PROLIFERATION RESISTANT NUCLEAR POWER TECHNOLOGIES: PREFERRED ALTERNATIVES TO THE PLUTONIUM BREEDER

by the following
members of the
LMFBR Review Steering Committee:

Thomas B. Cochran
Russell E. Train
Frank von Hippel
Robert H. Williams

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"First they said that there is no problem
now they say that there is no solution."

—Mason Willrich, May 1976

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SUMMARY

Our findings are as follows:

- U.S. nonproliferation objectives must take precedence over economic considerations.

- Nonproliferation criteria must be established to govern all fission energy activities, including R, D&D and the commercialization of fission energy supply alternatives (e.g. breeder and advanced converter reactors).

- The minimum criterion of acceptability for the commercialization of an energy supply alternative must be the demonstration that the development and commercial utilization of the technology by a non-nuclear weapons state leaves that state no closer to a nuclear weapons capability than would be the case if all its nuclear power were derived from low-enriched uranium fueled reactors operating in a once-through fuel cycle mode (that is, without reprocessing) and with verified spent fuel storage in secured international facilities.

- The plutonium breeder and its associated fuel cycle does not meet this minimum criterion of acceptability. Indeed it would put into the fresh fuel of reactors worldwide enormous quantities of material which could be converted into nuclear weapons within a matter of days. The implications in terms of nuclear weapons proliferation are awesome.

- The immediate issue in the U.S. advanced reactor development program is whether or not to terminate the Clinch River Breeder Reactor Project. We believe that termination of this project and all other activities associated with the demonstration and commercialization of the plutonium economy is essential if the U.S. is to have credibility internationally in its efforts to prevent nuclear weapons proliferation. Merely postponing the Clinch River Project for 1-3 years would not provide the strong and clear signal that is needed.

- We believe that the breeder R&D program should be converted to a program aimed at preserving nuclear fission as an energy option for the long term in a manner consistent with U.S. nonproliferation objectives.

- We do not advocate the pursuit of any particular technology. It is our view that scientists and engineers should be given considerable flexibility in selecting the most promising technologies that conform to nonproliferation criteria established by an agency or agencies having a national security outlook (e.g. ACDA).

- We note, however, that making fast breeder reactors such as the LMFBR inherently proliferation resistant may be intractable. Fast breeder reactors by their nature are tied to fuel cycles which contain nuclear weapons useable material in the fresh fuel of a significant fraction of all reactors. If, after careful technical review, this connection is found to be indeed indissoluble, the U.S. should shift the focus of its base research program on advanced reactor technology away from fast reactors toward thermal neutron reactors.

- To show that there exist alternative uranium conserving fuel cycles that are much more proliferation resistant than the plutonium fuel cycle, we have given particular attention to the denatured uranium-thorium fuel cycle, for which the fresh fuel would contain no nuclear weapons material and the highly radioactive spent fuel could contain very little.

- Slightly modified* versions of today's pressurized water reactors on a denatured uranium-thorium fuel cycle could support a nuclear generating capacity that would provide for a hundred years more electric power than is generated on the average by the entire US electric utility system today, using only about two thirds of the uranium in US high grade uranium ore deposits, as officially estimated by ERDA.

- Even if the most pessimistic forecasts of high grade U.S. uranium resources should be realized, the large amounts of uranium in low grade ores such as the Chattanooga shale, which could not be used in today's reactors, would be an economically viable backup resource for uranium conserving light water reactors operating on a denatured uranium-thorium fuel cycle.

- The high end of the electricity demand forecasts considered by ERDA's Task Force on the Fission Breeder - Why and When is based on wholly unrealistic expectations of future electricity prices. The principal analysis advanced in support of "midrange" growth (5% annual growth rate) is an industry report which envisions that a 40% decline in the real price of electricity between 1975 and 2000 will act as a stimulus for consumer demand. It is much more likely this price will grow at least 65% in this time frame.

- The view still appears to be prevalent in the nuclear energy supply sector that U.S. energy and electricity consumption must continue to grow almost as rapidly as in the past or else the nation will experience massive unemployment, a weakening of U.S. economic strength, and the permanent condemnation of a substantial fraction of the U.S. population to poverty. We reject this veiw. Energy growth at or near historical rates can be achieved only by continued energy waste. We believe that such energy waste would undermine rather than strengthen U.S. security.

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* The only modification would be the addition of heavy water to the coolant (spectral shift operation) in varying amounts over the fuel life.

• Preliminary results of the most comprehensive engineering study which has yet been made of the potential for increasing the efficiency of U.S. energy use indicate that rising energy prices and public policy initiatives will lead to much slower growth in energy consumption than we have experienced in the past. By the year 2010 the U.S. GNP could be doubled with only a 40 percent increase in energy use by introducing those energy efficiency improvements which would be economically justified if the real price of energy were to roughly double in this same period.* In an independent analysis we have arrived at almost the same results. While these results cannot be regarded as forecasts of what will happen, they show that the U.S. has the flexibility to choose a low energy growth path, through the adoption of energy efficiency improvement policies, that would greatly facilitate the achievement of U.S. nonproliferation and environmental objectives without jeopardizing U.S. economic well-being.

• Although electricity consumption will probably continue to grow somewhat faster than total energy use for the remainder of this century, we expect that the difference between electric and total energy growth rates will be much less than in the past. A very large fraction of U.S. primary energy use is already devoted to the generation of electricity (about 30 percent), and most of the remaining 70 percent of U.S. energy consumption goes to end uses such as process heat, transportation, and feedstocks which cannot be economically electrified. Furthermore, we expect that in the future the price of electricity will no longer be falling rapidly relative to energy prices in general.

When we add the above considerations to the expectation that U.S. GNP growth will slow toward the end of the century due to the slowing growth rate of the labor force which is expected during that period, we find it difficult to project a growth rate for electricity averaging more than 3 percent per annum out to the year 2000.

With electricity use growing at 3% per year, ERDA's projection of 350 Gwe of nuclear capacity in 2000 is too high to be credible, even though this capacity is only about one third the capacity projected for 2000 when the time-table for plutonium breeder commercialization was originally set. It is unlikely that nuclear generating capacity in the year 2000 will be more than 250 Gwe.

• The viability of relying on proliferation resistant uranium conserving reactors instead of plutonium breeder reactors over the next century does not depend sensitively on the growth rate assumed for nuclear power in this century, but does require a plateauing of nuclear generating capacity early in the next century.

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* Drs. John Gibbons (Chairman) and Clark Bullard (Member), Demand Panel Committee on Nuclear and Alternative Energy Systems, ERDA sponsored study under the auspices of the National Academies of Science and Engineering, private communication and briefing by Dr. Gibbons to the LMFBR Steering Committee, April 5, 1977.

- We believe that U.S. energy consumption will have to approach a plateau by at least early in the next century. Otherwise it is almost inevitable that continued rapid growth in both fission and fossil energy use will have exceedingly damaging social and environmental consequences.

I. Introduction

At the direction of President Carter and Presidential Assistant for Energy Affairs Schlesinger, ERDA was directed to conduct an intensive review of the Liquid Metal Fast Breeder Reactor (LMFBR) development program in general and the Clinch River Demonstration Breeder Reactor (CRBR) in particular. ERDA turned the responsibility for this review over to Robert Thorne, Acting Assistant Administrator for Nuclear Energy.

As a Steering Committee for the LMFBR Program review Mr. Thorne selected a group of 13 individuals, most of whom were known supporters of the LMFBR Program but a few of whom - namely ourselves - had expressed concerns about the implications of the Program. Acting ERDA Administrator Fri asked the Steering Committee to come back with policy "alternatives [which are] balanced, credible, objective, accurate, and take into account the viewpoints of the various interests in the breeder program represented."*

Historically ERDA and its predecessor the Atomic Energy Commission favored the plutonium breeder reactor for development over alternative nuclear technologies largely on grounds of perceived technical and economic advantages. For the purposes of this review, however, President Carter directed ERDA to give special consideration to the security risks inherent in the large-scale commercial circulation of plutonium which would be associated with the plutonium breeder both here and abroad.

To assist the Steering Committee Mr. Thorne established a number of task forces. Unfortunately the task force efforts were very

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*LMFBR Steering Committee Transcripts, March 3, 1977, p. 3.

limited due to the short time allotted to them and they were unable to develop much new in the way of analysis. In particular at the time of this writing, the task forces had not been able to develop:

a) a coherent discussion of alternative uranium conserving nuclear technologies which might be more nuclear weapons proliferation resistant than the plutonium breeder reactor and its associated fuel cycle, or

b) an analysis of nuclear growth projections which adequately take into account the likely impact of higher electricity prices along with recent and expected federal policy initiatives which can be expected to bring about substantial improvements in the efficiency of U.S. energy use.

A large fraction of the Steering Committee - in particular those members from the utilities, ERDA's national laboratories, and the nuclear industry appeared as of the March 25th meeting to have reached the conclusions that the AEC/ERDA breeder R&D program does not possess any fatal flaws and that this program should be carried out with considerable urgency if the U.S. is to avoid a uranium supply crisis at the end of this century. We found the reasoning by which these members had arrived at their conclusions unconvincing. We were therefore asked by Mr. Thorne to write a separate report setting forth our own analysis and conclusions.

Our group has a spectrum of views on the necessity and desirability of fission power for the long term. This report is premised, however, on the assumption that R&D should be continued to preserve fission energy as a major energy option for the long term in a manner consistent with U.S. nonproliferation objectives. This means that the R&D effort must be directed toward utilizing with greater efficiency the energy stored in one or both of the relatively abundant isotopes uranium-238 and thorium-232 in addition to the rare isotope uranium-235 which provides most of the energy released by current fission reactors. To this extent we support the ends of ERDA's breeder reactor program - but, as will become clear, we do not agree with the means.

The critical importance of the nuclear weapons connection to nuclear power development has been recognized in many independent analyses, both here and abroad. For example, it emerged as a central concern in the recent British Royal Commission report on Nuclear Power and the Environment,* which said:

> It appears to us, that the dangers of the creation of plutonium in large quantities in conditions of increasing world unrest are genuine and serious.
>
> For this reason we think it remarkable that none of the official documents we have seen during our study convey any unease on this score. The management and safeguarding of plutonium are regarded as just another problem arising from nuclear development, and as one which can certainly be solved given suitable control arrangements. Nowhere is there any suggestion of apprehension about the possible long-term dangers to the fabric and freedom of our society. Our consideration of these matters, however, has led us to the view that we should not rely for energy supply on a process that produces such a hazardous substance as plutonium unless there is no reasonable alternative.

At the same time this report also concluded:

> We have considered whether this country should seek to abandon nuclear fission altogether, but even if it could be confidently supposed that this could be done without risk of unacceptable restrictions on energy supply in the future, we should not think that such a strategy was wise or justified. We do not think that continued operation of the existing Magnox reactors, or the eventual operation of the thermal reactors that are now being installed or considered, can be thought to constitute an unacceptable hazard when judged against the benefits, provided that existing standards are maintained, as we have every reason to believe they will be.

In expressing strong concerns about a plutonium economy and in judging that present nuclear power technology does not pose unacceptable public risks the Royal Commission has taken a position similar to

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*Nuclear Power and the Environment, the Sixth Report of the Royal Commission on Environmental Pollution, London, September 1976. See Appendix A for more details.

that expressed in the recent Report of the Nuclear Energy Policy Study Group sponsored by the Ford Foundation.* Our analysis here is similarly framed by our conviction that in the future development of nuclear power all economic and technical considerations must be secondary to the objective of obtaining a high degree of separation between nuclear power and nuclear weapons technologies.

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*Spurgeon M. Keeny et al., Nuclear Power Issues and Choices, a report of the Nuclear Energy Policy Study Group, sponsored by the Ford Foundation and administered by the Mitre Corporation, Ballinger, Cambridge, 1977. See also the letter from Hans Landsberg, a member of that group, to Mr. Thorne reproduced in Appendix B .

II. The Nuclear Weapons Connection

While the link between nuclear weapons proliferation and U. S. domestic nuclear energy policy and the relative efficacy of various nonproliferation strategies are issues of intense public debate, there is general agreement on several points. The potential for nuclear weapons proliferation is a grievous problem, and substantial efforts should be committed to avoid proliferation. The proliferation problem should be attacked by a combination of policies designed to a) weaken the incentives toward proliferation (e.g., strengthen the security of non-nuclear weapons countries through the peaceful resolution of international disputes); b) strengthen the disincentives of non-nuclear weapons countries (e.g., increase the political and economic cost of acquiring nuclear weapons capability through the threat of sanctions); and c) strengthen international safeguards where possible by closing loopholes and removing limitations and deficiencies, (e.g., eliminate legal approaches that allow non-nuclear weapons states quick access to nuclear weapons material).

The proliferation problems posed by existing reactors that do not rely on reprocessing and the recycling of plutonium are complex and dangerous, but perhaps not impossible to manage. Containment will hinge upon the success of the policies mentioned above. We recognize that these policies have only been broadly identified.

Controlling nuclear weapons proliferation will certainly become impossible, however, if the nuclear industry here and abroad launches its proposed next step: nuclear fuel reprocessing for the purpose of plutonium recycle and widescale deployment of plutonium breeder reactors.

Once reprocessing is sanctioned, large flows of recovered plutonium and plutonium stockpiles will become a worldwide reality.* As a consequence a short route to the acquisition of nuclear weapons compared to the construction of dedicated facilities would be through the civilian nuclear power program.**

The reprocessing of spent fuel and the recycling of plutonium*** in fresh fuel for reactors would allow non-nuclear weapons states to acquire and stockpile nuclear weapons useable material - seemingly for peaceful purposes. Without violating any of the international safeguards agreements, they could design and fabricate weapon components and move to a point of being as little as hours away from having nuclear weapons - perhaps needing only to introduce the fissile material into the weapons. The non-nuclear weapons state in such an event would have all of its options open. Under these conditions, international safeguards agreements serve as a cover for nascent weapon states; concealing the signs of critical

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*Each commercial-size LMFBR would contain about 3 tons of plutonium - enough to construct several hundred nuclear weapons. At each annual refueling about one-half this amount would be removed. A commercial-size (1500 MT/yr) fuel reprocessing plant would recover annually sufficient plutonium to construct over one thousand nuclear weapons if it reprocessed LWR fuel; and up to ten thousand nuclear weapons if it reprocessed plutonium breeder fuel.

**In this regard, it should be noted that the unanimous opinion of the weapons design and arms control communities has been that it is not the lack of a capability to design a nuclear device which is the pacing consideration in acquisition of a first weapon, but, instead, it is the availability of nuclear weapons materials which can be turned to weapons purposes. See the summary sections on "The Problem" and "The Response" reproduced in Appendix C from the report. Nuclear Proliferation and Safeguards, issued on March 18, 1977 by the Congressional Office of Technology Assessment.

***Or any other weapons material, such as highly enriched uranium or uranium-233.

changes until it is too late for diplomacy to reverse a decision to "go nuclear."*

Even the acceptance of the plutonium breeder as an energy option provides the justification for the early development of a reprocessing capability by any country. (At the moment, reprocessing facilities lack that legitimacy, given the marginal economics of reprocessing and recycle for today's reactors.) We seriously doubt that either national commercial size reprocessing plants or mixed-oxide fuel fabrication plants can ever be subjected to effective international safeguards - that is, safeguards which provide a high probability that diversion of weapons material can be detected in a timely fashion. In any case a non-nuclear weapons country would always have the option to shift its "peaceful" nuclear program to a weapons program. Countries having national reprocessing facilities and breeder reactors could therefore circumvent the very considerable political problems and cost inherent in building one or more plutonium production reactors otherwise necessary for the production of large quantities of weapons-grade plutonium by establishing their nuclear weapons option through their nuclear electric generation program.

Many of these problems were recognized almost immediately when the problem of nuclear weapons proliferation was first analyzed at the end of World War II. Thus the central conclusion of the Acheson-Lilienthal Report on the International Control of Atomic Energy published in 1946 was that:

> "We are convinced that if the production of fissionable materials by national governments (or by private organizations under their control) is permitted, systems of inspection cannot by themselves be made 'effective safeguards... to protect complying states against the hazards of violations and evasions.' " **

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*See the analysis "Proliferation and the Future of Nuclear Power," prepared at our request by Professor H. A. Feiveson of Princeton University's Woodrow Wilson School of Public and International Affairs and reproduced in Appendix D.

**A more extensive excerpt may be found in Appendix E.

In light of the above considerations, we believe that U.S. energy policy, to be consistent with U.S. nonproliferation objectives, must include the following elements:

1. U. S. nonproliferation objectives must take precedence over economic benefits. This is a restatement of the Ford Administration policy.

2. Nonproliferation criteria must be established to govern fission energy activities, including R, D&D, the commercialization of fission energy supply alternatives, (e.g., breeder and advanced converter reactors), licensing, exports and our international posture.

These criteria should be sufficiently restrictive to define unambiguously our nonproliferation objectives, while allowing scientists and engineers as much freedom as possible in designing proliferation resistant nuclear power technologies that conform to the ground rules, i.e., our nonproliferation objectives. (One such criterion is proposed in 3 below). We restrict our consideration here to nonproliferation objectives, since other processes or mechanisms exist to handle health and safety considerations (e.g., EPA and NRC regulations and the NEPA process). The U.S. currently has virtually no criteria covering proliferation.

We believe that nonproliferation criteria are even more important than the current safety regulations and criteria that presently govern the domestic nuclear power industry. As appropriate these criteria could be expanded to cover fusion energy and other technologies that are weapons related.

3. The minimum criterion of acceptability for the commercialization of an energy supply alternative must be the demonstration that the development and commercial utilization of the technology by a non-nuclear weapon state leaves that state no closer to a nuclear weapons capability than would be the case if all its nuclear power were derived from low-enriched uranium fueled reactors operating in a once-through fuel cycle mode (that is, without reprocessing) and with verified spent fuel storage in secured international facilities.

This leaves the non-nuclear weapons states at least months to years away from obtaining via this technology the fissionable material necessary for the production of nuclear weapons.

It is important to note that there are promising uranium conserving nuclear reactor systems that are much more proliferation resistant than the LMFBR-based system, which has been the almost exlusive focus of advanced reactor R&D efforts in the U. S. and abroad. (See Section III.)

4. The U. S. must abandon all activities aimed at the demonstration and commercialization of plutonium recovery from spent fuel via chemical reprocessing for the purpose of recycling in national reactors.

Continuation of present activities aimed at the demonstration and commercialization of the plutonium fuel cycle must be abandoned. These activities would jeopardize U. S. nonproliferation initiatives by legitimizing the argument of non-nuclear weapons states that reprocessing is necessary for energy independence and that their reprocessing facilities are peaceful.

If reprocessing and the recovery of unused fuel should eventually become necessary to conserve uranium resources, such activities should be carried out only at centers established under international auspices and maintained under tight security. All plutonium (or other weapons usable material) recovered from spent fuel would remain at these sites under tight security and could be used as fuel only at internationally controlled reactors at these sites. Because of the enormous quantities of plutonium involved, this activity would not be practical for plutonium/uranium fuel cycles that require chemical reprocessing.*

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*Co-processing or co-precipitation of plutonium with uranium has been proposed by ERDA as an approach that "could potentially eliminate separated plutonium from the reprocessing and recycle scheme." [ERDA Budget for FY 1978 submitted by the Ford Administration]. Although co-processing provides an additional safeguard against terrorist and other non-state adversaries, it does not meet the minimum acceptable criterion in 3 above. A non-nuclear weapons state with such a facility would need only to change the chemical agents used in the reprocessing operation to convert the facility to the production of pure plutonium. Furthermore, it is a simple chemical operation to separate the plutonium from the co-processed plutonium and uranium mixture. Thus, if the co-processed plutonium and uranium mixture is permitted in a non-nuclear weapons state, it would still be only a matter of days away from having weapons usable material in hand.

The demonstration and implementation of reprocessing and recovery activities associated with international centers should not take place before the necessary institutional arrangements for establishing these centers are in place and criterion 3 above is assured.

5. The Clinch River Breeder Demonstration Project should be cancelled.

The purpose of the Clinch River Project has always been to move the breeder program and its associated fuel cycle toward commercialization. The continued focus of ERDA's fission R&D program on the Clinch River Project and the succeeding generation of demonstration plutonium breeder reactors therefore would strongly conflict with our nonproliferation objectives. The CRBR and its fuel cycle as presently conceived do not meet the minimum criterion for acceptability in 3 above.

As an alternative to the presently conceived CRBR Project, ERDA has suggested that the CRBR could be utilized as part of an effort to demonstrate the operation of LMFBR's on a denatured uranium-thorium fuel cycle. As discussed at the end of Section III, the LMFBR operating on a denatural uranium-thorium fuel cycle makes no sense. It does not breed enough U^{233} and it breeds too much plutonium with the result that one-half to one-fourth of all the reactors would have to operate on plutonium fuel and therefore be located in international fuel cycle facilities. In the ERDA scenario the reactors operating on plutonium would be in national parks - presumably in weapons states - and subject to IAEA safeguards. It is hard to see how such an extension of the inequities between nuclear weapons and non-nuclear weapons states to the civilian sector would be accepted.

We cannot expect other nations to forego a plutonium economy if we act as though plutonium recycle and plutonium breeders are indispensible elements of our own national energy policy. Several countries, but principally France, West Germany and Japan, are expressing serious doubts about our intentions with regard to the bilateral negotiations on nonproliferation policy. The only way in which the U.S. can clearly signal its intention to meet its nonproliferation objectives is by cancelling the demonstration and commercialization aspects of the U.S. plutonium breeder program.

6. The U. S. breeder effort should be continued but converted to a long term option program that pursues breeder and near breeder technologies that are sufficiently proliferation resistant to meet the minimum criterion for acceptability in 3 above.

While we doubt that a "proliferation proof" fuel cycle can be developed, we know there are fuel cycles which can permit much higher resource utilization than the current "once through" uranium based fuel cycle and which can be made far more "proliferation resistant" than plutonium fuel cycles that require chemical reprocessing.

We recommend therefore that ERDA shift the thrust of its advanced fission R&D program from its current emphasis on the commercialization of the plutonium breeder and its associated fuel cycle to the pursuit of more proliferation resistant resource conserving fission technologies that meet the minimum criterion of acceptability.

As noted under element 5 above ERDA has suggested the LMFBR, operating on the denatured uranium-thorium fuel cycle, as an alternative proliferation resistant technology. This fuel cycle makes no sense, however, for reasons previously mentioned and discussed in more detail at the end of Section III.

7. The decision on which major new nuclear energy technology to demonstrate and commercialize must not be left to the nuclear industry and ERDA, subject only to review through the ordinary budget process. Rather the decision should only follow the recommendation of the President and approval by the Congress, following a comprehensive nuclear weapons proliferation impact assessment carried out by an agency with responsibilities for national security - e.g., the Arms Control and Disarmament Agency, the Department of State, or the Department of Defense.

The decision is far too important to be determined by the energy supply community.

III. Proliferation Resistant, Resource Conserving, Nuclear Technologies

For purposes of illustrative calculations below, we will assume a scenario in which U.S. nuclear capacity grows linearly from 40 Gwe in 1975 to 120 Gwe in 1985 (the estimate used by ERDA's Task Force on the Fission Breeder - Why and When), to 400 Gwe in 2015 and then levels off. At this level the nuclear-electric power plants operating at a 65 percent average capacity factor would generate 20 percent more electrical energy each year than was generated by all U.S. power plants in 1975. (See Section IV for a discussion of nuclear growth projections.)

The cumulative U_3O_8 requirements for this scenario with all the nuclear capacity being LWR's operating on a once-through fuel cycle would be 2.3 million tons by 2025. When this number is compared with ERDA's official estimate of 3.7 million tons of U_3O_8 in high grade deposits in the U.S.,* it would appear that uranium resource limitations would not be an immediate concern.

ERDA's Task Force on the Breeder - Why and When has concluded, however, that perhaps one half of high grade uranium resources estimated by ERDA's National Uranium Resource Evaluation Program might not be found.** This appears unlikely to us (see Section IV) but let us suppose for the sake of argument that this most pessimistic conclusion should prove to be correct. As we will show below there are other simpler more proliferation resistant approaches than the LMFBR to improve the efficiency of the uranium resource utilization.

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*Under $30/lb forward cost.

**On the basis of private communications from five geologists acting as the uranium resource subgroup of the Supply Panel of the NAS-NAE Committee on Nuclear and Alternative Energy Systems.

We do not wish to advocate the development of any particular alternative fuel cycle. It is our view that scientists and engineers should be given considerable flexibility in selecting the most promising technologies that conform to nonproliferation criteria as established by an agency or agencies responsible for national security. However, to illustrate one possible course, we focus here on a fuel cycle described by Feiveson and Taylor* based on the production of U^{233} from thorium and the "denaturing" for nuclear weapons purposes of the produced U^{233} with U^{238}. In this fuel cycle nuclear fuel going to and from nuclear reactors would be no more attractive a target to would-be bomb makers than the fuel of reactors operating on the current low enriched uranium fuel cycle. A brief description of this particular concept is given in Appendix F.

Recent technical studies indicate that the annual uranium requirements of a heavy water reactor operating on this fuel cycle would be less by more than a factor of four than those of an LWR operating on a once-through uranium fuel cycle. An essentially unmodified pressuried water reactor using "spectral shift control" through the addition of varying amounts of heavy water to its coolant during its fuel life could do almost as well as the denatured uranium-thorium fuel cycle - a reduction by a factor of 3-4.** (See Table III-1).

A uranium resource conservation strategy that could be implemented much more quickly than the commercialization of the LMFBR would therefore be

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*Harold A. Feiveson and Theodore B. Taylor, "Security Implications of Alternative Fission Futures," Bulletin of the Atomic Scientists, December 1976.

**EPRI, Assessment of Thorium Fuel Cycles in Pressurized Water Reactors (EPRI NP-359, 1977); P.R. Kasten et al., Assessment of the Thorium Fuel Cycle in Power Reactors (ORNL/TM-5565, 1977). These reports give the annual fuel requirements for U^{235}-Th-U^{233} fuel cycles without U^{238} denaturant for the U^{235} or U^{233}. The required amount of make-up U^{235} is somewhat greater with the U^{238} than without it. The factor four cited here for the CANDU reactor was calculated for a denatured uranium-thorium fuel cycle by Dr. Charles Till, Argonne National Laboratory.

TABLE III-1. Uranium Requirements for a 1 Gwe Nuclear Reactor

Reactor Type	Fuel Cycle	U_3O_8 Requirements (tons)[1]		
		Startup	Annual	Lifetime
LWR	U(Once-through)	410 [2]	167	5250
LWR (Spectral Shift)[3]	U-Th(Denatured, Recycle)	1000 [4]	48	2300
HWR[5]	U-Th(Denatured, Recycle)	711 [6]	40	1830
LWR(Spectral Shift)	U-Th(Denatured, Recycle, Replacement Reactor)	--	48	1440
HWR	U-Th(Denatured, Recycle, Replacement Reactor)	--	40	1200

Notes

1. Assuming 0.2% tails for enrichment operations, a 30 year reactor life, and a 65% average capacity factor. It should be noted that the ERDA Task Force on the Fission Breeder - Why and When assumed a higher capacity factor of 75%, which we regard as unrealistic. The 65% capacity factor we have adopted is the one ordinarily assumed in ERDA projections for LWR's (see, for example, ERDA-48) and even this value is higher than the 55-60 percent capacity factor currently being experienced by LWR's when they should be operating at capacity factors considerably above their lifetime averages. The use of a high capacity factor results in greater lifetime fuel requirements than we have estimated here - e.g., 6200 tons of U_3O_8 instead of 5250 tons for the LWR operating on a once-through basis.

2. For initial core only.

3. See references cited in footnote on p. III-2. The effect of denaturing was estimated by an ERDA Task Force in the report Assessment of Nuclear Alternatives with Constraints on Pu Use (April 1, 1977).

4. For initial core plus two years of reloads.

5. Data from Dr. Charles Till, ANL, personal communication.

6. For initial core plus 1 year of reload.

to convert LWR's to operate as Spectrum Shift Control Reactors operating on a denatured uranium-thorium fuel cycle. As shown in Table III-1 the lifecycle uranium requirement for such a reactor, with reprocessing and recycle, would be about 56% less than for an LWR operating with low enriched uranium on a once-through fuel cycle basis. Moreover, when this reactor is eventually replaced, at the end of its useful life, the replacement reactor would require over its lifetime 73% less uranium than a present day LWR operating on a once-through basis. If all light water reactors introduced after 1985 were operated on this basis,* cumulative uranium requirements through 2025 for our 400 Gwe scenario would be 1.4 million tons, compared to 2.3 million tons for today's LWR's operating on the once-through fuel cycle. Moreover, because the replacement reactors have such low lifetime fuel requirements (see Table III-1), a resource of 2.3 million tons would sustain 400 Gwe till 2075, while 3.7 million tons would last to nearly the year 2150.

It should be noted that the viability of relying on proliferation resistant uranium conserving reactors instead of plutonium breeder reactors over the next century does not depend sensitively on the growth rate assumed for nuclear power in this century, but does require a plateauing of nuclear generating capacity early in the next century. For example, if nuclear generating capacity should reach the assymptotic level of 400 Gwe in 2000 instead of 2015 the cumulative

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*The introduction of Spectral Shift Control Reactors in all new units after 1985 was advanced as a feasible option in the ERDA Task Force Report on the Assessment of Nuclear Alternatives with Constraints on Pu Use. However, at the Steering Committee meeting on April 5, several members expressed the view that a 1985 introduction date may be somewhat optimistic. A delay of 5 years in introducing the Spectral Shift Control Reactor would result in the commitment of an additional 0.18 million tons of uranium. However, the penalty would be considerably less if reactors were shifted to the denatured uranium/thorium cycle without spectral shift in 1985, while delaying the spectral shift feature for new reactors till 1990, because most of the uranium savings are associated with switching to the thorium based fuel cycle.

uranium requirements through 2025 would be 1.5 instead of 1.4 million tons.

In summary, one does not need a 10,000 + year solution - the plutonium breeder - to attack a 100 year problem.

One of the reasons why the nuclear industry has opted for the uranium-plutonium fuel cycle for light water reactors rather than the uranium-conserving uranium-thorium fuel cycle is that the uranium-thorium fuel cycle requires a higher initial investment in uranium and uranium enrichment than the uranium-plutonium fuel cycle. The lower refueling requirements of the reactor on the thorium cycle show up in net savings only after the first 10 years. Because of the large discounts applied to such future savings and the extra interest charged on the higher initial investment for the uranium-thorium fuel cycle, the EPRI report calculates that the U^{235}-Th-U^{233} fuel cycle would be approximately 0.5 mills per kwh more expensive than the uranium-plutonium fuel cycle and that therefore the economics are probably "not sufficient to motivate the commercial development of the thorium cycle by the private sector."* We would suggest, however, that the improved proliferation resistance of the denatured uranium fuel cycle and the associated potential improvements in the efficiency of uranium use in current nuclear reactors might justify a national policy decision to opt for a denatured uranium-thorium fuel cycle despite this economic penalty, which is equivalent to a 1-2% increase in the cost of the electricity delivered to the consumer.

Finally it is important to realize that the introduction of these uranium conservation techniques into LWR's or HWR's makes it "thinkable" to exploit many millions of tons of uranium resources that are not counted in ERDA's

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*By way of comparison, however, Atomics International in a recent study ["Pool-Loop-Hybrid LMFBR Plant Comparison," submitted to ERDA and EPRI, Atomics International, June 30, 1976, Vol. 7, p. 94.] estimated that the total energy cost for a pool type LMFBR would be 1.7 mills/kwh (1976 dollars) less than for the loop type LMFBR design favored by ERDA and subsequently chosen as the design for the prototype large breeder reactor.

high grade uranium resource estimates. Thus, for example, while the uranium in one ton of Chattanooga shale* would yield an amount of energy in an LWR on a once-through fuel cycle equivalent to that yielded by only one ton of coal mined for a modern fossil fuel plant**; the same uranium would be equivalent to approximately 4 tons of coal if used in a HWR operating on a denatured uranium-thorium fuel cycle.

It is obvious therefore that in the absence of the plutonium breeder, the uranium resource "crisis" postulated by the ERDA Task Force could occur only if the nuclear industry refuses to make the changes in fuel cycles which will result in the dramatic increases in the uranium utilization efficiencies which are possible in today's reactors.

Of course the full benefit of these fuel cycles would only become available with reprocessing and recycling of the recovered uranium and thorium. The EPRI report concludes, however, that "no unique or fundamental [technical] constraint is imposed on the deployment of the thorium fuel cycle due to reprocessing or fabrication since these technologies appear to be relatively well developed and/or similar to those required in the uranium cycle."

We wish to stress once again that, in our view, it is imperative that spent fuel storage and reprocessing be carried out in international facilities. Only with such arrangements can the denatured uranium-thorium fuel cycle be as proliferation resistant as the low-enriched uranium fuel cycle operating in the once-through fuel cycle mode. The institutional problems involved in internationalizing the "dangerous" parts of the denatured uranium-thorium fuel cycle may be surmountable because weapons usable nuclear materials will be present only at the reprocessing plant in this fuel cycle. According to current plans for the plutonium fuel cycle one such plant would service approximately 50 nuclear reactors.

* 70 ppm U_3O_8, 70 percent recovery factor.
** 23 percent losses in cleaning, 10,000 Btu/lb.

In the plutonium fuel cycle weapons usable material would be present at every reactor. The fuel would be of the order of 10-20 percent plutonium and the fresh fuel in particular would provide a tempting target for diversion. For this reason it has been suggested by one of the ERDA task forces that the LMFBR could be operated on a denatured uranium-thorium fuel cycle.*

Unfortunately, because the LMFBR is a fast neutron reactor the fissile loading of the U^{233} in the core would be so large (about 10 percent vs. about 2 percent for a CANDU**) that the denaturing U^{238} (about seven atoms of U^{238} for every atom of U^{233}) would leave little room for thorium. The result is that a large amount of plutonium would be bred in the "denaturant" (uranium-238) as uranium-233 in the "fertile" thorium in the core and blanket. The amount of U^{233} produced would not be sufficient to refuel the LMFBR - in fact it appears likely that the LMFBR would require at least as much denatured uranium as make-up fuel as a CANDU.* The higher breeding ratio of the LMFBR could only be exploited, therefore, if a substantial fraction (of the order of one-third) of all reactors could be operated on the bred plutonium.* In contrast a CANDU on a denatured uranium-thorium fuel cycle would discharge in its spent fuel only about 3 atoms of fissile plutonium for every one hundred atoms fissioned.***

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*<u>Assessment of Nuclear Alternatives with Constraints on Pu use</u> (April 1, 1977).

**P. R. Kasten et al., <u>Assessment of the Thorium Fuel Cycle in Power Reactors</u> (ORNL/TM-5565, 1977).

***Charles Till, Argonne National Laboratory, private communication.

IV. Timing Considerations

Throughout the early 1970s ERDA's predecessor, the AEC, was projecting that by the year 2000 there would be operating 1000 or more Gwe of nuclear capacity (see Table IV-1). The lifetime uranium requirements for this capacity, when provided by LWRs operating on a once-through fuel cycle, are over 5 million tons, which exceeds AEC-ERDA estimates of high grade uranium resources. The AEC and ERDA therefore argued that it would be necessary to introduce a nuclear reactor with much lower uranium requirements by the 1990s. Their candidate has been the LMFBR.

Over the last two years, however, ERDA has repeatedly revised its nuclear growth projections downward (See Table IV-1). In fact the current midrange projection for 2000 (350 Gwe) is not much greater than what was projected for 1985 in 1971. Since the lifetime uranium resource requirements of 350 Gwe are only about 1/2 of ERDA's high grade uranium resource estimate, it would appear that the date of introduction for a uranium conserving reactor and its associated fuel cycle could be deferred by some decades at least, giving the United States a breathing space in which technological and institutional arrangements could hopefully be developed which would more effectively separate civilian nuclear power from nuclear weapons technology.

In the face of diminished nuclear power demand growth, however, a new element concerning the timing of breeder program has suddenly been discovered - the possibility that U.S. resources of uranium in high grade ores might be much lower than officially estimated. As pointed out in the previous section of this report, one of the ERDA Task Forces has received a private communication to the effect that a group of five geologists associated with the NAS/NAE CONAES study has concluded that perhaps half of ERDA's high grade uranium resources might not be found.

TABLE IV-1

AEC-ERDA Projections of the Year 2000 U.S. Nuclear-Electric Generating Capacity

Date of Projection	Nuclear Capacity (Gwe) 1985	2000	Reference
January 1971	300	-	1
December 1972	280	1200	2
November 1974	231	1090	3
April 1975	160-245	625-1250	4
April 1976	225	450-800	5
October 1976	127-166	380-620	6
March 3, 1977	120	300-400	7

References:

1. "Forecast of Growth of Nuclear Power" USAEC Report WASH-1139, January 1971.

2. "Nuclear Power 1973-2000", USAEC Report WASH-1139 (72), December 1972.

3. "The Nuclear Industry 1974" ERDA Report WASH-1174 (74), November 1974.

4. "Total Energy, Electric Energy and Nuclear Power Projections, United States" submitted for the record by Roger W. A. Legassie, Assistant Administrator for Planning and Analysis, ERDA in Oversight Hearings on Nuclear Energy - Overview of the Major Issues, Hearings before the Subcommittee on Energy and The Environment of the House Committee on Interior and Insular Affairs, April 28, 1975, pp. 142-159.

5. A National Plan for Energy Research, Development, and Demonstration: Creating Energy Choices for the Future (ERDA 76-1) Volume 1, p. 29.

6. Edward J. Hanrahan, Director of Analysis, ERDA, "United States Uranium Requirements", speech presented at "The Uranium Industry Seminar", October 19, 1976, ERDA Press Release November 4, 1976.

7. Year 2000 projections: base case assumptions proposed to LMFBR Steering Committee, March 3, 1977 by Robert W. Fri, Acting Administrator, ERDA, Year 1985 projections: base case assumption used by ERDA's Task Force on the Fission Breeder - Why and When.

In this section we discuss both electricity demand and uranium supply estimates to establish their bearing on the timetable for the fission R&D program. We will show why we believe that even ERDA's most recent nuclear capacity projections still substantially overestimate the likely future growth for nuclear power. We will also comment briefly on the various uranium supply estimates that have been made.

Electricity Demand Growth

How much growth in electricity consumption can we realistically project by the year 2000? ERDA's Task Force on the Fission Breeder - Why and When takes as its midrange assumption an average growth rate of 5 percent till the year 2000, which would correspond to a rate of electricity consumption 3.5 times higher in the year 2000 than today. For an average thermal-electric conversion efficiency of 33%, the fuel requirements for the electrical sector in the year 2000 in this scenario would be equivalent to the energy consumption of the total U.S. economy in 1975. The 350 Gwe of nuclear capacity envisioned for this projection by itself represents a great deal of energy. Operating at a 65% capacity factor this nuclear capacity would generate more than the total U.S. electric energy production in 1975.

We find these projections incredibly high for three reasons: they do not reflect new electricity price trends that are well established; they do not reflect emerging trends that will slow total GNP growth beginning in the 1980's; and they do not reflect the increases in energy efficiency that will likely develop throughout the economy in response to both higher energy prices and new public policy initiatives relating to energy conservation.

When we asked for documentation of the "midrange" projection of 5% annual growth in electricity use, we were referred to the 1976 Edison Electric Institute report, Economic Growth in the Future, for the supporting analysis. We reviewed that report and found to our surprise that the 5 percent growth rate projection is obtained by using the Data Resources Inc. (DRI) econometric model and by assuming that average electricity prices in the year 2000 will be almost 40 percent less than they were in 1975.* This assumption is inconsistent with both current industry experience and projections. For example, the electric utility trade journal Electrical World projects that the price of residential electricity will rise 20% in real terms by 1985** and ERDA's Institute for Energy Analysis projects that electricity prices will increase approximately 65% by the year 2000.*** We feel that the IEA electricity price projection is probably fairly realistic, because it is what would happen if the average price of electricity rises by the year 2000 to the marginal cost for new power generation today.**** Thus the real price of electricity by the

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*In 1975 the average price per kwh was 2.7¢ ["1977 Annual Statistical Report," Electrical World, March 15, 1977, p. 59]. The year 2000 price assumed for the 5.3 percent average annual growth scenario in the EEI report is 1.7¢ per kwh in 1975 $ (p. 193).

**"27th Annual Electrical Industry Forecast," Electrical World, September 15, 1976, p. 52.

***Economic and Environmental Implications of a U.S. Nuclear Moratorium, 1985-2010 (ORAU/IEA-76-4, 1976).

****The busbar cost of electricity from a new nuclear power plant in 1975 dollars is about 2.7¢ kwh (see below).***** This can be converted to an equivalent cost for the average consumer through multiplying by 1.7, to account for transmission and distribution costs. It is very likely that the marginal cost for new coal generated electricity is about the same. If the average price of electricity rises to the marginal cost for electricity from today's new plants by the year 2000, then in the period 1975-2000 the increase in the real price of electricity would be nearly 70% in this period.

*****To estimate the busbar cost for nuclear power from a new plant we have assumed a capital cost of $750/kwe, a 15% annual capital charge, and a 65% capacity factor. We also assume operating and maintenance costs are 2.0 mills/kwh and that the fuel cycle costs without recycle are 5.2 mills/kwh (see T.H.Pigford,"The Analysis of the Cost of Electrical Energy from Nuclear Power Plants," Report No.NE3008, Rev.1, Nuclear Engineering Department, Univ. of California at Berkeley, August 1976.)

year 2000 is likely to be 2½-3 times larger than that projected in the EEI report.

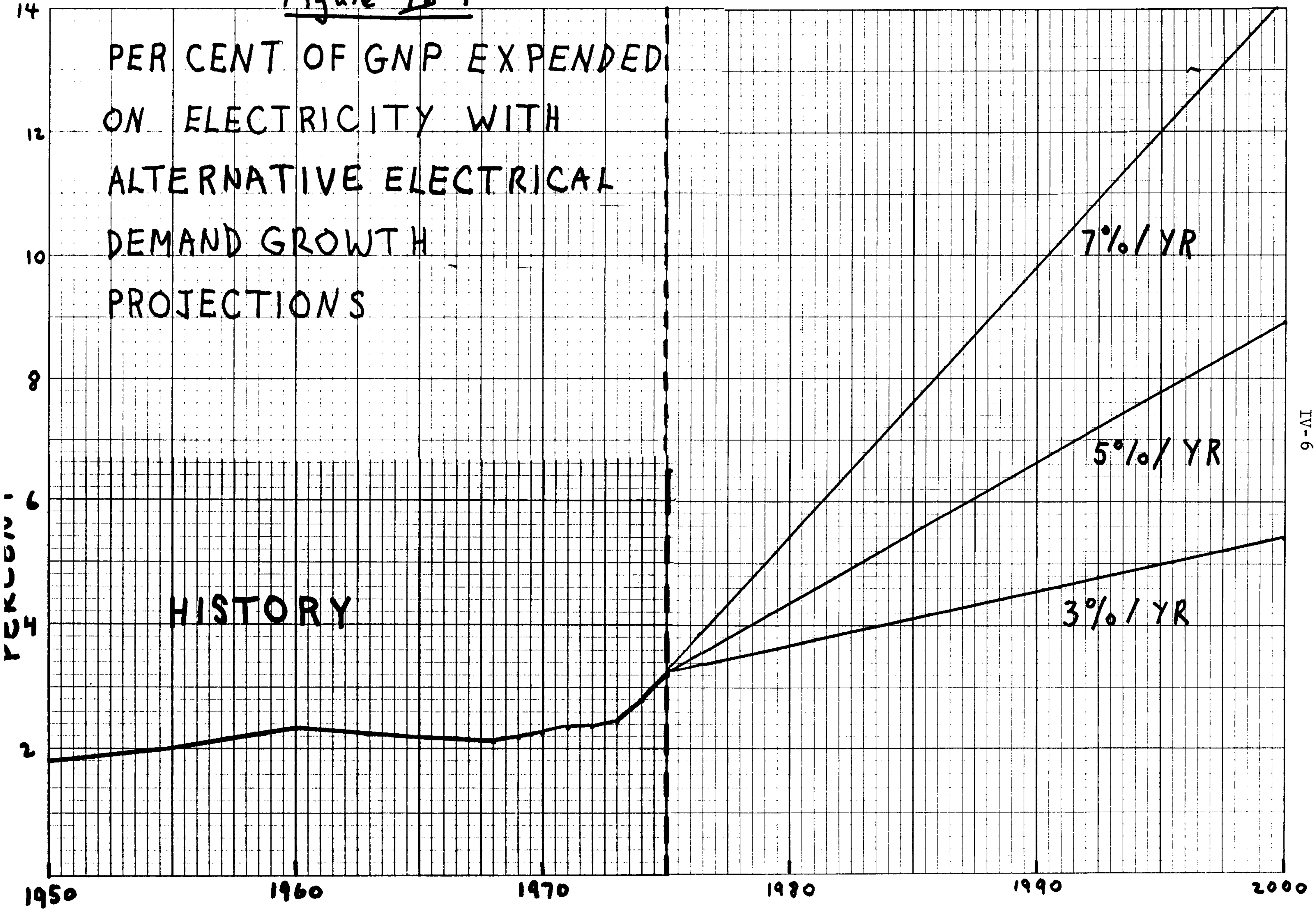
The assumption of a continued declining real price for electricity is absolutely essential to obtain the 5.3% electrical demand growth in the DRI projection, however, because the DRI model reflects the fact that the fraction of GNP spent on electricity historically has varied only slowly with time (see Figure IV-1). While electricity demand grew more than twice as fast as GNP in the past, expenditures on electricity grew only slightly faster than GNP because the real price of electricity was falling at nearly half the rate of electricity growth (see Figure IV-2). Rising electricity prices change this situation dramatically and will dampen electricity growth considerably. Before we show how much dampening of growth we expect, however, we will first consider another factor: GNP growth.

The EEI report projects that the GNP will increase at 3.7% per year between 1975 and 2000. This is somewhat faster than the 3.3% growth rate for the last 25 years. It is very likely, however, that the GNP will grow on the average <u>more slowly</u> in the future than in the past because: (a) population growth trends will lead to a drastic reduction in the growth rate for the labor force in the last 15 years of this century, and because (b) labor productivity is not likely to grow faster in the future than in the past*. It appears** that under these circumstances even a 3% average annual growth

* Because of increased investment requirements not related to production, a growing share of investment outlays going to replacement outlays, as opposed to new investment, and a continued decline in the role of agriculture in the economy.

** See Frank von Hippel and Robert H. Williams, "Nuclear Energy Growth Projections," testimony prepared on behalf of the State of Wisconsin for the NRC's GESMO Hearings, March 4, 1977. This testimony is reproduced in Appendix G.

Figure IV-1


PER CENT OF GNP EXPENDED
ON ELECTRICITY WITH
ALTERNATIVE ELECTRICAL
DEMAND GROWTH
PROJECTIONS
HISTORY
7%/YR
5%/YR
3%/YR
14
12
10
8
6
4
2
1950
1960
1970
1980
1990
2000

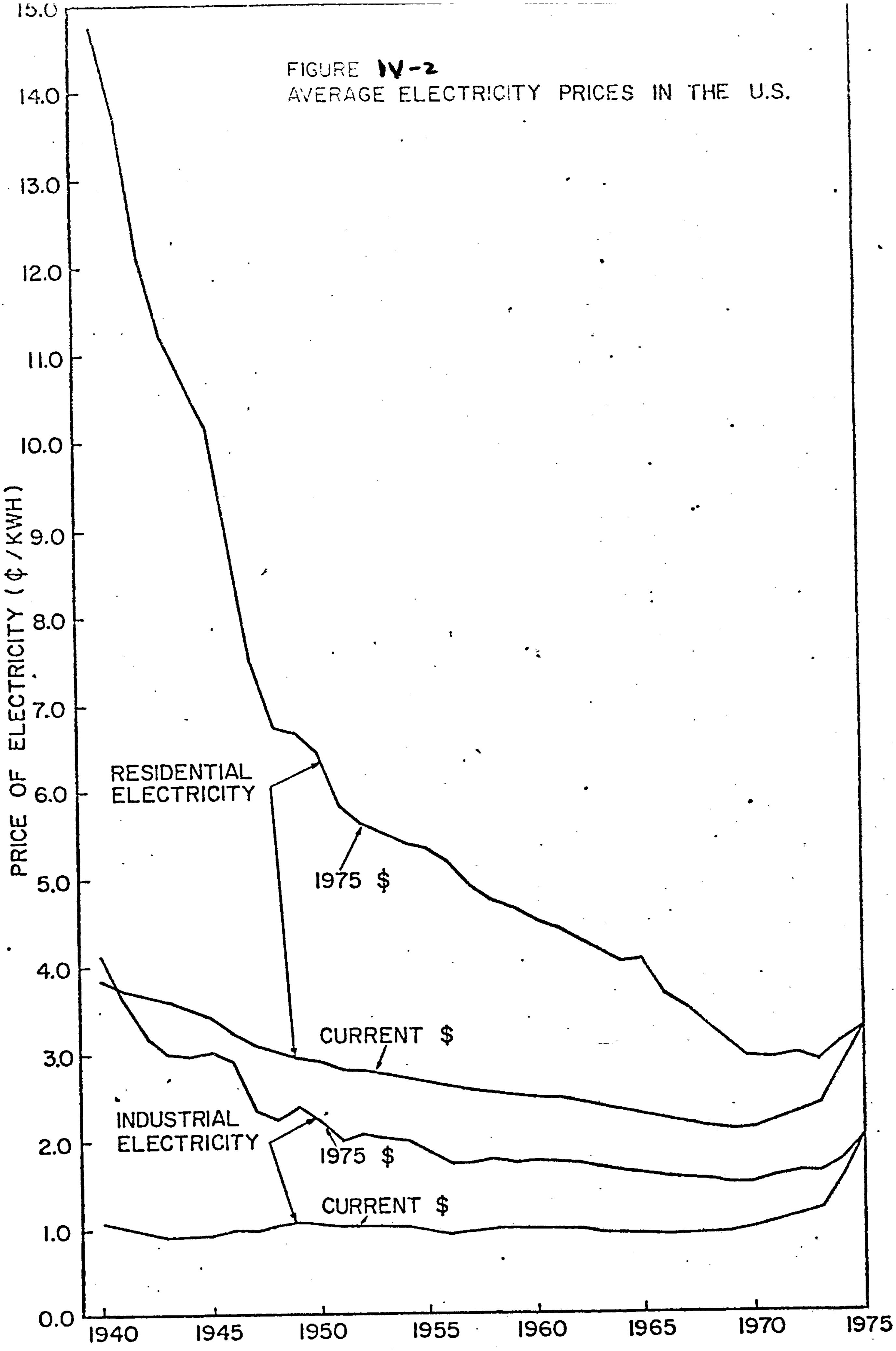


FIGURE IV-2
AVERAGE ELECTRICITY PRICES IN THE U.S.
PRICE OF ELECTRICITY (¢ / KWH)
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
RESIDENTIAL
ELECTRICITY
1975 $
CURRENT $
INDUSTRIAL
ELECTRICITY
1975 $
CURRENT $
1940
1945
1950
1955
1960
1965
1970
1975

in GNP over the next 25 years is optimistic.

With rising prices and slower GNP growth all of ERDA's electricity projections involve a substantial break with the historical experience that the fraction of GNP spent on electricity has been nearly constant. We expect that there will be some increase in the historical share because of a shift to electricity from other fuel forms. However, we do not expect that the break with historical experience will be as dramatic as would occur with 5 or 7 percent annual load growth (see Figure IV-1), where the share of GNP spent on electricity would be nearly 9 and 15 percent respectively in 2000. We do not feel that the corresponding radical shifts in the composition of GNP are likely in this time frame. Fortunately, however, there is good evidence that a healthy economy can be sustained with much lower electricity load growth than this.

It is very likely that rising energy prices and public policy initiatives promoting greater efficiency of energy use will lead to much slower growth in energy consumption than we have experienced in the past. Preliminary results provided to the Steering Committee by members of the NAS/NAE CONAES Demand Panel, a group which has made the most comprehensive engineering study yet of the potential for increasing the efficiency of U.S. energy use, confirm this thesis. One of these results is that by the year 2010 the U. S. real GNP could be doubled with only a 40 percent increase in U.S. energy use simply by introducing those energy efficiency improvements which would be economically justified if the real price of energy were to roughly double in this same period. No major lifestyle changes would be involved in this scenario relative to the arrangements which would prevail in the economy if the price of energy were to stay constant.*

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*Drs. John Gibbons (Chairman) and Clark Bullard (Member), of the Demand Panel of the Committee on Nuclear and Alternative Energy Systems (CONAES), an ERDA sponsored study under the auspices of the National Academies of Science and Engineering, private communication and briefing by Dr. Gibbons to the LMFBR Steering Committee, April 5.

If the economic well being of the U. S. is so insensitive to the energy intensity of the economy over the long term, it would appear to us that national security and environmental health would be much better served by energy efficiency - encouraged by efficiency standards, incentives to improve the efficiency of energy use, or energy taxes if necessary - than by the level of energy waste implicit in the growth expectations of the utility industry. We believe these results are a very effective rebuttal to the argument that economic growth must be accompanied by an approximately proportionate energy growth. * That the impact of greater efficiency in our energy use would not necessarily be detrimental to our economy is also evident from the observation that the economies of other developed nations which have historically had energy prices considerably higher than the United States are also considerably less energy intensive. This decreased energy intensity does not seem to have impaired the vigor of the economies of Sweden, West Germany or Japan. **

It would appear, therefore, that the rough proportionality of U.S. economic and energy growth in the past was more a reflection of the approximate constancy if not a slight decline of real energy prices in a now vanished era of cheap and abundant domestic energy supplies (a "fuels paradise") than any intrinsic requirement of economic growth.

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*See e.g. "Economic Growth, Employment, and Energy" by Chauncey Starr et al., Electric Power Research Institute, paper submitted to the LMFBR Review Steering Committee, March 3, 1977.

**J. Alterman et al., Energy Consumption and Economic Activity: Comparative Pattern in Nine Industrial Countries (Resources for the Future, forthcoming, 1977.)

One of the specific findings with which we were provided by members of the CONAES Demand Panel study is that, with electricity prices doubling between now and 2010 (which would result from a continuation of the trend we feel is likely in the period to the year 2000), utility generated electricity would grow more slowly than GNP, or - based on our expectations of future GNP growth - somewhat less than 3% per year. *

In our own analysis (see Appendix G) we obtain results very similar to these. In response to rising prices and new energy conservation initiatives we project that a doubling of GNP could occur by the year 2000 with energy use increasing by only about 30 percent.** We expect electricity use to grow faster than total energy use, but no faster than GNP, i.e., again at about 3% per year.

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*Specifically the CONAES Demand Panel projected that central station electricity use would increase at an average rate of 1 1/2 to 2 1/2 percent per year to 2010 if real GNP doubled in this period and at a rate of 2-3 percent per year if GNP increased 2.8 fold in this period.

**It will be seen that this is a somewhat greater increase of energy efficiency than projected by the CONAES Demand Panel members for the case of energy price doubling. One reason for the difference is that we assume that institutional barriers to industrial congeneration of electricity and steam can be overcome and that the economical potential for cogeneration will be exploited. Since the extra amount of fuel required to generate a kwh of electrical energy at an industrial cogeneration facility is approximately one half of that which would be required at a central station power plant, this would be a major contribution to increased U.S. energy efficiency. We note also that the CONAES Demand Panel members have another scenario in which energy prices quadruple by the year 2010. In this scenario they find that economically justified energy efficiency improvements would allow the GNP to double by the year 2010 with less than a 20 percent increase in total U.S. energy consumption - <u>still with no major lifestyle changes</u>. Even if U.S. energy prices do not quadruple by the year 2010, it might be justified to require that some of these energy efficiency improvements be made anyway for other reasons such as the reduction of U.S. dependence on oil imports and the reduction of the environmental and social costs associated with most energy supply technologies.

With electric energy consumption growing at 3% per year, ERDA's nuclear capacity projection of 350 Gwe of nuclear power for the year 2000 could be achieved only if both coal central station power generation and industrial cogeneration of electricity were greatly constrained. In Appendix G we show that, if instead coal and nuclear central station power plants generated equal amounts of electricity in 2000, and if economical opportunities for producing electricity via cogeneration at large steam using industrial plants were exploited, then nuclear generating capacity in the year 2000 would be no more than about 200 Gwe.

ERDA's Task Force on the Fission Breeder - Why and When argues that even with lower projections for nuclear capacity in the year 2000 the need for the plutonium breeder would be delayed by only a decade or so. This is because they assume that after the year 2000 nuclear capacity will grow indefinitely at a rate of 250 Gwe per decade. Such projections make as much sense as projections for automobiles based on historical trends, which result in automobiles by the year 2000 getting 9 mpg and carrying less than one passenger. After the year 2000 the labor force and hence GNP will probably be growing even more slowly and further opportunities for increasing the degree of electrification of the energy economy will be limited. Electricity use as well as total energy use will likely be growing very slowly in that time horizon. In fact, we believe that U. S. energy consumption will have to approach a plateau by at least early in the next century. Otherwise, it is almost inevitable that continued rapid growth in both fission and fossil energy use will have exceedingly demaging social and environmental consequences.

completeness, however, we wish to comment briefly on alternative uranium supply estimates.

While ERDA's Task Force on the Fission Breeder - Why and When has concluded that the uranium in ERDA's "possible" and "speculative" resource categories (which represents one half of ERDA's estimate of 3.7 million tons of U_3O_8 in high grade deposits) may not be found - reflecting the views of the five geologists on the CONAES uranium resource subgroup - resource economists traditionally have criticized the estimates of ERDA's uranium geologists as being too conservative. For example, the Report of the Nuclear Energy Policy Study Group sponsored by the Ford Foundation concluded that

> "Evaluated in the context of history and with an awareness of the peculiarities of the data, existing uranium resource estimates emerge as biased significantly on the low side."

In support of this view, the Nuclear Regulatory Commission's report of its own industrial survey of U.S. uranium resources* concluded that ERDA's estimates were probably low by about a factor of two, partly

> "...because recent significant finds have not yet been reported to ERDA (because evaluations have not been completed or because commercial considerations dictate confidentiality)."

We have appended to our report the paper "Uranium Scarcity: Myth or Reality?" prepared for the Steering Committee by Vince Taylor of Pan Heuristics. Taylor presents cogent arguments to the effect that we are far from uranium resource scarcity.

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*See Final Generic Environmental Statement on Use of Recycled Plutonium in Mixed Oxide Fuel in Light Water Reactors (NUREG-0002, 1976, Chapter XI, Appendix D.)

Uranium Supply

If nuclear power growth is going to be so slow, then it doesn't really matter much what the uranium supply numbers are, because not even the most pessimistic projections would justify early commercialization of breeder reactor technology. And as we have shown in Section III, there are many uranium resource conserving alternatives to the LMFBR that appear to be considerably more proliferation resistant than the LMFBR technology. For

V. LMFBR Economic Considerations

There have been numerous cost-benefit studies of the LMFBR program. Most of the analyses by independent reviewers have been highly critical of the breeder program and the AEC/ERDA cost-benefit analyses. An evaluation of the principal cost-benefit analyses of the U.S. LMFBR program prior to April 1976 has been prepared for the use of the Joint Economic Committee by Mark Sharefkin of Resources for the Future.[1] This report is attached as Appendix I. In his thirteen point summary (Appendix I, p. VII), Sharefkin concludes:

> The uranium resource analyses [in these C/B analyses] exclude consideration of major determinants of future uranium resources. They are structured in such a way as to import a pessimistic bias to uranium supply productions.

Furthermore, based principally on reductions in projected demand for electric energy, Sharefkin concludes the breeder could be delayed.

Most recently, the Nuclear Energy Policy Study Group sponsored by the Ford Foundation[2] examined the economics of nuclear power in general and plutonium recycle and the breeder specifically. With respect to nuclear power in general the Study Group concluded,

> Our quantitative analysis has confirmed the conclusion we arrived at by more general reasoning: energy costs within the range we foresee are not critical to determining the economic or social future. The fears that energy scarcity will force fundamental changes in economic and social structures or the lifestyle of the industrialized world are not well founded.
>
> Specifically, our analysis indicates that the costs of delaying nuclear power would not be significant in this century, but in the next century could reach as much as 2.5 percent of annual GNP–although costs on the order of 1 percent of GNP are more likely. Even under the "High Nuclear" assumptions, there are policies that would reduce the social costs and risks of nuclear power while

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[1] Mark Sharefkin, "The Fast Breeder Reactor Decision: An Analysis of the Limits of Analysis." A study prepared for the use of the Joint Economic Committee, Congress of the United States, April 19, 1976.

[2] Spurgeon M.Keeny,Jr.et al, Nuclear Power Issues and Choices, report of the Nuclear Energy Policy Study Group, sponsored by the Ford Foundation, Administered by the Mitre Corp., (Ballinger, Cambridge, Mass.), 1977.

We can add little to this debate based on our own expertise. However, in light of the historical record, we find the arguments that present estimates are likely to be biased on the low side more persuasive than the arguments of impending shortages.

We conclude that, in light of the diminished expectations concerning nuclear power growth and the substantial possibilities for conserving uranium with only minor modifications of present day power plants, there is ample time to resolve uncertainties in the estimates of uranium resources before any urgent need for a breeder reactor can be demonstrated.

> maintaining most of the economic benefits. Plutonium recycle can be delayed indefinitely, at essentially no economic cost. Breeders can be postponed several decades into the next century at costs that are small (less than 1 percent of GNP) under the worst conditions and very small (on the order of 0.1 percent of GNP) under more likely assumptions about costs, elasticities, fossil fuel supplies, and enrichment technologies.
>
> Our analysis also shows that the benefits of nuclear power are highly dependent on the ease of reducing demand for conventional energy forms and expanding our supplies of fossil fuels. The uncertainties inherent in assumptions about price elasticities, costs, and coal production mean the economic costs of delaying nuclear power could approach the values calculated in this study or could be nearly zero.

The Study Group's economic analysis of the breeder is reproduced in full in Appendix J. The Study Group concluded:

> ... that there is little advantage in terms of economics or energy supply assurance in early commercial introduction of LMFBRs. Introduction of the breeder may be deferred for ten, twenty, or more years without seriously affecting the economic health or energy security of the United States. As long as there is a world market in low-enriched uranium, a similar conclusion appears to apply to other countries. The social costs associated with breeder introduction argue strongly for deferral.
>
> The relaxation in the breeder timetable recommended here has implications for the nature of the U.S. strategy in research and development on fission alternatives. There is time to pursue a broader research and development program on the breeders and on more efficient converter reactors. Delay will permit the development of more successful breeders should they be needed. In such a program, the Clinch River project, as presently conceived, is not necessary and could be canceled without harming the long-term prospects of breeders. In fact, a premature demonstration could even be detrimental to these prospects.
>
> It is important to continue work on the breeder, with a longer time horizon and an emphasis on its role as insurance. The goal should be to provide a range of more attractive choices at a series of decision points extending into the early decades of the next century.

One member of the LMFBR Steering Committee has stated that, while the econometric model used by the Ford-Mitre Study implies that the breeder and reprocessing were uneconomic and unnecessary, the same model with a more conservative set of assumptions indicated the opposite conclusion, namely that breeders and reprocessing would be very valuable to the nation's economy. (Transcript of the March 25 meeting of the Steering Committee, p. 79.) This reference is to a recent analysis by Manne.[3] It is well known that economic analyses of the breeder are very sensitive to a few key input assumptions, particularly: a) uranium price as a function of demand, b) electric energy growth and the nuclear capacity fraction, and c) the capital cost difference between light water reactors (LWRs) and breeders. As displayed in Figure V-1, Manne's electrical energy demand function predicts that 10 trillion kwh of electric energy by 2005, over five times the present level, and predicts furthermore that this demand would double again by 2013. Between the years 2000 and 2014, Manne projects 1500 Gw of breeders will be brought on line. Clearly Manne's projections are anything but conservative.[4] Indeed they are absurd.

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[3] Manne, Alan S., "ETA: A Model for Energy Technology Assessment," the Bell Journal of Economics, Autumn 1976, pp/ 379-406.

[4] Manne also assumed breeders will cost only 17 percent more than LWRs, whereas industry estimates of the LMFBR/LWR capital cost ratio compiled by the ERDA Cost Estimate Working Group range from 1.25 to 1.6.

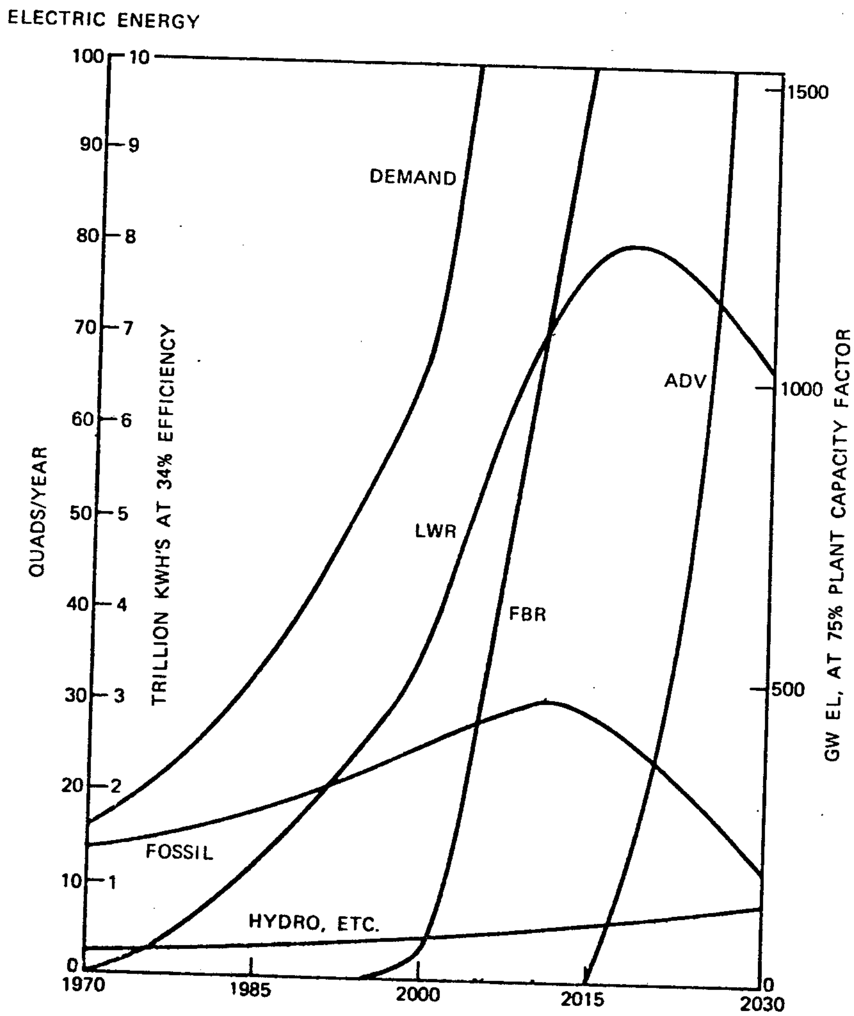

Figure V1 . Base case - electric energy demand and supply; from "ETA: a model for energy technology assessment," Alan A. Manne, The Bell Journal of Economics, Autumn-1976, p. 389.