ORAU/IEA-80-11 (P)
Proceedings



# ACCEPTABLE NUCLEAR FUTURES: THE SECOND ERA

The minutes from an IEA workshop
May 28-30, 1980
Oak Ridge, Tennessee

Morris W. Firebaugh, Editor



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The **Institute for Energy Analysis** was established in 1974 as a division of Oak Ridge Associated Universities to examine broad questions of energy policy. More specifically, it assesses energy policy and energy research and development options and analyzes alternative energy supply and demand projections from technical, economic, and social perspectives. The Institute focuses primarily on national energy issues, but it is also concerned with international energy questions and their implications for domestic energy problems.




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August 1980



Institute for Energy Analysis
Oak Ridge Associated Universities
Oak Ridge, Tennessee 37830

This views expressed herein are those of the contributors and are not necessarily those of the Institute.

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# FOREWORD

The IEA Workshop on Acceptable Nuclear Futures: The Second Era brought together some of the most prominent early workers in the field of nuclear energy to examine the state of the art and to suggest directions and criteria for designing an acceptable future nuclear energy system. Topics of discussion ranged from the technical characteristics of present and future reactor systems to the institutional issues of energy need, electrical substitution, alternative nuclear applications, and safety implications. As is frequently the case with such conferences, it was easier to identify problems with the present system than to agree on proposed routes to a second nuclear era.

The range of opinions expressed at the workshop was too broad to permit the development of a simple consensus. We have tried to reconstruct the essence of the exchanges in these edited proceedings. Several IEA participants have reviewed these minutes, but the precise wording is the sole responsibility of the workshop secretary.

This meeting marked Jim Lane's last contribution to nuclear energy before his sudden, unexpected death on June 7. His insights would have been most useful in our attempts to delineate a second nuclear era. He will be sorely missed by colleagues of a lifetime who attended the workshop.

Morris W. Firebaugh
Workshop Secretary

Alvin M. Weinberg
Director, Institute for
Energy Analysis

June 22, 1980

## LIST OF ABBREVIATIONS

| | |
|---|---|
| AEC | Atomic Energy Commission |
| ACRS | Advisory Committee on Reactor Safeguards |
| BEIR | Biological Effects of Ionizing Radiation |
| BR | Breeding ratio |
| BWR | Boiling water reactor |
| CANDU | Canadian deuterium uranium |
| CONAES | Committee on Nuclear and Alternative Energy Systems |
| CR | Conversion ratio |
| CRBR | Clinch River Breeder Reactor |
| DOD | U.S. Department of Defense |
| DOE | U.S. Department of Energy |
| EIA | Energy Information Administration |
| EPRI | Electric Power Research Institute |
| FBR | Fast breeder reactor |
| FFTF | Fast fission test facility |
| GCFBR | Gas-cooled fast breeder reactor |
| GPU | General Public Utilities Corporation |
| GWe | Gigawatt-electric |
| HTGR | High temperature gas-cooled reactor |
| INPO | Institute of Nuclear Power Operations |
| LMFBR | Liquid-metal fast breeder reactor |
| LOCA | Loss of coolant accident |
| LWR | Light-water reactor |
| MWe | Megawatt-electric |
| NASAP | Nuclear Alternative System Assessment Program |
| NRC | U.S. Nuclear Regulatory Commission |
| NSAC | Nuclear Safety Analysis Center |
| PWR | Pressurized water reactor |
| REA | Rural Electrification Association |
| TVA | Tennessee Valley Authority |

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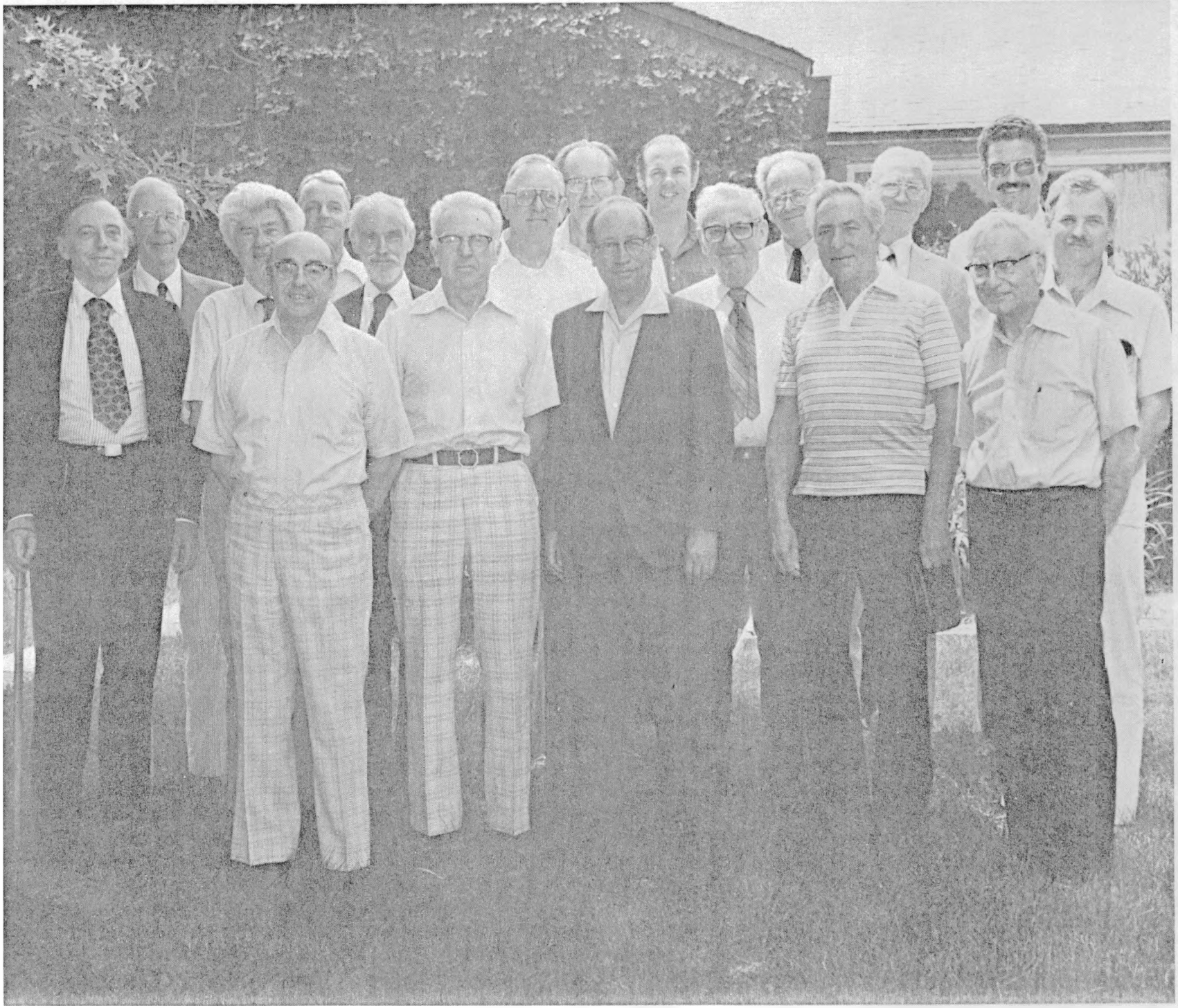
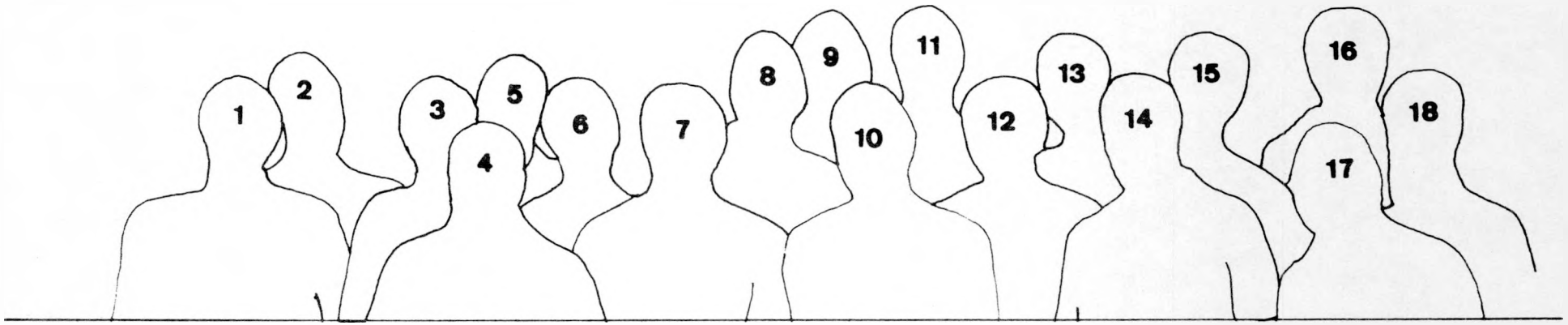


# NUCLEAR WORKSHOP

Institute for Energy Analysis
Oak Ridge Associated Universities
Oak Ridge, Tennessee

May 28-30, 1980




1. Ed Schmidt
2. Manson Benedict
3. E. P. Epler
4. Jim Lane
5. Cal Burwell
6. Peter Fortescue
7. Beecher Briggs
8. Milt Edlund
9. H. G. MacPherson
10. Karl Cohen
11. Hugh Kendrick
12. Paul Cohen
13. Irving Spiewak
14. Joe Dietrich
15. Bob Rainey
16. Morris Firebaugh
17. Alvin Weinberg
18. Uri Gat

*Ken Davis was not present for the photograph.

SESSION I

BACKGROUND AND PURPOSE

Alvin M. Weinberg, Institute for Energy Analysis

We at the Institute have been concerned for many years with the design of an acceptable future nuclear energy system. Several of you have participated in one or both of our Gatlinburg workshops devoted to this topic.[1-2]

In the United States we now have a nuclear moratorium for all practical purposes, although the recent California court decision preempting nuclear regulation to the federal government has far-ranging implications. It could allow Diablo Canyon to come on-line this summer. It seems that the only places where nuclear energy is thriving are France, Japan, and the Eastern bloc.

On a worldwide basis, the 525 reactors will soon produce 10 percent of all our electricity. However, as long as five years ago such people as Ed Schmidt were saying that the first nuclear era was coming to an end and that we must begin to design the second. The President's Commission on Three Mile Island called for a change in how we do the nuclear business, and INPO, NSAC, and the insurance pool represent the industry's response to the lessons learned from TMI. It is still not clear where NRC will come down after reordering its house.

At the Gatlinburg workshops we looked at possible institutional changes to help make nuclear more acceptable. Here we want to consider technical changes that would help accomplish this goal. Bill Stratton of Los Alamos has suggested that the China Syndrome could not have occurred at TMI even if the high-pressure injection system had been kept off.

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[1]M. J. Ohanian, ed, An Acceptable Future Nuclear Energy System, ORAU/IEA(R)77-26 (Oak Ridge, Tennessee, Oak Ridge Associated Universities) 1977.

[2]M. W. Firebaugh and M. J. Ohanian, eds, An Acceptable Future Nuclear Energy System: Gatlinburg II, ORAU/IEA-80-3(P) (Oak Ridge, Tennessee, Oak Ridge Associated Universities) 1980.

If the views of President Carter and Gus Speth prevail, we can expect no new reactor orders before the year 2000. But if public opinion turns around, new orders may roll in. Morris Firebaugh tells me the latest Harris poll shows that 50 percent of the public favors building more plants and 38 percent is opposed.

Manson Benedict, Massachusetts Institute of Technology

I think there will probably be no new breeders built in the United States during the next 20 years, but the need for breeders may become apparent sooner.

W. Kenneth Davis, Bechtel Power Corporation

We are talking about a 25-year lead-time for breeders or any new reactor system.

Weinberg

We should also consider ideas on new breeder reactors--for instance, Rickover's idea of turning PWRs into breeders. Bob Ferguson arranged for DOE to provide the seed money for this workshop in the hope that we can come up with a proposal for a technical reevaluation of reactor design.

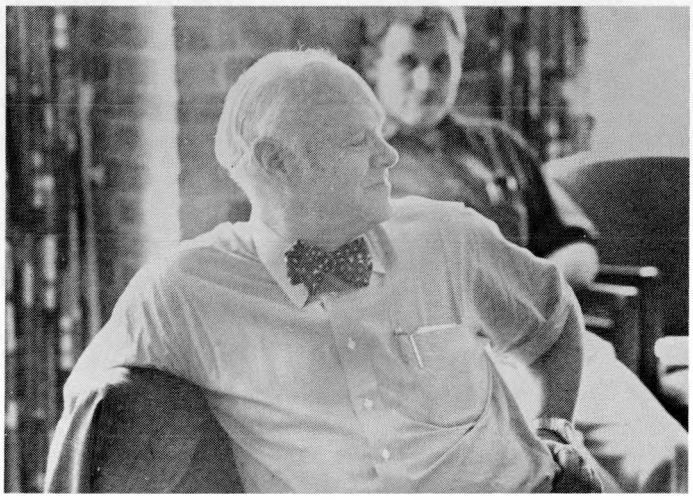
Davis

Such a study may be valuable even if examination of the alternatives leads to the conclusion that the present system is the best one.

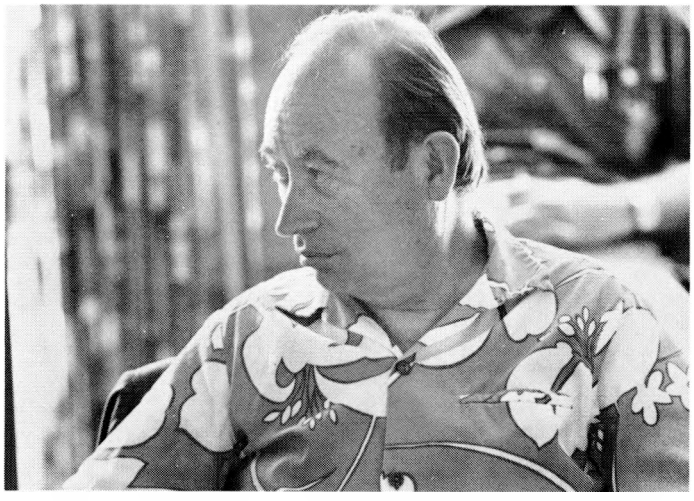
Karl Cohen, General Electric

In my analysis there are three simple reasons for the troubles in the nuclear industry:

1. The utilities have no money.
2. Because they have no money, the utilities do not want to foresee load growth.



Ken Davis



Karl Cohen

3. Again because of the lack of money, the utilities do not want to go through the whole licensing hassle.

It is clear that the utilities need oustide financial help.

Weinberg

Like a government takeover?

K. Cohen

There are two precedents for such government support--TVA and the REAs. The solution may be something like the Chrysler loan guarantee to help the utilities raise money. It may be necessary to use the national security argument--the threat of a Middle East oil cutoff.

While I was not too fond of the Nuclear Alternative System Assessment Program, perhaps we need an SASAP--a Safety Alternative System Assessment Program--to look into the safety and economics of alternative designs. It is clear that we have plenty of time to carry out the study.

H. G. MacPherson, Institute for Energy Analysis

How can the old, experienced people take a fresh look at these alternative systems? Don't we need fresh people for such a study?

Peter Fortescue, General Atomic Company

I think we would come up with the same pattern of reactor development if we had it to do over again, but now we have the advantage of a longer term perspective.

Davis

We picked the present system because we knew how to do it. It was a practical decision, not necessarily one based on the best reactor design. But we cannot ignore where we and the rest of the world are now. The United States may still have some freedom of options, but the rest of the world does not. There seems to be an emergence of the LWR in other countries, England and the USSR being the most recent. However, there is not room for

more than a handful of suppliers. Since the demand for electricity has slowed, the number of suppliers must necessarily decrease.

Weinberg

Is this the message you will be giving to the British Parliament?

Davis

I will point out that LWRs have been safe and reliable and that we have an enormous investment in people and training. Our industry could turn around and produce the LMFBR given time and adequate incentives, but fear of the China Syndrome is not an adequate or justified incentive.

Bankers are very conservative in making loans. Because they want to get their money back, they will ask, "How did the last one you built work?" The reactor business is going multinational, with sales continuing overseas. So you have to make an excellent case, including proven demand by customers and new licensing procedures, before you can move to a new reactor system.

Weinberg

Have you looked at the economics of the CANDU system?

Davis

We did a report five years ago on CANDUs built in the United States. Our conclusion was that the economics were critically dependent on fixed charge rates, which we assumed at the time were 6 to 7 percent. The CANDU has a higher capital cost, and the licensing costs would be considerable for the first reactor off the line. Someone would have to pay a large bill for the first United States CANDU.

Fortescue

How sensitive are the economics to the cost of heavy water?

Davis

Not very sensitive, but we assumed a lower cost for heavy water than its present price.

Fortescue

Of course, the Magnox system is the worst possible combination of low burn-up of fissionable material, high plutonium production, and the requirement for guaranteed customers for the plutonium produced.

Weinberg

The worst part of TMI has proven to be the $2 billion cost of cleanup, not the China Syndrome.

Davis

There were a number of problems at TMI-2. The major one is the press treatment of the accident. Kemeny himself has said he was horrified by the press treatment of the incident.

The actual economic loss has come primarily from replacement fuel costs for both TMI-1 and TMI-2. The cleanup cost is likely to be considerably greater than published estimates. The financial problems of GPU result as much from the consumption of oil by the Jersey Central system as from TMI-related costs.

In the long run, TMI may have demonstrated the validity of the basic design concepts as it seems to have done in foreign countries. The biggest single problem remains that of press distortion.

K. Cohen

Let's not create opposition where there is none.

Paul Cohen, Consultant

The fate of the LWR will be determined by the performance of present reactors and by incidents much less serious than China Syndromes. INPO and NSAC will help improve that operating record.

Weinberg

The problem is with the size of the operating utilities. A 30-reactor system has the expertise and structure for safe operation.

P. Cohen

But you still run the risk that NRC would shut down all reactors of a given type in the case of an accident in any one of them.

Davis

The financial capacity is increased for a larger utility. However, the legal, regulatory, and antitrust obstacles to restructuring the industry are great. These problems exist for coal-fired as well as nuclear operations.

Karl Cohen is right--the utilities' problems are primarily financial. The regulatory commissions will not face up to the need for revenues. Some utilities have even had to borrow money from their local banks to pay their coal bills.

MacPherson

For years, electric bills were falling and everything was fine. Now that costs are rising, customers complain.

P. Cohen

The state of Pennsylvania recently made two noteworthy decisions: They decided not to lift the TMI operating license, and they granted the rate increase to GPU to help cover increased costs. I think we should distinguish between how things are likely to go and how they ought to go. I disagree with Ken Davis on the degree to which the press deserves blame. NRC was responsible for much of the problem. They based all their analyses on worst-case studies. While Harold Denton was reporting that the hydrogen bubble was dangerous, Ed Zebroski was standing right beside him saying that it was no problem.

Milton Edlund, Institute for Energy Analysis

After reading about the bubble in the newspaper, I was able to calculate in a few minutes that it was no problem.

Weinberg

I sense that no utility executive really felt that the TMI accident was possible before it happended. If nuclear energy can survive TMI, TMI may save the industry.

Fortescue

There are two very important lessons to be learned from TMI. First, it is much more difficult to protect the plant than it is to protect the public. Second, a protracted cleanup operation keeps the problem before the public.

One meltdown accident would kill the industry. Our emphasis should be on preventing protracted incidents.

Davis

TMI presents the spectacle of a hazard whose correction is actually being impeded by NRC.

P. Cohen

Only the President can override NRC on this issue. Even the Governor of Pennsylvania has come out in favor of venting the krypton gas.

Davis

The governor also says that Mr. Pollard of the Union of Concerned Scientists is creating the residents' psychological problems, not just reporting them.

Weinberg

Perhaps we should return to technological issues and what the criteria for new systems should be.

Fortescue

The first criterion should be avoidance of protracted problems and assurance of plant protection. This will automatically assure the protection of the public.

If I felt that nuclear energy was just a stopgap until the sun warms us all, I would join Jane Fonda in the antinuclear crusade. It may even be that fusion is the second greatest enemy of nuclear fission energy because the average man on the street believes that fusion has no associated radioactivity. In distinguishing between short- and long-term options, we must study these alternatives.

MacPherson

The public actually believes that solar is a viable alternative to nuclear power.

Weinberg

It is not just the public--Sweden recently published a study on solar versus nuclear. Gunnar Myrdal wrote the preface.

Fortescue

If nuclear fission is just a stepping stone to another long-term energy source, then we should drop it.

Weinberg

Even Eugene Wigner has stated this.

Fortescue

Either we must develop a system that does not rely on breeder reactors or we must put breeders with a high breeding ratio (such as the Russian breeder, with a reported BR of 1.5) in enclaves that provide fuel for 9 or 10 burner reactors as satellites.

Davis

The need in the rest of the world is not for large nuclear parks but for satellite reactors. The decisions of other countries are driven by economic as well as technical considerations. The British cannot afford to build a breeder until they get a partner, even though they have a beautiful design.

Edlund

I believe that we can take an evolutionary approach to the problem and that we should look at the PWR to see what can be done. We have calculated doubling times in the range of 15 to 20 years for PWRs with a tight lattice and heavy-water cooling. We can improve the conversion ratio according to the economics of fuel availability, and in time we may want to build relatively small breeders.

My calculations show that we can build a 500-600-MWe integral steam supply reactor similar to that on the "Otto Hahn" for about the same cost per kW as present 1,000-MWe reactors. In studies for the Electric Power Research Institute we did a complete double-ended guillotine break LOCA and got lower temperatures in the core than for an equivalent accident in normal PWRs.

The cost to the industry may even be smaller than that for present reactors because of reduced size and corresponding interest costs. We may also be able to put such fuel-efficient reactors in other countries.

Weinberg

You may recall that Eugene Wigner claimed the breeder would arrive in one of two ways--full-blown as a brand new technology or gradually through an evolutionary process. I gather, Milt, you feel the evolutionary approach is feasible. This was also the approach Admiral Rickover tried.

Fortescue

Admiral Rickover's mistake was in pushing for a breeding ratio of 1.05 rather than settling for a conversion ratio of 0.9.

Weinberg

No law of nature says LMFBRs are ordained. Milt is saying we ought to look at modifying the LWR.

K. Cohen

We cannot, as a collegial group, decide on particular reactors, but perhaps we can decide on criteria to be used in selecting future systems.

Davis

Framatome is designing smaller reactors in the 300-500-MWe range for export to smaller countries.

Edlund

To summarize my position, I think that 1) changes from the present system will be evolutionary; 2) other designs will be safer; 3) the size can vary but will be in the range of 300-500 MWe; and 4) the present LWRs can be modified for breeding.

E. P. Epler, Institute for Energy Analysis

Several years ago, Dave Okrent, then at Argonne National Laboratory, reviewed the design of the LWR and concluded that the China Syndrome was in fact possible. Milton Shaw of AEC concluded that it was an industry problem rather than a problem for analysis by the national laboratories. The solution was to install large, complicated protective features.

An important principle of any safety device is that you must be able to exercise and test it without endangering the system being protected. The trouble today is the interaction of the safety features with regulation.

For instance, safety features designed to prevent a China Syndrome may cause water releases onto the floor of the reactor. This in turn creates a poor press image.

NRC is considering a hot line to each plant, with actual plant conditions continually monitored in Washington so that NRC can answer questions from governors. As NRC guidelines continue to change, Zion and Indian Point are actually worrying about closing down. After Sequoyah carried out the 5-mile-radius evacuation drill, the guidelines were increased to a 10-mile radius.

In summary, I would say that the problem is the interaction of safety features, government regulation, and the press.

Weinberg

One criterion for any future system should be a provision for allaying public fears by promoting better understanding of the facts.

P. Cohen

In the past, industry generally has solved its problems in private.

Weinberg

My perception is that there may be a swing away from the hypochondria associated with radiation danger.

P. Cohen

But NRC's attitude is the problem.

Fortescue

Experience shows that you must bend the rules to run a railroad. In England, workers have found they can bring the whole system to a grinding halt by "working according to the rules" rather than striking. This tradition is not an appropriate one for the nuclear business.

Davis

The problem is that any new reactor system must meet all of the old rules as well as the new ones.

P. Cohen

I worked on licensing the first chemical shim reactor. That plant would not pass licensing inspection now.

K. Cohen

The Kemeny Commission pointed out that the problem was in following rules, not in safety. If the government ran nuclear plants, we would not have to license them. My suggestion is to let the present system die away and start a new one.

MacPherson

Some years ago reactor manufacturers had over 50 orders for large reactors (about 1 GWe) before a single plant of this size had operated. So the normal procedure of incremental improvements was lacking. Customers for these reactors could not direct the product; they had to accept the product. Only NRC and ACRS could suggest safety improvements.

I will pass out an ORNL report[3] that contains ideas on improvements which could increase safety by a factor of 1,000. I see the TMI accident as vindicating the safety of present reactors, but I am not totally satisfied that everything is being done to improve safety that could be done. For instance, the hydrogen bubble proved to be no problem. But the hydrogen that collected in the containment did burn, producing a pressure burst in the containment building, and this was not expected.

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[3]O. H. Klepper and C. G. Bell, Underwater Corrosion Containment of Large Power Reactors, ORNL-4073 (Oak Ridge, Tennessee, Oak Ridge National Laboratory) 1967.

Weinberg

Are you saying that safety improvements result primarily from pressures outside the industry?

MacPherson

I suspect that even more improvements result from "unannounced" actions by industry.

K. Cohen

This problem is structural in the organization of the industry.

Davis

The question naturally arises, "What if we had no NRC?" I suspect that reactors would probably be simpler, all real safety features would probably be present, and the result would probably be safer reactors.

I think the real danger is the belief that NRC is responsible for safety. Unfortunately, this belief is still growing. At Bechtel, anyone who believes this gets fired.

Weinberg

Isn't there a conflict between "as cheap as possible" and "as safe as possible"?

P. Cohen

My position is that the operator is ultimately responsible for safety.

Joseph Dietrich, Combustion Engineering

I would take the position, "Don't pay attention to NRC--rather, make reactors safe."

Fortescue

I think we must answer the question, "What is the probability of cutting the Gordian knot by such a technical reactor study?"

Weinberg

Beecher, several years ago you said, "I'm uncomfortable because the reactor business is going too fast."

R. Beecher Briggs, Oak Ridge National Laboratory

First, one must decide whether nuclear fission is an interim or long-term energy option. If we decide that it is a long-term option, then we must decide on a particular type of breeder.

On the safety issue, I agree with MacPherson that if we had had no NRC or ACRS we would have had serious accidents long ago--probably more serious ones than TMI. This is in part because NRC had the people the utilities did not have and in part because they made the vendors think about safety.

Adverse publicity will continue as long as Licensee Event Reports are required.

In terms of the goals of this workshop, I think we should first look at what nuclear energy can do in the future, i.e., potential applications. Then we should examine what characteristics are required of reactor systems to meet these demands.

Epler

In the commercial airline business, the fatality rate decreased asymptotically during the last 20 years from 10 deaths to 1 per 100 million passenger miles. This asymptotic limit seems to be due primarily to pilot error, and nuclear institutional or regulatory procedures will also have asymptotic safety limits based on operator error.

Briggs

NRC should provide guidelines and monitor safety; it should not be responsible for the safety of plants.

Weinberg

DuPont puts high school graduates at the controls of its Savannah River reactors, but it also has many MIT engineers available to back them up.

Benedict

I think that our energy needs will continue to grow and that a major fraction of that growth will be electrical. Coal and nuclear energy are the only available options for producing that electricity. I do not expect solar photovoltaic to become economical. I would estimate that fusion has about a 25 percent chance of success. And I agree with the CONAES study on the availability of uranium resources.

I feel that the heavy-water reactor with plutonium recycle may prove feasible and that the CANDU on a thorium cycle is a possible longer term option. I like the HTGR, and I believe the LMFBR on a combined uranium-plutonium cycle should be kept in the picture because of its high fuel efficiency. All of these cycles require reprocessing, and all are advanced enough to prove feasible. The government should continue to support the development of all of them, although I do feel the molten-salt reactor is too remote a possibility to support. In any case, we must go ahead with reprocessing.

K. Cohen

Again we come back to institutional arguments. The government has essentially abandoned support of LWR development. This year the budget for LWR development is about one-fortieth that of the combined budget for solar, fusion, and LMFBR development. We need a new relationship in this area.

Weinberg

How would these ground rules and criteria be factored into a new study of the type we are discussing?

Davis

The money for the study must come from the government.

MacPherson

The utilities, as normal corporations, would plow back money for research.

Fortescue

I would disagree with Ken on the safety responsibility of NRC. The FAA, for example, should have been responsible for the safety of the DC-10. The FAA knew of the problem but decided not to worry about it until the accidents had occurred.

Weinberg

At the first Gatlinburg workshop the utilities were totally unwilling to change institutional procedures. By the time of the second Gatlinburg workshop (post-TMI), INPO and NSAC had been established and accepted by all United States utilities.

P. Cohen

The Russian reactor sold to Finland has a United States containment structure. Some call it the Eastinghouse reactor.

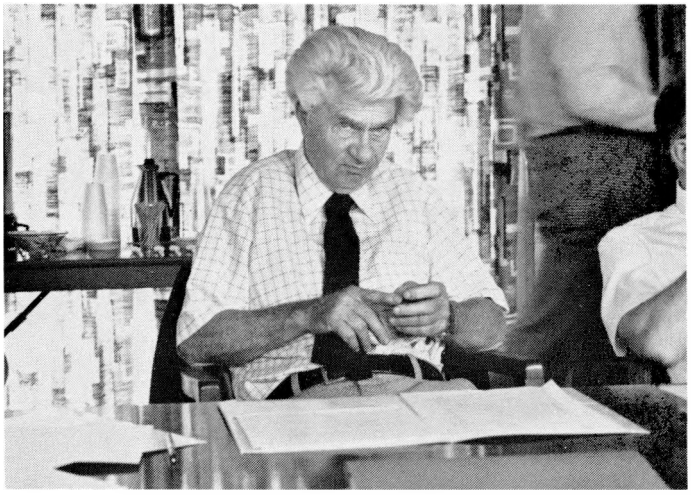
Fortescue

The Fort St. Vrain HTGR was without cooling for half-hour periods on three separate occasions. In every case the heating rate was precisely in agreement with theoretical predictions. We were fortunate to get these unanticipated verifications of the "forgivingness" of HTGRs and to realize that the vendors simply overestimate the capability of operators to control all possible events.

MacPherson

We should discuss the use of reactors for process heat. Since reactors can produce electricity for process heat applications, we can have process heat with no consumption of coal, gas, or oil, and without the attendant pollution.

Manson Benedict  Beecher Briggs



E. P. Epler

On the issue of the LMFBR, I feel the capital costs and perception of safety will make introduction of this system extremely difficult. However, we need to talk about the institutional changes necessary for the introduction of the breeder.

Dietrich

Vendors themselves believe that nuclear power will continue for a long time. Vendors are willing to spend money on the breeder, and they know they must pay the bill for continued development after a new reactor system is introduced. It's the R&D that breaks your back.

If possible, we must get rid of the China Syndrome--although we cannot solve the perception problem on this issue. I think the LMFBR faces a very serious problem conceptually because the hypothetical disruptive core accident will always be lurking in the shadows. The technical approach to this problem has been to prevent it--but this has not worked on the public perception front.

Even though NRC has required some procedures that were not cost-effective, they did enforce standards that prevented cost cutting by vendors.

Davis

It is not that we don't need NRC. It is just that they confuse safety with paperwork.

Irving Spiewak, Oak Ridge National Laboratory

I believe three possible goals of such a study are as follows:

1. If there is to be a second generation of reactors, LWRs will be its starting point. Therefore, one goal should be to design LWRs with more forgiving properties.

2. For the intermediate period (50-75-year time frame) we should look at the near breeder with advanced recycle, such as Milt Edlund and Admiral Rickover have proposed. The study would have to address such institutional questions as how to modify NRC to make it work more effectively.
3. For the long term, the study should examine various breeder designs.

## SESSION II
## LIMITS ON THE DISPLACEMENT OF OIL

P. Cohen

The paramount criterion in selecting any future system must be the issue of fuel assurance. Next, the study should examine the contributions nuclear energy can make to other social needs. This may involve, in the synfuels program for example, looking at what fraction of the raw material contributes energy and what part contributes actual product. I suspect that electrical energy will be an important part of such programs. My major concern is with the institutional problems nuclear energy faces today.

Weinberg

We also have to worry about the public's perception of nuclear risks. Paul Slovic's study[1] shows that the public has a greatly exaggerated estimate of the effects of a catastrophic nuclear accident.

James Lane, Institute for Energy Analysis

I would agree with Manson Benedict that the only really feasible source for meeting growing electrical demand is nuclear. But I think any new reactor system is highly improbable, with the possible exception of the LMFBR. I believe the evolutionary modification of the LWR is the best route to the next generation of reactors.

Fortescue

We all agree that we can make the LWR safe, but will the public perception of safety necessarily follow?

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[1] Paul Slovic, Sara Lichtenstein, and Baruch Fischhoff, "Images of Disaster: Perception and Acceptance of Risks from Nuclear Power," in Energy Risk Management, G. Goodman and W. Rowe, eds (London, Academic Press) 1979.

Weinberg

Let's turn now to the main topic of this session--the extent to which nuclear energy can substitute for oil. Cal, you have some information on the potential for further electrification.

Calvin Burwell, Institute for Energy Analysis

We have been doing some work for W. L. Lewis of DOE on the potential for switching from petroleum to electrical applications in case of an emergency oil cutoff. Some of the findings are interesting and contrary to the generally held image of electricity as an inappropriate form of end-use energy.

For instance, the provision of heating for the average house in the United States requires 102 million Btu of natural gas, 182 million Btu of oil, but only 34 million Btu of electrical end-use energy. This is because the average gas home-heating system is only 50 percent efficient (not 60 to 70 percent, as is sometimes suggested), and with electrical heat one has room-by-room control. In 1978, 56 percent of the nearly two million new home installations in the United States went with electrical heat; somewhat less than half of these used heat pumps.

Another finding not generally recognized but essential for predicting future electrical demand is that residential electrical applications are far from saturated. This point is illustrated in the following two figures and in Table 1. In Figure 1 we show the "pre-energy-crisis" projections by Tansil[2] of ORNL in 1973 for residential electrical demand, along with the subsequent data showing that even with substantial progress in home energy conservation, residential demand for electricity has not abated. The reason for this growth is apparent in Figure 2, which shows the percentage of households with electrical heat, water heating, and air conditioning. The data from the Energy Information Administration show a substantial increase in market penetration for major electrical appliances since, and presumably

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[2] John Tansil, Residential Consumption of Electricity, ORNL-NSF-EP-51 (Oak Ridge, Tennessee, Oak Ridge National Laboratory) 1973.

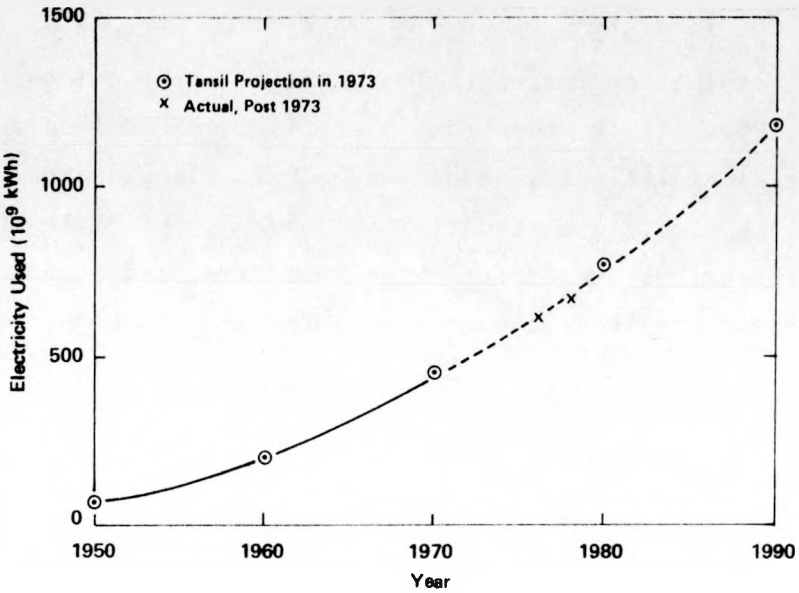


FIGURE 1

RESIDENTIAL ELECTRICITY USE

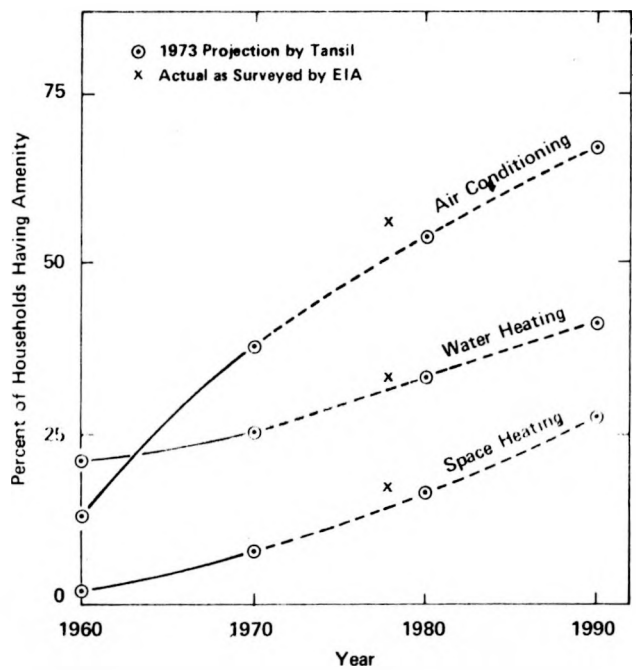


FIGURE 2

MAJOR ELECTRICAL SERVICES IN RESIDENTIAL SECTOR

as a result of, the 1973 oil embargo. In Table 1 we present data on the saturation of several other residential electrical applications and our projections for 1990. It is clear that there is room for considerable expansion of residential electrical demand. It is also clear that the introduction of the electric automobile will have a negligible effect on the growth rate of electrical demand for quite some time, and it will not be a particularly large energy user compared with residential electric devices already in use.

P. Cohen

The best and cheapest way to eliminate our foreign oil dependence would be for the government to subsidize the conversion to electric cars. It would cost $3,500 per car for 1,000,000 cars per year for 10 years. That's $3.5 billion per year compared with the $70 billion per year we now pay for foreign oil.

Fortescue

The ordinary internal combustion automobile is only about 5 percent efficient because of losses from idling, etc. We could greatly decrease our oil dependence by moving to the hybrid car, which achieves 30 percent efficiency through electrical drive and efficient on-board gasoline powered motors for continuous recharging of the batteries.

P. Cohen

There is a real problem with supplying enough materials to produce that many batteries.

Burwell

General Motors intends to introduce the electric car in 1984 and expects it to represent 10 percent of the GM production in 1990. It turns out that 60 percent of gasoline consumption is in urban commuting and 40 percent in interstate driving. Much of this commuter travel could readily

TABLE 1

PRESENT AND PROJECTED RESIDENTIAL USE OF ELECTRICITY

| | 1970 | | | 1990 | | |
|---|---|---|---|---|---|---|
| Use | kWh/House | % Saturation | $10^9$ kWh | kWh/House | % Saturation | $10^9$ kWh |
| Heating | 14,600 | 8 | 69 | 15,000 | 32 | 475 |
| Room AC | 1,950 | 27 | 33 | 1,850 | 41 | 75 |
| Central AC | 3,650 | 11 | 25 | 3,400 | 36 | 121 |
| Water | 4,500 | 25 | 71 | 4,300 | 64 | 272 |
| Refrigerator | 1,300 | 100 | 82 | 1,500 | 100 | 149 |
| Clothes drier | 990 | 24 | 15 | 1,000 | 65 | 64 |
| Dishwasher | 360 | 19 | 4 | 350 | 60 | 21 |
| Freezer | 1,380 | 23 | 20 | 1,300 | 46 | 59 |
| Cooking | 1,175 | 40 | 30 | 1,150 | 65 | 74 |
| Automobile | 0 | 0 | 0 | 2,500 | 3 | 7 |
| Other | 1,250 | 100 | 77 | 1,280 | 100 | 128 |
| Total | | | 426* | | | 1,445 |

*670 billion kWh in 1978

be switched to electric vehicles. If all ground transportation (i.e., cars, trucks, and mass transit) switched to electrical drive, electrical demand would be increased by only 200 GWe.

Weinberg

I sense that the doctrinaire arguments against electricity based on the Second Law morality are weakening.

Davis

Why argue the Second Law of Thermodynamics when the real issue is imported oil?

Weinberg

The Carter administration and DOE are beginning to realize this and are making explicit plans for substitution of this type. Henry Linden says it is possible to divert all nontransport use of oil to other sources. The climate is now congenial to this type of thinking.

Davis

The San Francisco Chronicle reported on a memorandum from Secretary Duncan suggesting more emphasis on nuclear and coal and less emphasis on solar energy.

Benedict

Another important area in which nuclear energy could be substituted for fossil fuels is that of industrial process heat production. In the industrial park concept, the reactor would supply heat at various temperatures for a variety of industrial applications. A large nuclear heat source such as a 3,000-megawatt-thermal HTGR could be used for coal to methane conversion. At present, using coal for fuel, the coal to methane conversion is only 55 to 60 percent efficient. With nuclear fission providing the process heat, this conversion efficiency would reach 90

percent. Such a conversion plant could process 33,000 tons of coal per day to yield 750 million cubic feet of methane gas. This process would require heating the working fluid (helium gas in this case) to the range of 1,000 to 1,200°C.

Spiewak

I think the process could operate in the range of 900 to 1,000°C.

P. Cohen

This would minimize not only the actual consumption of fossil fuels but also the associated problems of mining, waste production, and $CO_2$ production.

Davis

There is a great deal of underground water available, but much of it is brackish. About half of the water consumed in conversion plants goes into hydrogen generation for the production of methane. It may be necessary to pipe water some distance in certain areas.

P. Cohen

Jones & Laughlin Steel of Pittsburgh have closed down blast furnaces and are switching over to electric furnaces.

Spiewak

The optimum process for steel involves synthesis gas plus electric furnaces.

Davis

Another potential industrial application of electricity is the production of microwaves used to release oil from shale. At the Orinoco tar sands in Venezuela, for example, 50 percent of the oil produced is used to generate process steam that is pumped underground to release additional oil.

In this case we could trade nuclear heat directly for oil. And these tar sands are immense--several hundred square miles in area and 400 to 500 feet deep.

K. Cohen

There are two important features of such applications. First, the scale of these uses is appropriate for reactors. Second, the institutions operating them are not utilities, so it may be possible to avoid the suspicion of the present institutional structure. There is a certain attraction to converting nuclear energy directly into gasoline.

Davis

In southern California they are already producing 300,000 barrels of heavy crude per day.

Weinberg

Would we rather have reactors run by oil companies or by local gas and electric utilities?

Davis

The oil companies plan for a 20 to 25 percent profit for speculative ventures like synfuel production. If they do not plan for a profit in this range it becomes difficult to realize even a 10 percent profit.

Fortescue

There may be a limit to such direct nuclear industrial applications set by adoption of the linear man-rem hypothesis and postulated contamination of the final product. In terms of straight electrical production, the HTGR with a bottom cycle yields a 50 percent efficiency, which is comparable to the best cogeneration system efficiencies. The high efficiency makes the use of electricity for process heat applications more plausible.

Davis

Even though there have been at least a hundred studies on nuclear process heat applications in the past, the time may now be right for another one.

Weinberg

Cal and Irv have worked on this problem. Do you feel any of these industrial applications are feasible?

Spiewak

Yes, there is a good potential in those situations where there would be a 1-for-1 substitution of nuclear energy for oil. But the question seems to be, Should it be direct heat or electric heat?

Fortescue

Japan is going to the HTGR for process heat at 1,000°C in steel making and similar processes.

Davis

What we are saying is that, even apart from increased electricity production, industrial application may be a driving force for new reactor development. But I doubt that it will be the central one.

K. Cohen

I think we should try to change our image by making gasoline from nuclear energy. People like gasoline but hate the utilities.

Davis

Where do you see reactor orders coming from in the next five years?

K. Cohen

Bills are now in Congress for aiding in synfuel production. Nuclear reactors could fill a role here.

Hugh Kendrick, Department of Energy

Only the nuclear people want to hook nuclear to the synfuel program. The synfuel program has had an awful job just getting underway as it is. The Department of Energy may get some money for HTGR development, but we do not want to get caught in the Clinch River situation in which Congress tells us we have to spend all our money on LMFBR development.

Fortescue

In the United States we now have too much electrical capacity, so I expect the shift will be from oil to nuclear. The HTGR nicely fits both the temperature requirements for process steam and the safety features such a system should have.

Kendrick

How far into the future are we looking?

Weinberg

We are now effectively in a nuclear moratorium. Let's assume the first nuclear era will run its course through the year 2000. Is that really enough time to consider a new system? I think the general consensus here is that developments must be incremental.

We should discuss at least briefly Class 9 accidents (core meltdown with significant release from containment) and the effect of the linear hypothesis on consequence calculations. As you know, a one-dose exposure of 300 rads or more will cause severe sickness or death. But the CONAES study calculates 45,000 latent cancers from a Class 9 accident based on 5,000 man-rem per cancer plus the linear hypothesis. The linear hypothesis assumes that the risk from radiation is independent of both individual dose and dose rate, and depends only on total accumulated man-rem exposure. It turns out that the 45,000 figure is the result of integrating extremely low doses over a large population.

Edlund

If you assume the exposed population gets an additional 40 man-rem per year for 30 years, you arrive at the 45,000 figure. I think a more reasonable number is on the order of 1,000 additional deaths from the Class 9 event.

Weinberg

The Lewis report for the American Physical Society postulates that the average individual exposed in a Class 9 accident gets 7 rads during his lifetime, or approximately 100 to 200 millirem per year. The BEIR Committee in the forthcoming BEIR III report says that it is impossible to determine the effect of exposures below 10 rads.[4]

MacPherson

The Stewart-Kneale retrospective study[5] found that of children who later developed cancer, 15 percent had been x-rayed in utero. Of the children used as a control group, 10 percent had been x-rayed in utero. Based on these data, they conclude that the fetus is much more susceptible to radiation damage than are children at later stages.

This is the single most important study on which this widely held assumption is based. But the study is fundamentally flawed because the control group and the cancer group were two entirely different populations. Prospective studies in which the control group and the exposed group are drawn from the same population before the effect appears are considered much less prone to error and bias.

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[4] National Academy of Sciences, Division of Medical Science, Biological Effects of Ionizing Radiation III (Washington, D.C., National Academy of Sciences) 1980.

[5] Alice Stewart and G. W. Kneale, "Changes in the Cancer Risk Associated with Obstetric Radiography," The Lancet, January 20, 1968, pp. 104-107.

P. Cohen

I would claim that from the viewpoint of public attitude it does not make much difference whether the number of induced cancers is 45,000 or 1,000.

Kendrick

We certainly must do comparative risk analysis in accurately assessing nuclear energy, but we must be careful not to define away the problem. This approach would arouse even more resentment among the public than we see now.

P. Cohen

Ken, how much would it cost to redesign the PWR ab initio?

Davis

Quite a bit.

K. Cohen

I would say it would take 200 men two years. For 400 man-years you come up with a figure of $40 million.

Kendrick

Just two years ago Tom Cochran proposed this idea.

Davis

The present overall PWR design could be used, modified as needed to incorporate required safety features, and simplified wherever possible.

Epler

Who would decide whether the system was safe enough?

Davis

Eventually that would be done by NRC.

Briggs

Plant operators should be included in doing the design.

## SESSION III
## THE CASE FOR THE LIGHT-WATER REACTOR

Weinberg

I would like to review yesterday's discussion as the background for looking at the LWR and to bring Ed Schmidt, who has just arrived, up to date. As you recall, Ken Davis suggested that a critical review of reactor technology would be a good idea, even if the result is that the LWR still proves to be the best bet. The question was raised as to whether the breeder will appear full-blown as a completely new technology or incrementally through such techniques as a heavy-water-cooled FBR.

Peter Fortescue suggested that, on the safety issue, it is much easier to protect people than equipment. TMI demonstrated the great need for a capacity to recover quickly from such incidents. Paul Cohen stated that until now decisions have been categorized in terms of danger to the public rather than damage to equipment, which has been given second priority. It is now clear that damage to equipment does cause public concern.

At the heart of the discussion is the "electrical paradigm," which postulates that we replace all nontransport liquid fuel use with electricity, a part of which will be nuclear. Henry Linden has similarly proposed that all nontransport demands for oil be replaced by other forms of energy.

Karl Cohen pointed out that nuclear process heat applications may provide a way to bypass the institutional structural defects in nuclear energy utilization. We always come back to the claim that NRC is strangling the utility industry, but Mac and Beecher say that we would have had TMI long ago without NRC. The criticism lies in the assumption that "Safety is what NRC says it is."

P. Cohen

We used to say, "The job is as good as the customer."

K. Cohen

Utilities are frequently penny-wise and pound-foolish.

Dietrich

The most dangerous feature in the industry is the lack of communication across the interfaces between the vendors, the architect/engineers, and the utilities.

Weinberg

We always veer back to institutional problems. They place the boundary conditions on any possible technical fixes.

Fortescue

There is no question of the survival of nuclear power on a worldwide basis. The question is whether there will be "followership," let alone leadership, of the United States in the enterprise.

Ed Schmidt, Consultant

I have just returned from visiting the Cofrentes reactor station near Valencia in Spain. In my comments I am not going to use any words like "reactor type," "power density," or "coolant." In the early 1970s I became convinced that the first nuclear age was over. I had worked on plane procurement with the Air Force and with Tom Paine on the moon landing program. Producing a nuclear power reactor was far more difficult than procuring a plane for the military or even going to the moon. My friends in DOD laugh at how we do nuclear power--we cannot do it on a low-bid basis or even a profit-and-loss basis. I became convinced that the nuclear industry as constituted could not work.

I was exposed to the early work on BWRs for General Electric. Based on my experiences visiting a great number of reactors throughout the world, my guess is that we may see a TMI-like accident every year or so. The Germans seem to do a better job with nuclear energy than we do. Siemens and Kraftwerk Union build better plants than we do because they have better institutional structures.

The energy problem in the United States, Europe, and Japan is not a shortage of electricity but of motor fuel.

I won large bets on the collapse of Iran, and I expect to win even larger bets when Saudi Arabia collapses. My prediction is that the half-life of oil flow from the Middle East is on the order of one to two years.

MacPherson

What will happen when the oil is cut off?

Schmidt

The Joint Chiefs of Staff will be responsible for oil allocation, and the available fuels will be allocated in approximately this order:

1. The Japanese self-defense force will get first priority.
2. The NATO forces will then get all the gasoline they need.
3. The United States ships will be mobilized, fueled, and moved to the Indian Ocean. Our military needs will double or triple from the present one quad per year.
4. Any remaining fuel will be allocated domestically.

To revive the nuclear industry, we must go the DOD route. We should procure reactors like we do big bombers.

K. Cohen

Look at how the LMFBR is being procured.

Briggs

That is why it is not being procured.

P. Cohen

It is not being procured because of projected cost. You have to look at the economics of the LMFBR.

MacPherson

The scenario of the CRBR went as follows: First, AEC requested designs from vendors. Then politics entered, and the project was split up so that

everyone got a chunk of the action. I am not convinced that the resulting product is as good as the PWR. The individual components are high quality, but the overall concept does not impress me.

Weinberg

The structure of the industry is about as wrong as possible for doing nuclear. Industry cites the creation of INPO and NSAC as a big step forward in solving the structural problems, but I and many of my fellow "think tankers" feel it may not be enough.

I think we should now turn our discussion to some of the specific technical considerations of the LWR. Ep, will you give us your feelings on the safety issue?

Epler

I have documented a number of incidents of common mode failures in reactors and have a paper to distribute on this subject by my favorite author.[1] The real questions are, What has been learned from these experiences? What are we going to do about it?

My conviction is that the major safety problem is how to get the heat out after a reactor scram. For controlling and protecting the fission process itself, we have separate systems that are of high quality and highly reliable. But for the more mundane job of getting the heat out we rely on the same system for control and protection, and it is built around much lower quality, off-the-shelf equipment. Our philosophy has been "we will let the operator worry about it," but we all know how disastrous the public struggles of operators proved to be at Three Mile Island.

What we need is a dedicated heat removal system separate from that used for control.

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[1] E. P. Epler, Common Mode Failure of Light Water Reactor Systems: What Has Been Learned, ORAU/IEA-80-7(M) (Oak Ridge, Tennessee, Oak Ridge Associated Universities) 1980.

MacPherson

Do we have dedicated safety instrumentation on LWRs?

Epler

To a certain extent, but it is not a completely independent system.

P. Cohen

I think we have to keep in mind the fact that the LWR is now a committed system. The future depends on the operation of present plants and those presently under construction. Certainly NSAC and other utility initiatives should be used to improve the operation of current reactors.

Therefore I think the most constructive approach or program would be as follows:

1. Assume nuclear power will survive (if it doesn't, it's all academic anyway).
2. Recognize that it takes a crisis to get any decision or action on energy policy.
3. Emphasize the need for assurance of the nuclear fuel supply.
4. Then consider other applications, such as nuclear process heat for synfuels, etc.

Weinberg

I guess the critical question on the survival issue is whether another TMI-like accident is likely. I take it that Ep and Peter believe it is, but Manson and Paul do not. How about you, Beecher?

Briggs

I do not believe it will happen.

P. Cohen

I will not make an absolute prediction. Arkansas-1 kept running after a seal failed because the dispatcher needed power.

K. Cohen

There are two separate problems here: how to improve the operations of present plants and how to design better second-generation plants. I think we should deal with the second problem.

Weinberg

But if the probability of a TMI-type event is really 0.002 per reactor-year, we will have more such accidents.

Fortescue

The number of reactors to use in such a calculation must be the number worldwide. There is an opportunity for a study on how to improve the safety and operation of present systems. If the sum total of the improvements identified in the study results in major retrofitting to achieve the desired increase in safety, then we ought to design a new system.

There are two generic technical questions that should be answered:

1. Is a system that must be kept pressurized long after shutdown the right one?
2. Is any metal pressurized system appropriate in light of long-term metal embrittlement due to radiation?

MacPherson

I think we should ask, What would we do if we started over from scratch in light of what we have learned from operating the current 175 reactors worldwide? We should set down criteria for a new ideal reactor. These must include 1) normal operating procedures, 2) safety considerations, 3) abnormal operating procedures, and 4) design planning for the sequence of events that would occur if there were a fuel melt.

Fortescue

The criteria should include the time required to fix the reactor in case of an accident.

MacPherson

And the procedures to be used for cleanup.

Epler

The reactor should be designed so that the operator could bring the reactor up to full power, leave the control room, lock the door, and open the circuit breaker--all with safe, automatic shutdown. Such a reactor exists, but it's not an LWR.

P. Cohen

If I felt there were a finite probability of a big accident with serious off-site consequences, I would be antinuclear.

Weinberg

The Reactor Safety Study[2] put the probability of a Windscale-type release of 20,000 curies at 1 in 20,000 reactor-years. Do you believe this, Paul?

P. Cohen

I do not put much stock in such studies.

Kendrick

Should there be another reactor system? If so, should it be a competitor or a successor of the LWR?

Weinberg

Are we already so wedded to the LMFBR that we should abandon the incremental approach to the breeder? Mac, what do you think?

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[2]Reactor Safety Study, WASH-1400, NUREG-75/014 (Washington, D.C., U.S. Nuclear Regulatory Commission) October 1978.

MacPherson

I taught a course on the LMFBR from 1960 to 1966, and during that time the attractive features claimed for it gradually deteriorated. Two of the initial attractions were:

1. The LMFBR provided economy from fuel savings, with only a slightly higher capital cost.
2. The higher operating temperature of the LMFBR provided a higher thermal efficiency than the LWR--on the order of 40 percent.

As experience was gained with the CRBR and more recent studies, these advantages disappeared.

I simply do not believe the projections that we can bring the costs of the LMFBR down from the present estimates of 2 to 3 times that of the LWR to a figure of 1.3 to 1.4. If the LMFBR costs 1.75 times the LWR, the price of uranium would have to rise to about $300 per pound for the breeder to compete. The American design calls for degrading the efficiency from 40 percent to 33 percent. The people from the LMFBR project did not publicly announce these higher costs until several years after they became aware of them. This might not be important if breeder deployment did not depend on the utilities. It might not be important in France, where they know they need the breeder and can spread costs over the rest of the system.

One can provide adequate safety by ingenuity, but there seems to be resistance to the idea that a core melt can happen. The CRBR has filtered release if the core melts because in that case one could not provide cooling.

K. Cohen

On the economics of the breeder--I was there when we wrote the report. We said it would cost 25 percent more than the LWR, which would be justified by savings in fuel costs, but this was when the LWR cost $100 per kWe. When the costs of the LWR go up to $1,000 per kWe, the economics are against the breeder.

Fortescue

We can look at the breeder in two completely distinct ways: as just a nicer (more fuel efficient) replacement for the LWR or as a necessary system for generating fuel for burner reactors. If we look at the LMFBR in this second way, the economics are different.

Dietrich

It is not fair to compare the CRBR with breeders in general. It is the first design, and it is being built in "starts and stops." That is the most expensive possible way to build a reactor.

Benedict

I do not believe breeders will cost as much as 1.75 times what LWRs do. I think there is a price between $80 and $300 per pound for uranium at which the breeder will become economical. The CRBR will provide a smooth transition when that time comes. I think we badly need the experience of finishing the CRBR to get economic and operational data to see whether Mac's pessimistic predictions are borne out.

We need "first-of-a-kind" assistance from the federal government for the breeder, coal gasification, synfuel, and any other experimental plants costing over $1 billion.

P. Cohen

By comparing the FFTF with the PWR, I expect the breeder will cost between 1.5 and 1.7 what the LWR does. But cost is not the only consideration. You must ask what a system can do for you.

Fortescue

I agree with Manson on the need for the CRBR. But I have two reservations: it is a loop-type rather than a pool-type breeder, and its design is an accretion of designs over a period of time.

I would stress that the breeder should be justified not on the basis of being just another power station but on its value as a fuel producer.

K. Cohen

The United States energy problem is not just what happens after the year 2000--it is imminent. But money is being spent on the breeder rather than on LWR development. All the money is going for a device for the next century.

Kendrick

Congress puts all the money into the breeder, much to the distress of DOE.

Benedict

I think the windfall profits tax should be spent on a balanced program of energy research, including nuclear energy.

Fortescue

I would like to summarize the case for the GCFBR. I have always looked at the GCFBR as a backup for the LMFBR. I believe breeding is critically important for any viable nuclear system. The GCFBR is comparable in cost to the HTGR--and this is an advantage. It may (and I stress may) be easier to license than the LMFBR. The design of the GCFBR provides for a water-cooled core catcher.

I would like to distribute a short article I wrote recently on the concept of "forgivingness."[3]

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[3]Peter Fortescue, "Gas Cooling and the Concept of 'Forgiving Design'," GAZ-2003A 1M 12/79 (San Diego, California, General Atomic Company) 1979.

## SESSION IV
## THE BREEDER

Edlund

As background to one incremental approach to the breeder, I want to discuss the question, What can you really do with an LWR?

First, to prevent LOCAs we must make sure the system has a dedicated heat removal system. Or we could use the technique from the Otto Hahn of a consolidated nuclear steam generator, in which both the core and several steam generators are integrated in one large pressure vessel.

Ten minutes after scram, the power level of a reactor has dropped to only 2.1 percent of full power. If the reactor core is kept small enough, natural cooling processes can protect it from core melt. I have calculated the cost of such a 400-500-MWe system to be about the same per kilowatt as for a 1,000-MWe reactor.

In work I am doing for EPRI I use a close-packed lattice of wire-wound rods with a pressure differential of 54 psi to give a coolant flow rate of 24.5 feet per second (compared with about 15 feet per second in conventional systems).

P. Cohen

You may run into problems because of that high speed of flow.

Edlund

The result of our LOCA analysis is that the maximum temperature the cladding reaches in a LOCA is 300 to 400°F less than in the case of a PWR, and with no cladding failure or growth. The system also enhances fuel supply because with a close-packed plutonium-uranium matrix with stainless steel cladding and light-water cooling we get a conversion ratio of 0.9.

The system could readily be upgraded to obtain a 1,000-MWe breeder with the following characteristics:

Fuel - 11 to 12 percent enrichment with plutonium
Blanket - 0.2 percent depleted $^{238}U$
Coolant - $D_2O$
Core radius - 6.84 feet (with blanket)
Core height - 4.4 feet
Heat rate - $10^{10}$ Btu/hr
Average energy of neutrons causing fission - 0.7 Mev
Cladding material - stainless steel 304
Maximum cladding temperature - 700°F
Linear power density - 14 kilowatt/foot maximum
Weight of fissile material - 5.2 metric tons
Breeder doubling time - 20 years

MacPherson

Could this 1,000-MWe design be retrofitted into the PWR?

Edlund

No.

K. Cohen

Have you tried a conversion ratio of 0.95?

Edlund

Yes, the close-packed lattice gives a CR of 0.9 for 40,000 megawatt-days per ton burn-up.

Kenrdick

We have had trouble at DOE in getting anyone to study new lattices for optimizing conversion ratios or breeding.

MacPherson

We simply need reprocessing. It will be commercially feasible when uranium reaches $200 a pound. The ORNL reprocessing group says it can be done now for about $370 per kilogram, which is $168 per pound.

Kendrick

Should reprocessing be a public or private enterprise?

Benedict

Government owned.

K. Cohen

Government owned.

Weinberg

Bennett Lewis said 20 years ago, "Breeders are not necessary!" Bennett's CANDU system required no reprocessing, and we can't ignore it. Of the world's reactors, 6 of the top 10 with highest capacity factor are CANDUs.

K. Cohen

You can push the CANDU to 10,000 megawatt-days per ton burn-up.

MacPherson

As an exercise, I compared the cost of a heavy-water reactor with a BR of 1.0 to the cost of an LMFBR, assuming a capital cost of 1.75 times that of an LWR. The costs are comparable.

K. Cohen

I think we should include heavy-water systems as part of the study.

Benedict

And we should have an architect-engineer firm do the detailed cost estimates.

Kendrick

As part of the nonproliferation study, we looked at more reactor types than you would want to examine as part of this study.

Concerning breeders, a new approach would be to consider them government-owned fuel factories and to build them in enclaves.

Weinberg

Peter, is it true that subsequent to 60 percent full-load operation the Fort St. Vrain reactor ran without coolant for half-hour periods on three different occasions?

Fortescue

Yes, and this characteristic facilitated early restoration of service. In the HTGR, the prestressed concrete reactor vessel is very effective at conducting the heat out. We could even scale up the HTGR to 600-MWe and retain its resistance to meltdown by adding photon "potholes" to radiate away the excess heat. Photon cooling (radiation of heat) turns out to be very effective at these high temperatures. For a LOCA in the HTGR, the normal flow of helium reverses to provide convective cooling upward through the core.

There is another promising system we are just beginning to investigate at General Atomic. This system uses thorium hydride fuel similar to the TRIGA reactor and is unique in that cooling is entirely by natural convection of sodium in a pot at atmospheric pressure. The system could yield a conversion ratio of 0.7, but the calculations are still uncertain on this number. It would have stainless steel cladding to retain the hydrogen in the thorium hydride.

Weinberg

I would like to summarize some of the main ideas presented here so far. Ken Davis suggested we start ab initio to redesign the LWR in light of our operating experience to date. Paul Cohen suggested that if nuclear energy survives it will be because of incremental improvements in safety brought about through institutional changes such as the creation of INPO.

In looking at the question of fuel assurance, we come to the breeder and to the issue of whether breeders should appear full-blown as a new technology or evolve incrementally through such systems as Milt Edlund described. There are also the "farther out" possibilities such as the molten-salt reactor and Peter Fortescue's thorium hydride system.

Finally, there seemed to be general agreement that not all reactors or reactor types are equally "forgiving."

P. Cohen

But we must recognize the trade-off between breeding ratio and "forgivingness."

## SESSION V

## IMPLICATIONS FOR INSTITUTIONS IN THE SECOND NUCLEAR ERA

Weinberg

I would introduce this session by reminding you of the remarkable change in attitudes between our Gatlinburg I workshop (pre-TMI) and our Gatlinburg II workshop (post-TMI).

Burwell

At Gatlinburg II Jim Green said that it took the Browns Ferry fire to wake up TVA. Herman Dieckamp, president of GPU, said that it took TMI to convince him that nuclear energy was a tough technology.

K. Cohen

I think it is appropriate to comment on why the chemical companies did not go into commercial power reactor operation. Chemical companies needed more money from the operations than did utilities. Now utilities do not have any money, and as a result we may have only 150 GWe of nuclear power by the year 2000 instead of the planned 400 GWe.

We will continue to see deterioration in the utilities' ability to build plants. Utilities need money, perhaps in the manner of the Chrysler loan guarantee. The first question is, How do we finish the backlog? The second is, How do we build more plants? Will the government build them? If so, will it be done by a procurement and competitive bid procedure?

MacPherson

Do you think it is reasonable to have the government build plants?

K. Cohen

Other governments (e.g., France and Russia) do.

Schmidt

There is a precedent for government involvement on matters of vital national interest--the Jones provision of the National Maritime Act, in

which the federal government advances 90 percent of the required capital. Three of the world's largest supertankers were built under provisions of this act by the Seatrain subsidiary of General Electric Credit Corporation.

The tanker fleet in Valdez, Alaska, cost three times what it would have on the open market because of the safety features required of ships built under this act. They are double hulled vessels with dual electric drive trains and other quality features to assure safety and a clean environment.

Spiewak

We are involved in a design study for a nuclear energy center for South Carolina. The project is funded by Bill Savage's group at DOE. The proposed site is owned by Duke Power, but the federal government specifies the region and would build the plant according to NRC standards. The plan provides for turn-key operation, and the plant would be sold to the operating utility consortia upon completion.

Under this system, the government undertakes the open-ended risks associated with time delays and cost overruns, but the utility ends up with the final ownership and management responsibility.

P. Cohen

The latest issue of Power Magazine describes cost escalation in fossil plants.

Burwell

There is also the proposal for a national grid.

Spiewak

But there is a lot of institutional opposition to the idea.

Weinberg

What would it cost to build a grid to displace 1.8 million barrels a day of residual oil?

Milt Edlund Peter Fortescue

Jim Lane Paul Cohen Irv Spiewak

Burwell, Spiewak

About $10 billion.

Burwell

The bulk transmission circuits to those sections of the country using residual oil are pretty weak.

Benedict

But 1.8 million barrels a day corresponds to about $27 billion a year.

Firebaugh

What are the actual figures on the present surplus electrical capacity?

Burwell

For my project on electrical substitution, I use a surplus in 1985 of about 60 GWe.

Weinberg

IEA projects an electrical capacity of 700 to 750 GWe for the year 2000.

Kendrick

EIA predicted 1,000 GWe for the year 2000, and so did CONAES.

K. Cohen

How comfortable would you be with 150 GWe of nuclear power by 2000?

Weinberg

We could live with it by using coal, as our nuclear moratorium study showed. But we would need 1.5 billion tons a year, and we are now up to 850 million tons per year production capacity.

Burwell

The national security aspect is an additional rationale for expanding the nuclear program. It should be included in our proposal.

Kendrick

In analogy to the Jones Act, the appropriate government agency could specify standards for government-supported reactors, and a regional NRC could enforce them.

Briggs

General Electric, Combustion Engineering, and Westinghouse don't all want to build the same reactor.

K. Cohen

Better the same reactor than none.

## SESSION VI
## GENERAL DISCUSSION AND SUMMARY

Weinberg

This workshop grew out of the concern, first expressed by Ed Schmidt and Karl Cohen, that the first nuclear era is coming to an end and that we should begin thinking about criteria for designing the second. Additional background issues were raised at Gatlinburg and by IEA on siting policy and institutional structure.

Our discussion here has ranged from questions of necessity and risk to Saudi Arabia and oil. MacPherson says several studies are required to address the important issues raised in this workshop. Hugh Kendrick cannot be here this morning, but he did leave me his notes, in which he has classified the issues into three broad categories--safety, breeders, and institutions, outlined as follows:

I. Safety Issues
   - A. A new look at the LWR.
   - B. Should there be another thermal reactor? What criteria should be met by a new reactor system?
   - C. Do we need to improve the availability of present systems? What are the implications for safety?

II. Breeders
   - A. Incremental approach like that suggested by Rickover and Edlund and/or
   - B. The LMFBR as planned, and/or
   - C. Some other (forgiving) breeder.
   - D. Should we reexamine the religion that we need breeders?
   - E. The concept of Fortescue's Cow--the breeder as fuel factory.

III. Institutions
   - A. NRC regulatory philosophy--how to monitor NRC.
   - B. The question of DOD-type procurement of reactors.
   - C. Financing of reactors in the pipeline and future reactors.

D. Nuclear energy and national security.
E. The role of electricity and potential for substitution.
F. Government operation of
    1. Enrichment plants
    2. Back end of the fuel cycle
    3. Nuclear power plants
    4. Building of nuclear plants.
G. Structure of the utility industry.
H. Siting policy.

These last two items are issues of long-standing concern to IEA, and I would like to add them to the list. Certainly this full list is equivalent to the CONAES or Ford/Mitre studies, and it should be done in one year, not four.

Epler

There are some real advantages in looking at the breeder simply as a fuel factory. With no electrical production required, we would not have to worry about siting the plant near the load. With the plants located in isolated areas, licensing might be easier. Breeders could be built near shale deposits, producing gasoline from process steam. Finally, it might be easier to provide subsidies because no money would go to the utilities.

Weinberg

In 1975 John Sawhill said breeders should be sited remotely.

Fortescue

In any case, the breeder must be close to the reprocessing plant to keep the out-of-pile time short for the product.

Edlund

The breeder must also achieve a 5-year doubling time.

Fortescue

That short a doubling time is required only if you are on the uranium-plutonium cycle. It is not important if you are on the thorium-uranium$^{233}$ cycle.

Weinberg

The original idea was "breeder reactor/reprocessing."

K. Cohen

It is essential to have large-scale, centralized reprocessing plus transport rather than small, dispersed reprocessing at breeder reactors.

Weinberg

We are really talking about grand strategy--whether we got to the present situation by a rational scheme or whether we need a new one.

MacPherson

If I am a shale oil producer, I can 1) burn part of my product, 2) buy coal, 3) import oil, 4) steal gas, or 5) build a reactor whose design has not yet been invented. Why would I buy the reactor?

P. Cohen

Circumstances might dictate it. The study would define conditions under which this might be true.

Fortescue

We must keep many options open. We must put a high rating on flexibility.

P. Cohen

Action at the national level is stalled because there is no consensus. A nuclear future must follow naturally from the larger energy picture.

MacPherson

Let me suggest some topics for specific reports:

1. Reactor heat sources for gasoline production
2. Energy sources needed for sudden interruption in energy supply
3. Examination of "forgivingness" of alternative reactor types
4. Institutional requirements for introduction of the LMFBR

Spiewak

IEA can not study all of the issues that Kendrick listed. We must narrow them down and study a few issues well. I would suggest that we focus more strongly on how we get to the second nuclear era. What new institutions do we need to deal with new technologies like reprocessing?

Schmidt

This workshop represents the best group of nuclear talent that it is possible to assemble. The situation reminds me of four expert French chefs in a room with one egg--debating the best way to make an omelet. Therefore, I suspect it is impossible for us to reach a consensus on any important nuclear issue. I also think it would be wise to drop the phrase "first nuclear era." Spoken with a New England accent, it could lead to unfortunate misunderstandings and to the question, "Why do you want a second nuclear 'error'?"

I think it is important from time to time to step back and ask, "What would happen if I removed myself from the picture?" If I ask not what I want to happen or what ought to happen, but rather what I think is likely to happen, I suspect we are in for a series of catastrophes. First, I expect that the half-life of Middle Eastern oil is on the order of 1 to 3 years. Second, I expect we are going to see another TMI-like accident every year or so. These events are going to converge, and each will moderate the effect of the other.

As the oil flow is cut off, NATO and Japan will be forced into a very stiff military and technological alliance, and our present imported oil supply will be diverted to Europe and Japan.

Next there will probably be a Watergate-type investigation on the issue, "Are some reactors safer than others?" The answer produced by this investigation will be "yes," and the result will be to shut down the lower one-third of the nation's reactors on the basis of safety, at least until the safety of those plants is increased.

It is instructive to look at the foreign experience with nuclear energy. In France the policy seems to be LWRs now, LMFBRs next, plutonium forever. In Germany they are turning to nuclear energy for process heat and fuel production. In Japan they are building reactors, but the energy from imported liquified natural gas already exceeds that from nuclear, and this ratio will increase.

In terms of what study the workshop should propose, I expect that in about a year there will be a major swing in national thinking toward new applications of nuclear energy, e.g., fuel factories. The new growth phase for nuclear energy will be its nonelectric role. A second area of major national concern will be on the comparative safety of the current reactors in the Western world. Such a study would examine and compare reactor types such as the BWR, CANDU, and HTGR, as well as various PWRs. This Institute should "catch the waves" in these two areas and plan to ride them by making appropriate proposals for study.

Weinberg

This leads to the question, "Why preserve nuclear energy?" Our IEA study concluded we could live with a nuclear moratorium. But this study assumed continuation of imported oil.

P. Cohen

We should proceed without making predictions, simply stating what options are available. Ed points out we may have to reduce our reactor inventory by one-third and that the next phase may be alternative uses of nuclear energy.

Epler

We are at the mercy of events. If an oil cutoff comes first, nuclear power will look good. If another TMI happens, nuclear power may survive, but it will look bad. We should get Congress to enact safety standards into law. We should also press for remotely sited breeders as fuel factories.

MacPherson

I do not think there is any place remote enough.

Weinberg

Hans Lutz from Switzerland concluded there was a difference between the operation of Swiss and American reactors.

K. Cohen

IEA cannot do a safety study, but it could set up the ground rules and criteria for safety. NRC is not even studying the problem. Numbers may not be good in specifying safety, but they are much better than adjectives.

Weinberg

What are your criteria for safe reactors, Karl? Is the BWR a safe reactor?

K. Cohen

There are a great many reactor characteristics with safety implications, and they all interact with each other and with other social considerations. Table 2, which is from a letter sent by Bob Richards to Robert Ferguson, shows some of these connections.

Schmidt

IEA could construct this matrix and assign coefficients of the polynomial to rank various reactors.

Spiewak

The NASAP study did just that for some 25 reactor systems.

TABLE 2

OPTIMUM FISSION SYSTEM

Selection Criteria

| | Health & Safety | Social | Assurance of U. S. Energy Supply | International Stability |
|---|---|---|---|---|
| No Loca/Melt | x | | | |
| "Hands Off" Safe | x | ? | | x |
| Underground | | x | x | |
| Missile Safe | x | | x | x |
| Control Room & Computer | x | | | |
| 1st Class Eng'n | x | | | |
| No River/Lake Cooling | x | x | | |
| Worker Radiation | x | | | |
| Public Radiation | x | x | | |
| No Long Life Wastes | x | x | | |
| Int'l Stability | | | | x |
| Diversion | | x | | x |
| Sabotage | x | x | x | x |
| Any Fuel Cycle | | | x | x |
| Continuous Process | x | | | |
| Unit Size | x | x | x | |
| Site Size/Location | x | x | x | |
| Fuel/Electricity | | | x | x |
| Shorter Schedule | | x | x | |
| Large U.S. Energy Source | | x | x | |
| Small/Large Business | | x | x | |
| Public/Private | | x | x | x |
| Regulatory Acceptance | | x | x | |
| Decommissioning | x | | | |
| Compatibility/Transition | | x | x | x |

K. Cohen

Their effort failed because they set the proliferation coefficient too high.

MacPherson

My position on safety is this: Either we take incremental steps, like INPO and NSAC, that prove adequate for safe operation, or we must take a step-wise jump to design a reactor that is absolutely safe and can be guaranteed so.

P. Cohen

You have to include waste processing and the whole fuel cycle.

Weinberg

Let's go around the room to give each participant and observer an opportunity for a summary statement.

Uri Gat, Oak Ridge National Laboratory

There have been a number of assumptions made here with which I do not necessarily agree, including the following:

1. More energy is needed.
2. Nuclear energy is needed.
3. The breeder is needed.
4. Alternative energy sources are not feasible.
5. The technical community should override public attitudes.
6. The public is opposed to nuclear energy.
7. Public opposition is the only obstacle to nuclear power.
8. The law of supply and demand does not work for nuclear energy.
9. Foreign pastures are always greener.
10. The driving force for nuclear power was only economic.
11. The driving force for nuclear power was only safety.

In determining what your study should accomplish, you should look at who will be the customer for your study results. You should assume it is the administration rather than the public and therefore should include administrative input in designing the study. You must discuss lead times for both the study itself and in the recommendations that emerge from it.

There is a delicate issue here involving public acceptance versus government guidance. Finally, on the issue of safety through emphasis on technique, I would point out that it is possible to override any safety system.

Fritz McDuffie, Institute for Energy Analysis

The public perception is that the risk of a catastrophic nuclear accident is extremely high. Any approach to guaranteeing safety would be the most productive one for designing a second nuclear era.

Briggs

The objective of the study should be to identify how nuclear energy can displace fluid fuels and provide additional fluid fuels. The study should address these fundamental questions: Why nuclear? What type of nuclear? How much nuclear energy is needed?

The future of the LWR will be determined by present operating experience. Hopefully, the industry working with INPO will be able to do it successfully. It would be valuable to study what the LWR of the future should look like. As many problems occur in reactor construction as in actual operation. This study could look at the HTGR, CANDU, and Russian steam tube system but probably should not focus on molten-salt or tight-lattice reactors.

From an institutional point of view, it seems to take too long to get decisions out of NRC, but the basic structure of the agency seems all right. Finally, do not ask Congress to make safety regulations. They can call for nuclear energy and even specify the word "safe," but they must not write the specifications.

Lane

There seem to be too many studies coming out of this conference. The first priority should be the issue, "What would you do it you started over again?" This might lead to criteria that would identify the bottom quarter of the nuclear industry, which should, in fact, close down. A study of alternative reactor types could perhaps be done better by an architect-engineer firm.

Another good study would be "Potential of LWRs for High Conversion." Maybe the Admiral was right after all. The use of reactors as fuel factories is an intriguing concept, but I would give it a lower priority.

Fortescue

If the study yielded only a clarification of what is important in our present designs, it would be of value. Second, if new systems could be evaluated on safety criteria it would be worthwhile.

P. Cohen

The nuclear industry needs continuity. It also needs a "super containment" system because of the pilot error that Uri has mentioned. Finally, we need to study alternative applications of nuclear energy, and I would disagree with some of the other participants on the timing of the introduction of such uses.

Epler

There is the number 1 problem of a core melt accident and how to avoid it or deal with it. Then there is the problem of public perception and acceptance. At present the public will not accept the release of krypton from TMI. We can increase safety by distance (remote siting) or by concentric layers of shielding. Finally, the future of nuclear energy will be determined by events beyond our control.

Spiewak

I don't think it is appropriate for IEA to look at alternative reactor types, i.e., to get involved in a SASAP. Rather it should look into institutional questions and maybe at the LWR.

Dietrich

I am in favor of making nuclear plants as safe as possible. But I am not sure a study is a good idea because it in effect tells the public "We do not think they are safe."

Even if you are complacent over the Middle East situation, you would agree that the chance of an oil cutoff is at least 1 in 10 in the next year or so. A reasonable estimate of the chance of a war resulting from this event would also conservatively be put at 1 in 10. And if war breaks out, the chance of it escalating into nuclear war would have to be put at least 1 in 10. So our oil dependence means we risk at least 1 chance in 1,000 of a major nuclear war with millions of casualties.

Nuclear energy can help eliminate that risky oil dependence. As TMI and the press coverage proved, it is easier to scare the public than convince them.

K. Cohen

I suspect we should not make another study.

Burwell

I have reservations about IEA taking on too broad a study. I believe it is important that the United States has electricity. The Institute can point out what the options for electric substitution are.

Weinberg

The point still remains--you can have electricity with coal. Why do we have to go nuclear?

Schmidt

Within six months, South Africa will be making liquid fuels from electricity. South Africa has a magnificent energy program. The SASOL plant uses 0.25 GWe in the production of 40,000 barrels of oil/day from coal. They are developing a strong grid system so they can turn nuclear electricity into motor fuel.

Therefore, I would urge you to stop thinking of the United States as an isolated unit. Europe, Japan, and South Africa do not think this way. In 1940 the smaller "we" was turned by events into the larger "we." The Institute could study the world picture first and then turn to United States policy. A couple of IEA staff members could systematically survey foreign nuclear energy programs to see what lessons can be learned.

Weinberg

The Institute has done very general energy studies, e.g., the nuclear moratorium study. Bill Lewis is very interested in Cal's ideas on electrical substitution in previously unsuspected ways for foreign oil.

But here we are dealing with a different set of questions--how to make nuclear energy more acceptable. It is now clear that necessity and acceptability of nuclear energy are completely intertwined.

Schmidt

Nuclear energy is necessary for the Western world.

Weinberg

Thank you all for participating in this workshop.