-benefit relations or by economic growth potentialities. Especially important will be the extent to which the Nation's generally accepted foreign and domestic policies may be supported by the development of nuclear energy, and help provide solutions to worldwide energy problems.

Most of the productive applications of nuclear energy are deep in the developmental stage and may remain so for several years. Only isotopes, thus far, have crossed the threshold into competitive usefulness. For this series of Joint Economic Committee papers, perhaps the atomic-energy expenditure programs fall more sensibly into the "research and development" category than "natural resources." No single classification can be satisfactory, however, since the purposes of nuclear-energy development are multiple, covering national security, foreign aid, as well as natural resource development. National policies governing the scale and quality of this development program have roots extending into virtually all the budget categories used by the committee's staff.

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[8] Addresses by AEC Commissioner Libby have reported the hundreds of millions of dollars that have already been saved by industrial applications of isotopes.

Size and direction of development spending

The magnitude of peacetime public expenditures for atomic energy—military and civilian purposes—is without parallel. Since the beginning of the effort in the National Research Council (1940), the total investment by the Government has exceeded $17 billion, of which $15 billion has been expended since the war. (See table 6.) The investment in plant approaches $6.6 billion, and costs of all operations are now nearly $2.0 billion. The Commission's major expansion programs, begun in 1950, have now been largely completed and yearly costs of new plant are running at $320 million—one-fourth of the peak reached in fiscal year 1954. (See tables 6, 7, and 8.)

TABLE 6.—*U. S. Government investment in atomic-energy program, June 1940 through June 1957 (preliminary)*

[In millions]

	Appropriation payments, net of reimbursement
War Department (NDRC, OSRD, and MED): Fiscal year 1941 through fiscal year 1947 (part)	$2,233.4
Atomic Energy Commission: Fiscal year 1947 (part) through fiscal year 1957	13,577.6
Total payments, net	15,811.0
Unexpended balance of appropriations, June 30, 1957	[1] 1,284.8
Appropriations transferred	5.6
Total appropriated funds	17,101.4
Less collections paid to U. S. Treasury and property and services transferred to other Federal agencies (net)	107.6
Total investment through June 30, 1957	16,993.8
Less cost of operations, including depreciation and obsolescence from June 1940 through June 30, 1957	8,591.4
AEC equity at June 30, 1957	8,402.4

[1] $2,324,000,000 of appropriations for fiscal year 1958 not included.

Source: 1956 Financial Report, U. S. Atomic Energy Commission, October 1956. Preliminary 1957 data from Division of Finance, AEC, Oct. 2, 1957.

TABLE 7.—*Summary financial data for U. S. Atomic Energy Commission, fiscal years 1950–57*

[In millions of dollars]

Fiscal year—	Cost of operations [1]	Percent increase	Plant construction costs incurred	Percent change	Completed plant at June 30	Percent increase
1950	414.8		256.1		1,809.6	
1951	494.6	19.2	459.2	79.3	1,924.8	6.4
1952	684.2	38.3	1,082.2	135.7	2,133.9	10.9
1953	904.6	32.2	1,125.6	4.0	3,149.5	47.6
1954	1,039.2	14.9	1,215.1	8.0	4,090.3	29.9
1955	1,289.5	24.1	842.5	−30.7	5,858.3	43.2
1956	1,608.0	24.7	301.7	−64.2	6,466.0	10.3
1957 (preliminary)	1,968.3	22.4	317.0	5.1	6,596.7	2.0

[1] Includes depreciation.

Source: 1956 Financial Report, U. S. Atomic Energy Commission, October 1956. 1957 data from Division of Finance, Oct. 2, 1957.

TABLE 8.—*AEC investment in plant and equipment, June 30, 1957, preliminary*

[In millions]

	Completed plant	Construction in progress	Total	Percent of total
Production facilities:				
Raw materials	$7.1	$0.4	$7.4	0.1
Feed materials	233.9	21.9	255.8	3.7
Gaseous diffusion plants	2,318.2	8.4	2,326.7	33.7
Production reactors and separation areas	1,560.7	68.0	1,628.8	23.6
Weapons production and storage	709.8	39.1	748.9	10.8
Heavy water	262.7	1.3	264.0	3.8
Other production facilities	340.9	13.9	354.8	5.2
Total production	5,433.3	153.0	5,586.3	80.9
Research facilities:				
Laboratories	541.4	24.3	565.6	8.2
Reactors	84.1	94.8	178.9	2.6
Accelerators	60.2	13.4	73.6	1.1
Other	66.1	11.9	78.0	1.1
Total research	751.8	144.3	896.1	13.0
Communities	267.3	4.1	271.4	3.9
Other	144.3	9.9	154.2	2.2
Total	6,596.7	311.2	6,907.9	100.0

NOTE.—Detail may not add to total due to rounding.
Source: Division of Finance, U. S. Atomic Energy Commission, Oct. 2, 1957.

Current rates of operating expenditures and plant construction for research and development on nuclear reactors for military and civilian purposes are shown, insofar as they have been segregated by the Atomic Energy Commission, in tables 9 to 13. The key facts indicated by the AEC's figures are these:

Thus far, roughly $450 million of development and construction expenditures have been dedicated to civilian reactors.

By rough comparison, about $900 million of development and construction expenditures have been devoted to military reactor development (excluding construction of the materials production reactors at Hanford and Savannah Rivers).

Expenditures for military, civilian, and undesignated reactor research are expanding rapidly. For each of these categories, annual development expenses are now (fiscal year 1958) more than double those 2 years ago.

Government commitments to support "cooperative arrangements" with groups outside the AEC are just beginning to be substantial, but no expenditures for construction are expected until fiscal year 1959.

In brief, these development expenditures for civilian purposes are on the order of many millions annually—$150 million is a guesstimate—and they are rising rapidly. They are large, too, when compared with expenditures rates for military reactors. Important technical, economic, and national policy objectives can be set forth to justify such large and growing expenditure programs; they also raise the question of still further expansion in public expenditures.

Technically, reactor developments of the last few years have revealed the need for an extensive program along several promising lines, including not only a wide variety of technically feasible designs for central station powerplants, but also reactor designs for ship propulsion, for remote use, and for radiation processing. The United Kingdom has found it best to concentrate on two lines of power-reactor design, one being practical immediately and the other holding promise for the longer term. The United States, however, has not had to decide on 1 or 2 courses of development and has proceeded on many fronts, at least at the experimental level.

Furthermore, the scientists and engineers in AEC and industry have found the task of bridging the cost gap between technical feasibility and competitive usefulness to be more difficult and time-consuming than it apeared in 1953 and 1954. Also, the volume of private investment in reactor development and construction, while significant and growing, has proved to be less than presupposed by passage of the Atomic Energy Act in 1954 permitting wider private participation in atomic energy development.

Finally, on the political front, each year since the President's far-sighted U. N. atoms-for-peace address in 1953, the international situation has become a progessively more impelling reason for wider international cooperation in nuclear energy. The wide declassification of United States information on reactor technology, the scientific conference at Geneva (1955), the numerous bilateral agreements, the startling success and expansion of the British reactor program, the formation of Euratom with United States encouragement, and the Suez crisis—all of these events underscore the desirability of a reactor development program that fully supports the Nation's foreign policy objectives, as well as the purely domestic.

The roots of national policy for power reactor development

Practical manifestation of the need for civilian applications of nuclear energy preceded the formation of the Atomic Energy Commission, pursuant to the Atomic Energy Act of 1946. The Manhattan Engineer District (MED), recognizing the promise of the atom for productive purposes, began before the end of the war a number of exploratory power reactor projects, particularly at Oak Ridge. The institution of three national laboratories, a product of the MED, was a most constructive step taken at this time, laying the ground for wide development of nuclear energy under Commission auspices.

Considerably later, the AEC in 1949 established the Reactor Development Division which led to the "industry participation program" and, later, to the declaration of Commission power reactor policy, June 24, 1953. The Commission's declaration, in brief, held "* * * the attainment of economically competitive nuclear power to be a goal of national importance * * *," recognized the responsibility of the Commission to continue reasearch and development, and to promote the construction of experimental reactors which contribute to technology and to design of economic units; and, among other things, expressed the conviction that progress toward economic nuclear power could be further advanced through participation in the development program by "groups outside the Commission." The act of 1954 gave body to virtually all the Commission's proposals for providing reasonable incentives for encouraging wider participation.

The President's atoms-for-peace address, December 8, 1953, set forth the policy objectives that now underlie the provisions of the 1954 act providing carefully circumscribed authority and conditions for permitting wider international cooperation in certain atomic energy matters.

These developments are the primary policy bases for nuclear energy development programs, and from them stem the criteria for evaluating the character of the expenditure programs in this field.

Suggested criteria

The six criteria listed here are illustrative of the relevant questions and the brief comment on each is intended to evoke discussion and provide background rather than to represent a sufficient answer.

The primary standard to be suggested is this: *Is the program adequately supporting, without the waste of resources or jeopardy to national defense and security, the Nation's major policy objectives, first, to achieve, without delay, economic nuclear energy applications through the efforts of both Government and private enterprise; and, second, to permit the achievement of foreign policy objectives that necessitate growing international cooperation?*

Differences in personal value judgments about these questions explain much of the controversy concerning the desirable rate and scale of atomic energy programs. Yet recent debate has suggested that a narrowing of extreme points of view may be occurring. Acceleration of reactor development has been generally accepted by the legislative and executive branches. Moreover, it is accepted that, although domestic needs for a new source of power are not pressing, the needs of Western Europe, Japan, and other free nations are urgent. (See table 1.) There is no question that it is in the United States policy interest to participate in fulfilling these needs. Finally, it is accepted that nuclear energy development calls for the technical and financial resources of both the Government and industry, but with the Government taking the lead in experimenting with new approaches to reactor design.

Not yet resolved is the detailed manner in which the Nation goes about the problem of reconciling its domestic and foreign programs for nuclear energy. The domestic development program is motivated primarily by the goal of achieving economically competitive nuclear power through reliance on the efforts of nongovernmental groups, supported by strong Government assistance. On the other hand, the more urgent foreign program, motivated primarily by international necessities, presupposes the early availability of economically useful nuclear power. While the premises of the two programs seem to be in conflict, it is possible with the ample resources we possess to contemplate a nuclear power development that is aimed at accomplishing the purposes of both policies. The key issue then is how to rectify the present disparity between the domestic and foreign programs of the United States.

Is the domestic development program to be further accelerated—beyond that warranted by considerations of private motivation and resource needs—or should the scope and pace of the foreign program be cut back to the level of technical realities at home? It would be fruitful to explore both sides of this question at some length, but circumstance and judgment suggest that the second alternative is politically difficult, if not impossible. Our foreign policy and the atoms-for-peace program have led us to 10 bilateral power agreements, the formation of the International Atomic Energy Agency, full support of

Euratom, and the offer of quantities of nuclear fuels. The prospects for augmenting the scope and depth of the effort to achieve economically useful nuclear power may be revealed in the course of examining a few other standards for evaluating the domestic developmental program.

Is there a marked disparity in the pace of reactor development as between military and civilian applications? Is the civilian program interfering with the military reactor development effort? The fact of 2 nuclear-propelled submarines in operation, 14 more vessels now being built, and several more planned, is sufficient evidence that available resources are being found adequate to support a large military reactor program without major diversions to civilian development projects. Civilian reactors, benefiting to a degree by transference of the military reactor technology, have not moved nearly so rapidly to full-scale construction. Only one full-scale, Government-owned power reactor is now approaching completion, and this is a direct offshoot of a design developed for naval ship propulsion. The evidence suggests a gap between the two programs at the construction level Moreover, the technology of military reactors is not necessarily in the best direction for civilian development; virtually all of the military reactors being built or planned are of the pressurized water design using enriched uranium as fuel. The basic reactor design found suitable for ship propulsion holds no certainty of producing economically competitive central station nuclear power. Several other avenues need and have been receiving investigation.

Is technical progress toward economic use of reactors being sustained and are technical breakthroughs being fully exploited? There has been until recently an obvious preoccupation in the development and construction program with designs that employ natural water and enriched uranium—to the apparent subordination of several other designs, such as the natural uranium heavy-water reactor, the gas-cooled natural uranium reactor, and reactors using plutonium as fuel, among others. The number of technically feasible reactors is great and the capacity of the United States program to explore several simultaneously is a marked advantage (but fertile source of confusion).

Thus, the Government experimental program now covers not only pressurized and boiling-water reactors, but also such reactors as the sodium-graphite, homogeneous, fast breeder, organic-moderated, and liquid-metal fuel. It is at the small, experimental reactor level—rather than at full-scale construction—that the Government has achieved generally recognized success in accomplishing major steps in reactor technology. Indeed, a leading reactor specialist (Zinn) has indicated that the design concept of every power reactor was first developed in connection with the AEC program for the construction of small experimental power reactors.

With the exception of the homogeneous reactor concept, each of the five designs in the Commission's 5-year reactor program (1953) has successfully passed through the small-scale, experimental stage and is substantially ready for full-scale demonstration. In general, major technical advances—such as the boiling-water concept—have been specifically confirmed by experimental reactors of small size, but such advances have not yet been tested for their economic promise at full scale. This experience must be secured soon.

Is the development program being managed in a manner that assures the efficient and reasonably full use of both government and industry resources of technical and scientific talent? This standard presupposes the national importance of reactor development and not the dubious desirability of keeping scientists and technicians busy just for the fun of it. Evidence suggests that the present programs of development and construction are on a smaller scale than the technical resources of industry and government would permit.

Reactor engineering and construction capabilities, for example, are now very great, in part because the Commission's expansion of production reactors is long since passed. Moreover, there is still only a handful of large contractors carrying major responsibility for development and construction of reactors. Smaller companies and new entrants in the field have repeatedly stated that resources are available to permit a greater distribution of reactor development.[9] And it is still true that major segments of industry, that were formerly in the atomic energy program, have shown no disposition to return by participation in civilian development programs. Also, the national laboratories, all heavily engaged in government and industry programs, have contributed a stream of trained people to all parts of industry. (However, it may be fruitless to speak of potential industry resources that are available if the motivation for productive, profitable participation by nongovernment groups continues to appear remote.)

Are the tone and character of the development program such that the ever-present private versus public power controversy is not exacerbated and, indeed, not raised to a pitch that could stall the development program through failure to find mutually acceptable solutions to common problems? This problem is so thorny that there has been a self-protecting disposition in most statements discussing national policy for nuclear power to sweep the issue under the rug. One need be neither a fool nor an angel to attempt commenting constructively on this contentious matter as it relates to the expenditure program.

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[9] In response to an AEC invitation for proposals for engineering design of a 40,000-kilowatt nuclear-power reactor, 31 architect-engineer firms submitted proposals (AEC Release 1183, October 1, 1957).

Commonsense indicates that both the private and public sectors of the electric utility industry accept the desirability of joint government and industry efforts in developing economically competitive nuclear-power reactors useful in both types of systems. Also, each sector is opposed to having the developmental program become exclusively the province of the other. While granting the important potential contribution of the private utilities to reactor development, the public sector expects the program to be administered in a manner that permits its participation with adequate recognition of the differing financial capacity and needs of publicly owned systems. Similarly, the private utilities expect the development program to be administered in a way that provides necessary government assistance yet avoids arrangements that might extend the scope of federally owned utility systems or that might compromise the mandate of the act that the Commission is prohibited from generating electric power for commercial purposes (sec. 44).

These points of view are compatible—though the underlying fears that spokesmen of each sector have expressed concerning the aggressive ambitions of the other are not. While recognizing the views of the Executive branch on national power policy, one must also note that there is no clear evidence that administration of the civilian reactor program has favored one sector at the expense of the other. (See table 10 for the direct assistance being given private utilities and public, municipal, and cooperative systems.) Considering the high degree of government intervention required by reactor development and operation under the act, it would be an administrative accomplishment of surpassing skill if no conflicting claims of favoritism were expressed.

There is a continuing possibility, however, that this controversy could delay or prevent adoption of measures designed to encourage reactor development. It is probable, for example, that private industry will seek progressively greater degrees of government assistance in the construction and operation of full-scale power reactors and will continue to oppose steps moving toward Federal construction and operation beyond experimental sizes. At the same time, supporters of publicly owned systems will be impelled to question the desirability of greater government assistance to private reactor operation and may continue to urge outright Federal construction. However these extremes may finally be compromised or resolved, the impact will appear, in greater or lesser degree, in the reactor expenditure programs for development and construction.

TABLE 9.—*Operating expenses and plant construction costs for reactor development, through fiscal year 1958*

[In millions]

	Civilian power reactors				Military reactors	Controlled thermo-nuclear power	General research and development	Total development program
	AEC direct program	Cooperative arrangements program	Merchant-ship reactors	Total				
(a) Operating expenses:								
Through fiscal year 1955	62.0	3.9	0	65.9	237.6	7.4	146.5	457.4
Fiscal year 1956	42.3	0	.1	42.4	91.3	6.6	30.8	171.2
Fiscal year 1957	51.8	2.0	.7	54.4	154.2	11.0	44.9	264.7
Fiscal year 1958 (estimated)	82.9	13.9	3.3	100.1	180.6	21.7	51.9	354.3
Cumulative to June 30, 1958	239.0	19.8	4.1	262.9	663.7	46.7	[1] 274.1	1,247.6
(b) Plant construction costs:								
Through fiscal year 1955	7.1	.3	0	7.4	131.4	.7	181.2	320.7
Fiscal year 1956	8.7	.1	0	8.8	11.7	.6	12.6	33.7
Fiscal year 1957	36.6	.7	.3	37.6	31.0	.3	19.1	88.0
Fiscal year 1958 (estimated)	27.5	0	5.0	32.5	50.7	2.6	34.6	120.4
Cumulative to June 30, 1958	79.9	1.1	5.3	86.3	224.8	4.2	[1] 247.5	562.8

[1] Perhaps more than ½ of this sum is assignable to civilian projects.

Source: Division of Finance, AEC, Oct. 2, 1957.

TABLE 10.—*Reactor projects jointly financed and supported by AEC and outside groups—The "Cooperative Arrangements Program," fiscal year 1958 budget*

[In millions of dollars]

Utility	Electric capacity (kilowatt)	AEC assistance				Contractors' participation			Total cost
		Research and development [1]	Waiver of fuel-use charges	Construction	Total value	Research and development	Construction [2]	Total	
1st round:									
Yankee (Massachusetts) [3]	134,000	$5.0	$3.0	0	$8.0	(4)	$55.0	$55.0	$63.0
Power Reactor Development Co. (Michigan) [3]	100,000	4.5	3.7	0	8.2	9.0	45.2	54.2	62.4
Consumers (Nebraska)	75,000	26.2	1.3	24.0	51.5	0	16.6	16.6	68.0
2d round:									
Rural Cooperative (Minnesota)	22,000	[5] 2.8	.1	5.7	8.6	1.0	2.5	3.5	[6] 12.0
Wolverine (Michigan)	10,000	1.6	0	3.8	5.5	0	.8	.8	6.2
Piqua (Ohio)	12,500	[7] 3.5	.6	4.0	8.1	0	4.0	4.0	12.0
Chugach (Alaska)	10,000	[8] 9.9	.6	6.7	17.2	(9)	1.9	1.9	19.1
3d round:									
Florida group [3]	136,000	9.3	[10] 7.5	0	16.8	(4)	40.2	40.2	57.0
Northern States (Minnesota) [3]	66,000	6.0	1.0	0	7.0	0	21.6	21.6	28.6
Total	565,500	68.8	17.8	44.2	130.9	10.0	187.8	197.8	328.3

[1] In some instances includes postconstruction research and development.
[2] Including turbogenerator.
[3] Privately-owned. Others are publicly owned.
[4] Included in construction estimate.
[5] Excludes a maximum of $1,640,000 to cover postconstruction costs for operating expenses in excess of conventional costs.
[6] AMF Atomics, the reactor manufacturer, in September 1957 withdrew its cost estimates for this plant. New higher estimates are being prepared.
[7] Excludes $3,600,000 of postconstruction operating expenses.
[8] Excludes postconstruction operating expenses (maximum) of $2,500,000.
[9] $25,000 contributed by Nuclear Development Corp.
[10] Includes $5,000,000 waiver of heavy water use charges.

Source: Atomic Energy Appropriations for 1958, hearings before the Subcommittee on Appropriations, House; 85th Cong., 1st sess., pp. 223-232; and S. Rept. 791. Authorizing Appropriations for the Atomic Energy Commission, Aug. 2, 1957, pp. 9-14.

The last suggested standard, intimated by the preceding discussion, is this: *In seeking wide, industrial participation as contemplated by the act, are the forms and degrees of government assistance reasonable and clearly visible, and will they best serve the goal of achieving economically competitive nuclear power?* The extent of nongovernmental reactor development and construction, while increasing, has still not become large. One private, small experimental power reactor thus far has been constructed, and two full-scale plants are in process of construction that do not depend on substantial degrees of government assistance. A number of other nongovernmental plants are planned, each involving such direct government aids as preconstruction research and development, and waiver of fuel use charges, aside from such indirect benefits as government indemnification for reactor hazards, guaranteed fuel reprocessing charges and long-term fixed prices for byproduct plutonium.

Present government assistance, direct and indirect, is varied, subject to change and not easily identified. Yet there are still other aids that could be brought to bear, such as pricing plutonium at its weapon value, granting nuclear fuel without any use charges, pricing U–235 at out-of-pocket expense rather than full cost of production (including plant depreciation), and many others. Present and potential devices for assistance are so numerous and intricate that there is grave danger of the expenditure programs failing to consider both real and dollar costs pertaining to them. Also, there is a risk that additional assistance, designed mainly for the immediate purpose of accelerating technical development and gaining experience in full-scale plant operation, could become a permanent crutch in commercial operations, not only of generating stations, but also of supporting facilities. Achieving economically competitive nuclear power could become a simple, but meaningless bookkeeping task.

Unfortunately, there is no practical way to judge when the cost of additional government assistance exceeds the additional contribution to technical development. But the variety of devices already being used, within the limits of the "no subsidy" provision in the act (sec. 169) is itself a warning.

The only alternative to more and more government assistance, in order to promote technical development and private full-scale plants, is not necessarily the obvious one of Federal construction and investment. Though the desirability of doing so might be open to sharp differences of opinion, the expenditure program could continue to follow its present pattern: Industry being expected to construct full-scale demonstration reactors, and AEC taking responsibility for development and construction of experimental reactors—and such others as the Congress itself may specify in authorizing appropriations for projects and programs. The cost of constructing full-scale power reactors is large—on the order of $50 million to $75 million each. A national policy therefore that shifts the cost of constructing or operating demonstration plants to the Federal Government could have a large impact on the reactor expenditure program. Yet the expenditure rate could be doubled before approaching the present scale of the military reactor program.

If one accepts the desirability of accelerating construction of full-scale units in order to demonstrate the costs and reliability of nuclear power, then progress toward competitive reactors could be advanced by (*a*) increasing degrees of government assistance, (*b*) by outright subsidies, (*c*) by government construction, or (*d*) possibly by a mixture of these. If the premise of full-scale construction is not accepted, then extraordinary construction measures are not necessary and the present program may be relied on, perhaps at the cost of some delay, to provide the answers being sought. But there are differences among the technical experts as to the necessity of full-scale construction. Some stress the need for prior nuclear fuel experimentation and subordinate the role of plant problems; but most insist that full-scale plants for most designs are necessary, not only for proving out the fuel cycle, but also providing the operating and plant experience that different reactor designs require.

The fact that full-scale reactor construction requires between 4 and 5 years, including engineering design, and that construction of several reactor designs has not yet begun, means the construction phase that the civilian reactor program has only recently entered may be long indeed. The serious delays and obstacles the reactor development program has experienced may be measured by the low rate of construction costs currently being incurred. (See table 9.) In fiscal year 1958 the plant costs of the direct government program are actually less than in fiscal year 1957. More striking still, the reported construction costs of the "cooperative arrangements" program are nil in the current year, no construction being expected until fiscal year 1959.

This extremely limited construction effort, is partly offset by the current construction of a few privately owned plants and by the Government-owned plant at Shippingport, Pa. But it suggests that the development program may be lagging behind the scale of effort required to support the prompt achievement of major national policies set forth 3 and 4 years ago. One danger is that the present program may fail to complete the construction phase in time to be of maximum use in assuring the Nation's full participation in international developments and in meeting the needs of other countries. It seems likely that international developments not discernible now, as well as the foreseeable needs of the International Atomic Energy Agency, Euratom, and the bilateral agreements will place heavy demands on the Nation's ability to deliver, in the form of guaranteed reactor designs and performance.

Establishment of Euratom in particular opens the immediate and promising possibility of joint arrangements between the United States and the six nations in the construction of full-scale demonstration reactors in Europe. Were joint arrangements to be successfully worked out, the two-way benefits could be substantial. Euratom, a major step toward Western Europe's integration, would be able to make the first step toward the 15 million kilowatt target for 1967.[10] The United States on its part would secure the indispensable experience and knowledge of constructing and operating full-scale pilot units.

[10] A Target For Euratom, May 1957

[10] A Target for Euration, May 1957.

TABLE 11.—*Civilian power reactor construction costs, fiscal year 1958 budget*

[Costs in millions]

	Total estimated cost	Through fiscal year 1955	Fiscal year 1956	Fiscal year 1957	Fiscal year 1958	After
Pressurized water reactor	$50.0	$1.2	$7.1	$35.7	$6.0	0
Fast power breeder	29.1	0	0	.3	5.0	$23.8
Argonne boiling reactor	8.5	0	0	0	2.5	6.0
Liquid metal fuel reactor	17.5	0	0	0	1.5	16.1
Sodium reactor experiment	4.7	0	0	0	.3	4.4
Consumers Public Power District	24.0	0	0	0	.4	23.6
Rural Coop Power Association	5.7	0	0	0	1.5	4.2
Wolverine Electric Coop Association	3.8	0	0	0	.3	3.5
City of Piqua, Ohio	4.0	0	0	0	.5	3.5
Chugach Electric Association	6.7	0	0	0	0	6.7
Plutonium Fabrication Laboratory, Hanford	4.0	0	0	0	.5	3.6
Zero power reactor, ANL	2.7	0	0	0	1.8	.9
Power reactor test building and hot cells, LASL	2.6	0	0	0	.8	1.8
Hot cells and waste storage system, Santa Susana, Calif.	2.2	0	0	0	.5	1.7
Fuel Technology Center, ANL	10.0	0	0	0	2.0	8.0
Plutonium fabrication facility, ANL	3.0	.2	1.1	.5	1.2	0
Engineering test equipment for HRP, ORNL	.8	.1	.1	.2	.4	0
Plutonium recycle reactor, Hanford	15.0	0	0	0	5.0	10.0
Total	194.4	1.6	8.2	36.8	30.0	117.8

NOTE.—Totals may not add due to rounding.

Source: Division of Finance, AEC, Oct. 2, 1957.

TABLE 12.—*Plant construction costs for selected AEC programs, fiscal year 1958 budget*

[Costs in millions]

	Through fiscal year 1955	Fiscal year 1956	Fiscal year 1957	Fiscal year 1958
Biology and medicine	$29.5	$0.7	$3.4	$5.3
Physical research	116.2	9.1	12.5	28.9
Production of radioisotopes	0	0	0	0
Food irradiation	0	0	0	.4
Atomic power, by reactor concept:				
Pressurized water	1.2	7.0	35.7	6.1
Boiling water	.8	.6	.4	4.0
Homogeneous	1.0	0	0	.3
Fast power breeder	4.1	1.1	.5	10.8
Sodium graphite	0	0	0	1.2
Liquid metal fuel	0	0	0	1.5
Organic moderated	0	0	0	.5
Plutonium recycle	0	0	0	3.1
Pressurized heavy water	0	0	0	0
Advanced design	0	0	0	0
Cooperative arrangements program	.3	.1	.7	0
Total	7.4	8.8	37.3	27.5
Civil atomic propulsion	0	0	0	5.0
Thermonuclear power	.7	.6	.3	2.6
Military and classified projects	131.4	11.7	31.0	50.7
General research and developing, supporting operations, equipment, etc	181.2	12.6	19.1	34.6

Source: Division of Finance, AEC, Oct. 2, 1957.

TABLE 13.—*Operating expenses for selected AEC programs, fiscal year 1958 budget*

[Costs in millions]

	Through fiscal year 1955	Fiscal year 1956	Fiscal year 1957	Fiscal year 1958
Biology and medicine	172.1	28.4	31.6	36.0
Physical research	274.0	49.5	60.7	71.0
Production of radioisotopes	7.4	1.7	2.3	2.4
Food irradiation	0	0	.1	.1
Atomic power—by reactor concept:				
Pressurized water	17.2	15.2	14.6	21.0
Boiling water	9.0	4.7	5.0	5.0
Homogeneous	21.3	10.7	10.7	11.8
Fast power breeder	9.1	4.7	6.1	13.6
Sodium graphite	5.4	5.0	6.1	7.9
Liquid metal fuel	0	1.6	3.5	8.0
Organic moderated	0	.3	3.6	5.5
Plutonium recycle	0	0	1.0	4.0
Pressurized heavy water	0	0	.5	4.0
Advanced design	0	.1	.4	2.0
Cooperative arrangements program	3.9	0	2.0	13.9
Total	65.9	42.3	53.8	96.8
Civil atomic propulsion		.1	.7	3.3
Thermonuclear power	7.4	6.6	11.0	21.7
Military and classified projects	237.6	91.3	154.2	180.6
General research and developing, supporting operations, equipment, etc	146.5	30.8	44.9	51.9

Source: Division of Finance, AEC, Oct. 2, 1957.