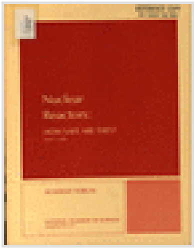

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NUCLEAR REACTORS: HOW SAFE ARE THEY?

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The National Academy of Sciences was established in 1863 by Act of Congress as a private, nonprofit, self-governing membership corporation for the furtherance of science and technology, required to advise the federal government upon request within its fields of competence. Under its corporate charter the Academy established the National Research Council in 1916, the National Academy of Engineering in 1964, and the Institute of Medicine in 1970.

FOREWORD

Robert R. White
Director, Academy Forum

Three major determinants in the future of nuclear energy are: the effects of nuclear radiation, the management and disposal of nuclear wastes, and the safety of nuclear reactors. The Academy Forum has convened three public discussions relating to nuclear energy: "Nuclear Radiation: How Dangerous Is It?" (September 1979), "Nuclear Waste: What To Do With It?" (November 1979), and this publication reports the third, held on May 5, 1980, entitled "Nuclear Reactors: How Safe Are They?"

The development and use of nuclear reactors present a dilemma. The low probability of a major reactor accident combined with its high potential impact require decisions that are difficult and unique.

The Academy Forum provides a public platform for the illumination and discussion surrounding the uses of science and technology. Its sources of funding are as diversified as the viewpoints of the panelists and the audience.

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INTRODUCTION

Daniel E. Koshland, Jr.

Professor of Biochemistry
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I would like to welcome you all to the Academy Forum, an institution that the National Academy of Sciences has established to discuss issues at the borderline between scientific expertise and societal values.

We have an interesting and perhaps easier mandate than some other Academy committees in the sense that we do not have to come to a specific conclusion. The purpose of the Forum is to discuss these issues, to bring together experts with a wide variety of viewpoints, to clarify those issues on which there is consensus, and to clarify the source of disagreement on those issues for which there is no consensus.

Among the issues we have dealt with in the past are the ethics and practice of human experimentation, the problems of coal, the problems of drug and food safety, and research with recombinant DNA. This Forum is part of a series on nuclear energy.

We have found from past practice that it is best to keep the Forum focused on one issue rather than allowing the discussion to wander widely with its participants operating from different bases or hypotheses that are never clarified. Some of you may say that we illuminate only part of the problem, and you would be correct.

We have had two previous Forums in this series. The first was on the health hazards of radiation. It dealt with the decrease in life expectancy or increase in disease from radiation spewed into the atmosphere in an accident or from radiation present in the background for workers in a nuclear plant. The second Forum was on the question of nuclear waste disposal. I mention the matters already covered in those Forums only because it may help us confine this discussion to reactor safety.

The panel has met informally and has agreed on three main questions on which to center the discussion. They are:

1. What are the risks in the operation of nuclear reactors, and what is the probability that each of these risks will occur?
2. What criteria are available for judging the acceptability of risks in a nuclear reactor accident, and how do they compare with alternate societal operations?

3. Are there ways of reducing risks in the future and, if so, what are they?

It is our tradition to have an open session in which panelists and members of the audience can participate in discussion of any other questions that are relevant and are not covered under the ones I have just listed. The format we will use is as follows. Each panel member will be given an opportunity to state his views on the first question. We will then give the panelists a short time in which they can cross-examine each other or add comments, and then we will have questions from the audience. At the end of that period we will go on to the second question, and then to the third so each question will be a unit in itself. At the end we will come back to the general subject.

I'd like to turn to the panel now and ask them to approach the first question: What are the risks in the operation of nuclear reactors, and what is the probability that each of these risks will occur?

HAROLD W. LEWIS: I guess my job is to start by laying out what we now know about the risk of nuclear accidents, and I'll try to do it in a way that will not overly infuriate my fellow panel members. Just so that we know what it is we're talking about, there are several points that have to be made.

First, the word "risk" is, of course, a word that has both emotional and technical content. In the technical content what we mean by risk usually includes both the probability of an accident and the consequences of an accident. The risk of my getting killed by going over Niagara Falls in a barrel is very small because I'll never do it and so you have to separate those two things.

Now, in the nuclear case it's much easier, although there is still some controversy, to calculate the consequences of an accident. Let me outline what we know and where we are on calculating the probability of an accident.

Popular attention has always been focused in the nuclear debate on the largest possible accident, which is, of course, the one of which most people are most afraid. Yet, it's probably one of the least likely of the accidents. Approximately 8 years ago, the Atomic Energy Commission commissioned probably the best study that had been done so far on the likelihood of a nuclear accident, using the best tools of the trade available at the time. A report was produced that has a lot of defects in it; it simply tries to go through the technology of a reactor and ask what different things there are that can go wrong and what the likelihood of each is. It isn't a very exact science. The report is usually called the Rasmussen Report or the Reactor Safety Study. One of the conclusions was that an accident has to go as far as having the reactor core melt before it produces a threat to the health and safety of the public. It's perhaps a bit questionable in view of Three Mile Island.

The probability that was obtained in that report was that this is likely to happen once in 20,000 reactor years. We now have 70 reactors operating. If you extrapolate to a total of 150, that means something on the order of one core-melt accident in 100 years, very, very roughly speaking, and then on top of that a core-melt accident need not hurt anybody. There are other calculations of the consequences that we'll be going into in great detail later.

Now, the number 20,000 isn't all that good, and there have been subsequent studies asking whether in fact the group that made that calculation was high, low, indifferent, imperfect, and so forth. I think the consensus of most people, not all but most people, who have studied it carefully since then has been that there is no evidence that that number is either high or low, but that it is less certain than the group that did the study thought at the time. They thought it was within a factor of five; that is to say, it could be five times higher or five times lower. Most people think it could be off by more than that, but most people do not believe that there is any real evidence that the probability is higher or lower. I believe that it is a fair number to begin the debate with as the probability of a core-melt.

You have heard a great deal in a previous Forum about the effects of low levels of radiation; I couldn't repeat that here. There are extra factors that go into the likelihood of hurting people, which we will be talking about. I would propose that we start out by saying that the probability of a core-melt is something like what the Reactor Safety Study said and go on from there.

JAN BEYEA: I am one of those few people Dr. Lewis mentioned who has found that there is evidence that the Reactor Safety Study was low in its estimate of the probability of a meltdown accident and breach of containment. The best evidence is the Three Mile Island (TMI) accident itself. When I go back and look at the prediction in the Reactor Safety Study, I find the estimate that a serious loss-of-coolant accident should occur every 4,000 reactor years of cumulative operations. In fact, TMI (which certainly was a serious loss-of-coolant accident) occurred after 400 reactor years' experience.

The unexpected occurrence of the Three Mile Island accident suggests to me that the Reactor Safety Study was too conservative in its estimate of the number of events that could lead to a meltdown at least by a factor of 10. I would argue, therefore, that we should not treat the report as the definitive work on accident probability.

Instead of arguing whether or not the 1 in 20,000 estimate for the chance of a meltdown (per reactor per year) is high or low, I think we should concentrate our attention on setting a range of accident probabilities--perhaps 1 in 2,000 to 1 in 200,000. There can be broader agreement among technical people about the range than there can be about the best single value to use. Although I believe the experience at TMI suggests that a number like 1 in 2,000 is closer to the truth, I realize that I cannot be completely certain and therefore am much happier quoting a range for meltdown probability.

In any case, for most public policy purposes, e.g., emergency planning, I think it is prudent to assume that the high end of the probability range is correct. And since a 1 in 2,000 chance of a meltdown implies that one or two will actually occur over the next 30 years, it follows that the actual occurrence of meltdowns should be taken as a serious possibility. (I would not, however, suggest that the high end of the meltdown probability range be used to compare health impacts of nuclear power with the health impacts of alternate electricity generating technologies, such as coal combustion, unless a similarly pessimistic view should be taken about the numbers used to generate the health impacts of the alternatives.)

It should be noted that not every meltdown will necessarily lead to a large release of radioactivity. The probability of a breach of the containment is also a controversial number. Although not specifically designed to withstand meltdowns, the large-volume containments (such as at TMI) may in fact contain most of them--say, three out of four. However, I doubt very much that small-volume containments (such as are used in boiling water reactors) would be able to withstand the pressure of gases generated during a meltdown.

My subjective feeling, which may differ from that of some of the others on the panel, is that the probability that the containment will hold in a meltdown is not great enough for us to ignore the possibility that a large release of radioactivity may occur some time in the next 30 years.

W. CONYERS HERRING: I think it's clear by this time that the question of whether the nonexperts should believe that the experts know what they're talking about is very much at the heart of what we're discussing; it is certainly a question that I had to wrestle with when I became chairman of the Nuclear Risk Literature Survey Committee. As an outsider to the field, I had to oversee perhaps not a definitive evaluation, but at least a reporting on the various claims made by the various kinds of experts, or reputed experts, on many different subjects.

It's obvious that there are two things that the nonexpert can do to get at least a little bit of orientation on technical subjects. One is, of course, to calibrate his experts to try to find out how many of the people with reasonable knowledge about the subject in question adhere to this, that, or the other view. I won't discuss this very much, but what I will discuss is the other thing that one can do, which is to try to formulate the questions in one's own way, and then apply common sense and experience to getting at least a ballpark estimate about the answers; one can then see if in this framework the things the experts are saying seem to make reasonable sense.

I would like to discuss in particular the application of this to reactor accidents. It is sometimes argued that because we have had only a rather limited number of years' experience with reactors--the figure 400 reactor-years was just mentioned--this really isn't enough for us to know whether they're safe or not, because a catastrophic accident might happen tomorrow and then we might regret that we ever had any reactors in the first place. I think such a statement is a little misleading. I think that if one breaks the problem of reactor-accident risk down into just a small number of rational components, one can get some useful information out of even the limited experience to date.

The main questions are as follows: First, as Dr. Lewis said a minute ago, how likely is it that an accident will happen that entails the melting of a major part of the core? Second, if the core melts, how much radioactivity is going to escape from it? Third, if this happens, does the containment building that surrounds the reactor core maintain its integrity? It's supposed to be airtight. Does it stay that way or does it develop holes or penetrations that will let a significant amount of radioactivity escape to the environment? And finally you have to ask what the radioactivity will do if it gets out in the environment; how likely is it to cause how much damage?

I think that when you break the problem up into those four questions you will see that the first question is by far the trickiest. How likely are we to have a core-melt? We haven't had a core-melt to date, and this is of course consistent with the Rasmussen Report's estimate that a core-melt is likely to occur once in 20,000 reactor years. But the probability might be once in only 500 reactor years, and that would still be perfectly consistent with our experience to date. At least we can set some sort of limit.The probability is not likely to be once every 50 reactor years, since in such case we would almost certainly have had several in only 400 reactor years of experience to date.

The second question, how much radioactivity escapes from the core if it does melt, is a rather technical one, and here we do have to fall back on the experts. But fortunately, there doesn't seem to be terribly much disagreement among all the different experts who have studied this; they all come out with very much the same figures. So, we can accept them with considerable confidence.

As far as the third circumstance is concerned, violating the integrity of the containment, this again is a rather iffy thing, but it is quite clear that in order for it to happen, additional failures and mishaps have to occur beyond those that are responsible for melting of the core. So, it is not unreasonable that the probability of a major escape of radioactivity, even if there is a core-melt, should be no more than a fraction of unity, as was indeed found in the Rasmussen Report and, more recently, in some of the "what if" postmortems on Three Mile Island.

Finally, if there is a major release of radioactivity, how much damage it will do depends on whether the reactor is located in a relatively heavily populated area or not; it also depends on the weather--such things as whether the wind blows the radioactivity toward a heavily populated center or blows it out to sea, and so on. It is of some interest to note that in the analyses of the Reactor Safety Study, and these I think are consistent in a general way with the American Physical Society study and with other studies that have been made, the average number of people who are likely to suffer, say, eventual death due to delayed cancers from long-time exposure to radioactivity is only a very small fraction of the maximum number that might if you had the very worst wind direction in a heavily populated area.

If we combine all these things, starting with the experiential datum that there is probably no more likelihood of core-melts than one in every several hundred reactor-years, we can come up with the conclusion that the average number of cancer deaths produced by reactor accidents is probably rather less than one per reactor-year, and surely not enormously greater than one. This simple reasoning doesn't, of course, rule out the possibility that the correct number might be as small as the estimate of about one-fourteenth of a death per reactor-year that was given in the Reactor Safety Study, or even smaller. My point is simply that even the crude boundary that the layman can estimate for himself can, as I hope we shall see later in the discussion, be of some use in helping decide whether accident risks should dominate our thinking about nuclear power.

KOSHLAND: I want to tell you how this panel was picked. Two members are more or less identified with being quite skeptical about the risks of nuclear power; two of the panel members are identified as being skeptical of the skeptics--that is, they're convinced that nuclear power can be done relatively safely; and two members are identified as being in the middle. The last category is the most difficult. I heard that in selecting the president of Yale, the search committee was told to get someone who's not too far to the left, not too far to the right, and not too much in the middle. We have strong opinions from very competent people, and I picked one from each category, and now I'd like to throw it open to members of the panel who haven't spoken.

JOEL YELLIN: I have a different view of the calculations of the Reactor Safety Study. I apologize for introducing further complexities, but there's a third view, different from those of Dr. Beyea and Dr. Lewis, and I think it deserves consideration.

Let me say first that I do not think risk is a well-defined concept. It certainly incorporates the concept of probability and an estimate of consequences, as Dr. Lewis has pointed out, but other things are also involved; for example, whether the situation one is concerned with is imposed or entered into voluntarily, and whether individuals *qua* individuals are at risk, or society as a whole is at risk. Because of those complexities, no one here should suppose that the numerical-risk estimates we discuss are in themselves a sufficient basis for making social decisions.

Setting conceptual problems aside, suppose one addresses this question: What will happen over the next roughly 40 years if the nuclear industry proceeds about as it has, with some modest growth? Then I would say, having looked in some detail at the nuclear risk calculations[1] that it would be no surprise if one or two serious accidents, injuring members of the general public, occurred in that time.

Let me put that in a different context. Roughly speaking, I suspect that the growth or decline of the quality of nuclear-safety regulation will keep pace with the growth or decline of the nuclear industry. There is some support for that view in the history of aviation safety, which has essentially kept pace with the very considerable increase in commercial air traffic. Of course this is a suggestion about the general picture over decades. One cannot exclude fluctuations in the quality of safety practice, and that's why I say the occurrence of serious accidents over the lifetime of present reactors would be unsurprising. This is not an optimistic view. There are many people who feel that the occurrence of the Three Mile Island accident suggests that the present level of risk is too high and that it must be decreased considerably if nuclear development is to go forward.[2]

As to the calculations of the Reactor Safety Study, I do not believe the results of that study can or should be used in making regulatory decisions. The uncertainties in the various probability and consequence estimates are simply too large. Following the calculation procedures literally, uncertainty factors of 100, a 1,000 or 1 million arguably enter the estimates at various points.[3] By no means does this suggest that we should

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[1] Yellin, The Nuclear Regulatory Commission's Reactor Safety Study. Bell Journal of Economics 7, 317 (1976).

[2] (I)f the country wishes, for larger reasons, to confront the risks that are inherently associated with nuclear power, fundamental changes are necessary if those risks are to be kept within tolerable limits.

Report of the President's Commission on the Accident at Three Mile Island (October 1979), p.7.

[3] The largest such factors are associated with the Reactor Safety Study's treatment of "common mode" failures, which involve coupled failures of ostensibly independent reactor components or combined equipment failures and human errors. There is general consensus among reviewers of WASH-1400 that the treatment of common mode failures in that study is unjustifiable.

take seriously the extreme upper end of the uncertainty band and declare reactors unsafe. To apply an analysis generally conceded to be faulty would only compound the original error. But it does tell us that until more defensible calculations are available we are thrown back to using a combination of qualitative judgments and observations of actual reactor operating experience.

HOWARD W. WAHL: Now I'm confused. I thought I understood something about reactor safety, and I've heard a lot of different numbers here.

As a practitioner of the art of reactor safety, I would have to say that from the standpoint of the way in which we in the business of designing reactor-safety systems quantify the risk, we generally pick the most conceivable accidents that are credible--they're actually very close to being incredible--and we use those as what we call design-basis accidents.

This includes core-melt with considerable release of fission products. We assume that the containments have some amount of leakage, generally not a great deal. But we transport fission products through those containments fairly freely without any recognition of real plate-out mechanisms or chemical reactions, which we know we couldn't prevent even if we tried very hard. And we subject people at the site boundary to doses that are probably hundreds or thousands of times higher than what we might realistically expect.

I think we have confidence from the Reactor Safety Study that there are very remote possibilities that, first of all, the core is even going to melt and, secondly, that we're going to get some of these transport mechanisms acting that we assume in our design calculations.

With all of that we still believe that anyone who is at the site boundary is not killed. He may get a dose that could be high as one-twentieth of what we call a lethal dose for half the population that would be subjected to it.

The point I'm trying to make here is that I think the Reactor Safety Study has given us some very valuable information. It's a different approach than what we use in designing reactor safety into the plant. In both cases, let's say the pragmatic approach that we take in licensing and designing the plants and in the experiences that we've had to date with an excellent safety record, I think we feel these probabilities are very, very remote; and that agrees pretty well with the Reactor Safety Study.

HARVEY BROOKS: I'd like to ask Joel Yellin a question. I'm not quite clear really what the bottom line is of what you were saying. Are you suggesting that we really can't know anything at all about the safety of or about the risks associated with nuclear reactors until we have enough reactor years of experience to set actuarial limits, as it were, based on that actual experience?

YELLIN: I think we can learn a great deal about reactor safety from systematic analysis of the sort that went into the Reactor Safety Study. And it may very well be true that one could point to weaknesses in reactor design, taking that sort of approach. But I am doubtful whether one can really compute reliably the absolute probability of an accident. In part that's because the actual results of that study are, as I said before, extremely uncertain. But I also doubt whether one can quantify the human aspects of these risks. The things that the Kemeny Commission was especially (and I think justifiably) concerned about in its report on the Three Mile Island accident--actions of operators under stress, the quality of maintenance, the "mindset" of regulators and industry executives--are extremely difficult to quantify, and I don't think that reliable estimates of the absolute probabilities of reactor accidents are in the cards.

BROOKS: Would you be willing to accept the proposition that in fact while the absolute probabilities are not very reliable, the relative probabilities of the different accident sequences are probably considerably more reliable than the absolute probabilities?

YELLIN: I don't accept much of what was done in the Reactor Safety Study. Formulas were used that have no physical basis, important classes of initiating events were omitted, the real uncertainties in the probability estimates were not accurately reflected in the final results, and the quantitative treatment of human errors was fanciful.[4] I can well imagine that an independent

[4] I am not alone in reaching these conclusions. See, e.g., Risk Assessment Review Group, report to the U.S. Nuclear Regulatory Commission, NRC report CR-0400 (1978); Reactor Safety Study (Rasmussen Report), Oversight Hearing Before the Subcommittee on Energy and the (continued next page)

group could reexamine the accident sequences, add new ones if necessary, and with a systematic approach similar to the one used in WASH-1400 gain valuable information about the relative probabilities of different sequences.

HUGH SIDEY: Well, my world is considerably different, but let me say there are at least two levels to this. One you gentlemen talked about in technical terms is the probability of accidents. I would point out to you that in the background--and that has as much to do, of course, with what happens in our national life as the other--there is an "accident" every night, whether it's in the movies, or on television, or in publications like mine. That probably would suggest that "once every 100 years" is once every 100 seconds or minutes in the minds of people. There surely is now, I observe as I go around this country, the feeling that in the nuclear industry there are apt to be frequent mishaps. And as we increase the plants surely they will be more frequent.

Part of that comes out of the kind of dark mood that we in the media are in and have been in. It comes out of the fact that you have provided a marvelous form of entertainment. I mean there isn't any question that Jane Fonda did very well in that movie, and there isn't any question it makes a good 90-second spot or 3-minute spot at night.

I would simply say that as you go along in these discussions, perception is a big part of it. It seems to me that over the time I've watched various developments, including the moon shot--we lost three men in that, which is more, of course, than we've lost in this episode--that the perception of the public of the danger they're in is also a great problem.

Up to this point I don't detect that people really believe that their life-style is going to have to change very much over these next few years. They believe that we will have enough power and energy, and therefore, that even that one accident, even though they hear what you say, seems too much, particularly when they've seen it in the movies. Thus, fear is exaggerated, but it has a real effect on nuclear planning.

Environment of the House Committee on Interior and Insular Affairs, 94th Cong., 2nd Sess. (1976) (statements of W.K.H. Panofsky, H.W. Kendall, and F. Von Hippel). The widespread criticism of the WASH-1400 statistical analysis has led the NRC to request the American Statistical Association to establish a committee to advise it on statistical applications.

KOSHLAND: Three Mile Island has occurred. It was not a meltdown. One side can say it was underestimated because we count it as a meltdown, a very serious accident, and the other side can say we can't count it as a meltdown because nobody got hurt. So the Rasmussen Report is neither verified nor disproved by Three Mile Island.

Now, did the Rasmussen Report discuss smaller accidents of the type that Dr. Brooks has mentioned and, if so, how good has its prediction been in this category? I just want to get where we are on the Three Mile Island accident and the Rasmussen Report.

LEWIS: Well, that's what I want to talk about. But to your direct question: In the Rasmussen Report, of course, the number 20,000 reactor-years is a very broad-brush number, not applicable to all reactors, and it describes what is called core-melt.

The Reactor Safety Study, the Rasmussen Report as we have begun to call it here, does not contemplate the kind of thing that happened at Three Mile Island in the sense that it says that whenever a core begins to get damaged it just melts completely. In that sense it's a conservative report, so there are no degraded conditions. Therefore, to ask whether the Rasmussen Report predicted that particular sequence of events, the answer is no, it wasn't programed to calculate that particular sequence of events.

KOSHLAND: Were there other kinds of accidents predicted that have or have not been verified?

LEWIS: It is never correct to look at something that has happened in the past and ask whether you correctly calculated its probability. The probability that we're all sitting in this auditorium is negligible, and yet we are. Whenever you look into the past, you discuss things that have happened, and if you had been asked to predict them in advance, you would, of course, not have predicted them in that detail. So, there is a difficulty in retrospective probability that just keeps coming up.

I've sat on committees that have nothing to do with reactor safety in which something that had a probability of one in a million actually happened, and people always say, "See, you got the probability wrong because it actually happened," and that's just bad statistics. And the example I always give is that if I were to give you a list of a million things, each of which has a probability of one in a million of happening, and my usual list in this town includes the Redskins going to the Super Bowl, and, you know, things like that. But I give you a list of an honest million things that have a chance of one in a million of happening this year. A statistician will tell you one of those things will in fact probably happen this year. The Redskins may go to the Super Bowl. And when that happens, people will look back and say Lewis is an idiot. That happened. You said it only had a chance of one in a million of happening. So you have to be very careful with retrospective statistics.

The component failures in the Rasmussen Report have happened often enough so people have begun to look at whether those failure rates were right. They do seem a little bit low, particularly some of the pump and pipe failure rates

BEYEA: That's a very convenient analysis in terms of probabilities. It sounds as if Professor Lewis is saying that if things go well, then the probability analysis in the Reactor Safety Study is okay, but if the study fails to predict that which it is supposed to predict, then all we have is a misunderstanding of probability. I can't see that.

The Reactor Safety Study failed to predict that which is most important the frequency rate of major accidents. It failed to predict Three Mile Island. It failed to predict the Brown's Ferry fire. And that's of public interest.

I think these incidents already have given us sufficient information to allow us to bypass arguments about the Reactor Safety Study's predictive capability. We already know from the frequency of occurrence of these two events--events serious enough to suggest that contingency measures for large releases should have been required--that serious accidents are occurring once every 200 reactor-years.

We can make predictions based on this experience regardless of the Rasmussen Report. Using the past as a guide to the future, we can expect that we will continue to have accidents that are shocking to the public every few years. I do not know how many of these serious events will actually turn out to lead to a large release of radioactivity. There is no technical methodology I know of capable of determining the probability in a way that inspires confidence.

If we never have such an accident, if we never have a large release of radioactivity in the course of the nuclear program, then nuclear power will turn out to be a very benign source of energy in my opinion (assuming we also ensure that the mill tailings from mined uranium are properly covered). If, however, 1 out of 10 of these intermediate-type accidents turns out to lead to a large release of radioactivity, then it's a different matter. Then I find that nuclear will catch up with coal in terms of its overall impact. One large release of radioactivity (including 50 percent of the radiocesium in the core) from the average site in the United States in my estimate would expose about 1 million people to radiation leading to the order of 10,000 delayed cancer deaths. It would lead to the contamination of thousands of square miles of land.

The psychological impact on the country would be enormous. Based on the seriousness of the psychological impact of Three Mile Island--an accident in which only small amounts of radioactivity were released in comparison to what might be expected in a large release--I think we can assume that the psychological impact of a release in which thousands of square miles were contaminated would be devastating.

HERRING: I would like to take issue with the last thing Dr. Beyea said about the consequences of a large release of radioactivity.

If you have a large release of radioactivity at one of our many reactors with random weather conditions and so on, the calculations in the Reactor Safety Study came up with the result--this was not published in the study, but this is what the calculations that were published correspond to--that the average number of cancer fatalities would be only about 1,000, something like that.

Now, you may prefer to put in different figures and so on and raise that somewhat, but the point is that whatever the number is, it is very much less than the maxiumum that you could get from such a radioactive release.

BEYEA: I'm assuming a release of 50 percent of the core cesium. It's a question of how you define a serious accident.

HERRING: That's the same thing that I was referring to in the figure I quoted--about 50 percent of core cesium.

HOWARD WAHL: I guess I would agree with your statement, Dr. Beyea, relative to whether you have this massive release of core fission products at a site--

yes, you're going to have long-term cancer deaths. The whole name of the game is to make sure that doesn't happen. In fact, if we ignore the Reactor Safety Study and look at reality, we find that, in the case of Three Mile Island and in the case of Brown's Ferry, the fission products were not in fact released to the environment. In the case of Three Mile Island, where they were released to the containment, they in fact did not get released to the environment.

The Kemeny Commission report went on to evaluate whether they could have been released to the environment if the core had left the reactor vessel and gone into the reactor containment. Would the containment have failed?

I understand, although it's difficult to get the information in its final form, that the conclusions of that group were that the containment would not have failed and, in fact, the core fission products would not have been released into the environment.

I want to be sure that we do not leave this audience with the impression that once every 200 reactor years we're going to be releasing massive amounts of radiation into the environment.

KOSHLAND: Now let us have some questions from the audience.

MARK GOTTLIEB, Environmental Protection Agency: Given the methodology used in the risk assessment undertaken in the Rasmussen Report, has there been a comparative study of other reactor types? By such, I mean the Candu reactor in Canada, or whatever.

Secondly, and perhaps more significantly, has there been any effort to incorporate the methodology of catastrophe analysis that's come out of France by Rene Thom as perhaps an alternative methodology for assessing the accident potential of nuclear reactors?

LEWIS: Well, the United States has been a little slow, although it's beginning to get farther along, in doing the kind of reactor-safety study that was done by Rasmussen and company. Some specific components of reactors have been studied.

The Germans have done a fairly complete study on their kind of reactor using the same methodology. The Swedes have also done it.

People have different views. I do not have the dim view of the Reactor Safety Study that Dr. Beyea seems to have. I believe one shouldn't throw the baby out with the bathwater, but that's something we could be debating all night.

There was a review group for the Nuclear Regulatory Commission, the so-called Risk Assessment Review Group, which heartily recommended that the NRC not try to do full-scale reactor studies a la Rasmussen on other reactors, but instead do mini-studies on them and in particular use the methodology for subsystems where it can be done very, very well, and use that as guidance in the regulation of the industry.

J. SAM MILLER, electrical engineering consultant, New Hampshire: I'd like to just throw in one more set of figures. I've heard Dr. Rasmussen discuss the Three Mile Island accident twice, once at Oak Ridge and once 2 weeks ago at a New York Academy of Sciences meeting. He states that he did predict the accident in his mathematical model, and I believe he did.

But his prediction was that we would see a Three Mile Island type partial meltdown once every 2,500 reactor-years. He said there was a 10 percent confidence variation on that, which would put Three Mile Island within his prediction at one in every 250 reactor-years, or once about every 3 operating years in the country for a Three Mile Island type accident.

I'd like to ask some members of the panel to comment on the possibility of serious accidents other than at an operating reactor. Namely, what do we do if we have a spent fuel pool accident, or what do we do if we have an accident in one of our present storage facilities, either Hanford or, God forbid, an earthquake at West Valley? And what do we do about the predictions for accidents at future storage sites where we're going to be storing these things 50 years from now, let's say?

KOSHLAND: The storage problem was really very well covered in our last Forum. Do you want to ask about other types of accidents, like earthquakes or pool accidents?

MILLER: Yes. Particularly spent fuel pools and on-site storage.

WAHL: I can respond relative to the assurance of releasing radioactive material to the environment from a spent fuel storage pool. If you would examine the margins that exist in those structures relative to the building we're in here or a hospital -- buildings in which we place a great deal of value on the seismic resistance or tornado resistance of the structure because it's a public building--you would find that while a nuclear power plant spent fuel storage pool is designed for much higher load conditions because the effects of earthquakes are two or three times as severe as those anticipated in a normal building code, we have additional factors of safety on top of those not allowing plastic structural response. We keep the structural elements in a linear range so that they're more predictable. So the overall margin of safety against failure due to an earthquake is in the neighborhood of five times greater than that for a hospital or public assembly building.

The other advantage that you would have in a spent fuel storage pool is that you do not have the driving force of the released steam that you would have in a reactor system, so you don't have the driving force to get those radioactive fission products out into the environment. Those are two very important factors of safety relative to the storage of the spent fuel.

BEYEA: I have a tough time convincing people in Washington of the seriousness of this problem. In fact, I've noticed that when I talk to people in Washington, everyone seems to be sure that, because they work in such an important town, they know what is a problem and what isn't. And, unfortunately, everyone I've talked to so far is convinced that the possibility of accidents at spent fuel storage facilities isn't much of a problem.

I would agree, however, that there is less of a potential problem than with reactor meltdowns for the reasons mentioned by the previous speaker. Theoretically, you can have a large release of radioactivity at a spent fuel pool or at any away-from-reactor storage pool, but the time frame of the accident seems to be much longer than the time frame associated with a reactor meltdown. There's just not as much energy available. Even with a breakdown in mechanical cooling it takes weeks to get overheating. Thus there would be considerable time available to repair the system provided there could be access to places where action was needed.

And so the scenarios developed by a group of us who did some critical analysis for the government of the state of Lower Saxony in Germany indicated that essentially a "loss-of-services" accident was necessary to get a serious release. You would have to lose the ability to service the facility for weeks--something that could happen at a reactor site if you had a meltdown. Even without a meltdown, a relatively minor accident could contaminate the facility, preventing access for a considerable period. In such loss-of-services situations, large releases of radioactivity would be possible; however, release of radioactivity from old fuel would not be likely to lead to immediate deaths, but could lead to large amounts of land contamination.

In any case, there is a fairly simple technical fix for this problem, which is to go to a type of dry storage in which you have natural cooling. With natural cooling you can avoid these loss-of-coolant accidents in the first place. In fact, the governor of the state of Lower Saxony, after hearing our testimony, took these hypothetical accidents very seriously. He decided that he would not accept as designed a proposed spent fuel storage facility that could hold up to 30 reactor cores of old fuel. He would only accept a design that used natural cooling. Dry storage is being actively studied now in the United States. I hope that it will be required here as well as in Germany.

Let me turn to the first question that was asked, i.e., whether or not the Rasmussen Report predicted the TMI "partial meltdown." It is true that the Reactor Safety Study assigned a factor of 10 uncertainty to the probability of most accident sequences, and therefore it is possible to argue that the occurrence of the TMI event did lie within the uncertainty band assigned by the study to the least serious loss-of-coolant accident sequence considered. However, even if one assumes that the TMI accident is comparable to the Rasmussen group's scenario, it is important to note that the actual frequency rate turned out to fall at the pessimistic end of the range given. This result leads me to conclude, as I stated earlier, that the mid-range values stated by the study should be considered low by a factor of 10.

In any case, had the Reactor Safety Study, and those who made use of it, highlighted the uncertainties in the calculations, talking about a meltdown probability ranging from 1 chance in 3,000 per reactor per year to 1 chance in 200,000 per reactor per year, then I think it would be fair to claim that the TMI incident had been "predicted." However, the fact that the number 1 in 20,000 was the only number emphasized to the public makes it difficult for me to take Rasmussen's claim seriously.

Having once again criticized the Reactor Safety Study, let me balance my remarks by inserting some words of praise. I do not want to give the impression that the study is all bad. Despite its flaws it has taught us, in my opinion, a great deal about reactor accidents; it has clarified the key questions that need to be asked, and it has implicitly suggested ways to make reactors safer. The study has been misused by some, but that always happens with studies of controversial issues.

UNIDENTIFIED: I am a nutritionist from York, Pennsylvania. I observe that nuclear power reactors do not exist in a vacuum, and I feel it's unrealistic for the panel to discuss accidents and safety of a nuclear power reactor without including a discussion of accidents and safety all through the nuclear fuel cycle, including the mining and milling accidents, et cetera.

KOSHLAND: In past Forums we have spent time on those issues. The only reason we're not discussing those topics tonight is so that we may focus on one of these problems at a time.

JOHN CLEWETT, Attorney-at-law: First of all, one very quick one. I can only identify one person who seems to be a skeptic. Perhaps you could point the other out.

LEWIS: That's the test you get when we're finished.

KOSHLAND: Everybody is being more cautious than I expected.

CLEWETT: In 1957 the industry approached Congress to say, in effect, that they were unwilling to build reactors commercially because of the potential for very large liability. It was only after the passage of the Price-Anderson Act in 1957, which has been renewed a couple of times since then and which severely limits the liability of those who run reactors, that commercial nuclear power was allowed to exist at all.

I'm wondering if some of the panelists would comment on that fact, because if reactors are as safe as some of the panelists seem to want to believe, why is it that the insurance industry refuses to insure them?

BROOKS: I think the problem is that the insurance industry really only insures actuarial risks; that is to say, risks on which there is experience, not risks for which the calculation is purely theoretical. The same problem has arisen in a number of other case, such as the swine flu vaccine case. I don't think that the interpretation that was implied by your question, i.e., that the industry believed the reactors were so unsafe that they had to be held harmless by the government, is really quite accurate. As time has gone on, the amount of private insurance that has been available to the nuclear industry has in fact steadily increased as experience has accumulated.

KOSHLAND: I think we may go on to the second question now: What criteria are available for judging acceptability of risks, and how do they compare with alternate societal options? Dr. Brooks, would you start on that?

BROOKS: I think the basic problem we're dealing with in this area is the question of average risks versus what I would call the spread of risks. Although I'm personally quite confident that the probability of a reactor accident causing death or injury to any member of the general public in the next 30 to 40 years is less than 1 in 100, and that the probability of an accident threatening thousands of lives is perhaps 1 in 10,000, I also recognize that such an accident could happen with equal likelihood at any time in the next 100 or 10,000 years, as the case may be.

In such accidents the number of long-delayed fatalities is likely to exceed the number of short-term fatalities by at least a factor of 30, and it is difficult to decide how these should be considered, especially since the delayed fatalities in fact mostly represent a 1 chance in 1,000 increase over the normal incidence of cancer. On a strict statistical basis, that is, the yearly number of fatalities computed as the probability times consequences per year, the threat is small compared with other risks experienced in our society and when compared with other means of generating electricity or even possibly compared with strong conservation efforts. But the lumpiness of the risk is really the problem. The fact that a single complex of risks can be tied to a large number of fatalities or a single discrete event can be tied to a large number of potential deaths makes it difficult to evaluate and throws it back essentially onto a political judgment . I think that is already implicit in a lot of things that were said in answer to the first question.

There are some similarly lumpy risks, such as major dam failures, liquefied natural gas disasters, and catastrophic oil storage fires, and we have much poorer calculations of risk estimates for these than we do for reactor accidents, uncertain as the latter are. I consider the risk of nuclear war growing out of a confrontation over oil supplies far more probable and much more catastrophic than any of these events, and far more likely in the next 40 to 50 years than any other.

For these reasons I am personally prepared to accept the risks of nuclear power, but recognize that this is an unavoidably subjective judgment that cannot be made on a scientific basis alone. To me the most worrisome accident and the one that I find most difficult to confront with respect to nuclear power is another minor accident comparable with or slightly worse than TMI, perhaps an accident that might kill half a dozen people in the short term and maybe result in as many as 200 deaths long term. I believe that this would be likely to result in a political decision to shut down most or all power plants at a time when we are considerably more dependent on nuclear power than we are today.

I believe that the social disruption, hardship, conflict, and even deaths resulting from such an event would far exceed the direct effects of the accident and would be much more traumatic and long-lasting.

However, it is also true that society could be traumatized, though in a somewhat different way, as a result of the rapid appearance of evidence of serious climatic effects resulting from commitment to coal-fired electricity generation and synthetic fuel production.

Clearly the question of acceptability of the risks in nuclear power depends on a number of criteria: first, the risk of alternate energy strategies, including failure to attain more optimistic conservation goals; second, other risks associated with industrial society compared to nuclear power; third, risks associated with background radiation and natural radioactivity in comparison with the population doses resulting from nuclear accidents; and fourth, the indirect social and economic consequences of even a relatively minor nuclear incident in the present political climate.

I guess I would feel it is this last question that I find hardest to deal with and that produces the greatest uncertainty in my own mind.

BEYEA: I think that regulators have a very difficult job in trying to come up with criteria for the acceptability of nuclear power or, for that matter, any other electricity-generating technology. First of all, it is impossible to say that plants are "safe." I don't know any scientific definition of the word. I know what it means to say that one technology is "safer" than another, but I don't know what it means to say a technology is safe in an absolute sense, since there is always going to be some residual risk.

Having rejected the concept of absolute safety as a criterion for acceptability, let me turn to the concept of "acceptable risk." The problem I have with this concept is that I am reluctant to call acceptable a risk that leads to actual deaths or carries the threat of deaths. Although most people do not realize it, all methods of generating electricity in use today take lives, and some threaten the loss of a great number of lives. As a result, I find it difficult to maintain that any present power source is acceptable, because I don't think it is acceptable to take lives. Such risks may be necessary for us to have electricity, but I don't want to call them acceptable.

The distinction was driven home to me many years ago in a class I was teaching in which I was discussing the various harmful side effects of different energy sources. A student stopped me to ask, "Why do people have to die to produce electricity?" I blustered a bit and gave a poor answer. But afterward, as I thought about what had been said, I came to the conclusion that the student had asked the crucial question--the question that I had missed. That question has stayed in my mind ever since. It seems to me that, as a society, we must begin to move in a direction that will eliminate the need for any future student to ask the same question. Eliminating deaths associated with energy technologies should be one of the guiding principles of our national energy policy. It is certainly not possible to eliminate all energy-related deaths immediately, and it may never be completely possible, but I think the idea repesents an important goal toward which we should be working.

And so, from a moral perspective, I find the concept of acceptable risk to be flawed as a criterion for accepting nuclear power. I find it very difficult to accept what Harvey Brooks just said, namely, that we should be satisfied if the risks from nuclear power are comparable to other risks we face in the society. Such a position implies that these other risks are also acceptable. As long as there exist ways to reduce risks in our society for both energy and other technologies, I think it is inappropriate to call them acceptable. I would prefer a doctrine of "necessary risk" to a doctrine of "acceptable risk."

It is not just nuclear power that is risky. Every energy technology I have looked at has some harmful side effects, some deaths, associated with it. Fossil-fuel burning produces air pollution, which causes deaths. Nuclear power produces radioactivity (or it is unearthed during mining) that will be released into the environment at some time--radioactivity in sufficient quantity to produce some cancer deaths. Even a tightening of houses throughout the country to reduce energy-wasting airflow can increase indoor air pollution by an amount sufficient to produce a certain number of deaths from cancer.

In each case there are ways to reduce the resulting number of deaths. If we are clever, or if we are willing to spend more money, we can reduce the risks associated with using electricity. I do not claim that we should pick on nuclear technology to the exclusion of others. I think we should spend just as much effort on improving coal plants as we do on improving nuclear plants. Similarly, when we build new houses to meet new energy-saving criteria we should reduce the sources of indoor air pollution at the same time--for instance by installing plastic vapor barriers beneath basements of buildings to cut down the amount of radioactive radon gas seeping into house air from the soil.

To conclude, I do not think there exists an energy technology that is "acceptable" from the safety point of view. There are no free energy lunches. However, some electricity-generating technologies are better than others, and it is the more benign technologies toward which we should be moving. I do not think people in Washington, D.C., have faced up seriously to the process of ranking the various energy options according to their health and safety aspects.

KOSHLAND: Mr. Wahl, I'm going to call on you. I'd like you to say something so outrageous that Dr. Yellin turns out to be a skeptic and so that my prestige and credibility are raised.

WAHL: Well, I hope that I get to be the skeptic at some point.

I think the first two gentlemen have talked about the business of analyzing risk relative to nuclear power and other types of power. Unfortunately, I'm in the business of having to design power plants, and I guess what we find is that we have to meet criteria. The question was what criteria are available to judge the acceptability of the risk.

We leave that job to the Nuclear Regulatory Commission. As a practitioner in the art for a little over 20 years, I would make a very positive statement that we can't imagine anyone could be tougher than the NRC. They don't stop at the federal criteria. There are criteria in the Code of Federal Regulations that say this is in fact where you have to place the level of risk when you design the plant. You're designing to release limits that in effect try to prevent harm to the population at large and, probably more importantly, to individuals at the site boundary.

I don't think we've found a better way from the standpoint of a pragmatic approach to getting the job done, and that's a different problem than analyzing a bigger picture. That's not to say that we shouldn't be concerned about risk. I think that the criteria do a very good job of setting a level of risk. I guess I would have to agree with Dr. Beyea that there isn't any way to produce power that is totally risk-free or death-free. In fact, the experience to date is that it probably costs more lives to build the plants than it does to operate them, even including the accident scenarios and the probabilities. That doesn't mean we're going to stop building reactors any more than we're going to stop building bridges or automobiles. But there are criteria on what the acceptable level of risk is today. They're in the Code of Federal Regulations. I think they are fairly severe criteria. We've done cost-benefit work on ways to meet or exceed those criteria, and we have found ways within the metropolitan siting areas whereby we can, through additional cost to the containment systems or filtration systems, enhance the safety of the plant or reduce the risk.

So these techniques are available; they're not unknown. It's a question of what criteria the federal regulations apply to judging the risk.

KOSHLAND: Dr. Yellin is shaking his head, so I have hopes for him.

YELLIN: I don't particularly like the term "acceptable risk." It implies that there exist specific numerical estimates of risk that in principle can be precisely computed. It suggests that such estimates ought to be used in making decisions about the various risks society faces. And it assumes that somewhere, if we could only find it, there's a universal numerical standard of "acceptability" against which the results of risk assessment calculations can be compared.

I don't believe such a standard exists, and I don't think pure numerical risk estimates ought to be the sole or even the dominant consideration in making societal decisions. After all, risks are not physical phenomena. They are abstractions, and any "risk assessment" is therefore deeply colored by the social context in which it is to be applied.

It would no doubt be easier for people who have to make decisions to have numerical risk estimates to compare against an absolute standard, or to place on a relative scale. One could organize a society on that basis, but I suspect only a minority would want to live in it. The complexities that make a creative life possible would gradually disappear. Those fragile aspects of human existence that William James once called the "fuliginous mists of affection, . . . the swamp-lights of sentimentality," would vanish. And for those people who retained the old values, society's decisions, cast in "rational" numerical form, would express no more than the will of the decisionmakers. In principle, a numerical framework for risk estimation can be compatible with a wide variety of value systems. But as a practical matter, the conventional "expected value" approach favors a narrow spectrum of individual patterns of ethical preference.[5]

On the other hand, one certainly can ask the question: How should we choose between different means of producing energy? We do choose, in subtle ways when we set long-term national energy priorities, and explicitly when a utility decides whether to buy a conventional power plant or a nuclear reactor. It's a close comparison, however. With respect to coal there are considerations such as the ones Dr. Brooks talked about: the effects of carbon dioxide on the global climate, the efficiency with which we can clean up the emissions from a coal-fired power plant, and the health consequences of those emissions. And for nuclear power one has to consider, among other things, the future effectiveness of nuclear safety regulations, the nature of possible future reactor systems, and the implications of different ways to close the nuclear fuel cycle.

In present circumstances, given the large uncertainties involved, we should not make exclusive energy production choices, but should try to maintain diversity. I take the principle of diversity to imply that we should leave the

[5] For an opposing view see Starr & Whipple, Risks of Risk Decisions, Science 208, 1114 (1980)

door open for a move, over the very long term, away from central station power technologies.

SIDEY: Here again, trying to sum up the public mood is a bit difficult. But it seems to me, as Dr. Brooks suggested, that this ultimately comes back to a political decision.

The political environment in the country has to do with events around the world. I think acceptability finally comes down to the state of panic or nonpanic of people. I do look for rather somber times ahead. I think we have gone through these postwar years with very little inconvenience. I think most Americans at this point really don't believe that their power supply will be interrupted. Perhaps it's beginning to sink in a little bit. Ultimately I suspect that in the political environment it will boil down to a matter of survival, and I guess in those simplistic terms that we journalists use, it comes down to freedom.

Do we finally approach--and I suspect we will before long--that point where we look around the world and we see the Soviets on the march or whatever is happening and we see our own economy in decline? Perhaps we begin to run out of energy. Then I think the probability that you talk about takes on an entirely different meaning in that world. We begin to suggest, at least to ourselves, that perhaps the worser evil is a national decline that might lead us into nuclear war.

What I see is, perhaps, the element of inconvenience in national life playing a great part in this, that indeed it will finally end up in the political environment, and that the figures finally may not be that meaningful.

LEWIS: I'd like to just say a few words against oversimplifying this. There is a tendency in dealing with the acceptability of nuclear power to oversimplify and to accuse people who want to judge acceptability in quantitative terms of being stupid, and of seeking a specific threshold number such that if the number is 10 and the reactor is 9.99, it's acceptable, and if it's 10.01, it's not acceptable. I don't think any of us really believe that. I think that's a straw man, and I just wanted to dispose of that.

Obviously, acceptability of any complex industry has to do with public acceptability, acceptability to regulatory agencies, to government. Other industries have had a bad time achieving acceptability. The aviation industry had a bad time achieving acceptability at the very beginning.

Most of us don't remember that. The basis for acceptability in the end has to do with the benefits that you derive from the thing you are doing. Obviously, reactors would not be acceptable, whatever the low level of the risk, if they didn't do anything for us. That's clearly so. And if what they do includes the avoidance of war--I don't think so much of nuclear war as of a conventional war in the Near East--that's very good. In my view, although many people argue about the economics, they also make electricity a little cheaper than most other ways of making electricity, and that's good.

The risks are those that we're discussing here, which are accidents; but there are also risks associated with things that have been dealt with in other Forums. It's a whole complex of issues in which the society as a whole, helped, not hindered, by its experts, has got to decide whether the benefits, on balance, outweigh the risks and outweigh the downside elements.

Many of my friends are very much involved in comparing the risks of nuclear power with the risks of making the same amount of electricity from coal or in comparing the risks of nuclear power with the risks we normally assume in other walks of life. We accept automobile technology even though we know a certain number of people get killed in it. I submit that neither of those is particularly interesting or particularly important, because in all of these technologies the only real issue is whether we get more out of it than we put into it in the way of risk. Risk is a form of cost and should be, in my view, included in all the other costs. When we have some understanding of the costs, including risks, we'll make a societal decision about whether it's worth it.

I discovered not too long ago that the riskiest thing that we can do in life is canoeing. I have a 10^{-6} probability of getting killed for every 9 minutes of canoeing. I found that just an astonishingly high probability, and I wondered how they could have known how bad I am at canoeing. But it has no relevance to the question of whether I'm willing to assume nuclear risks in order to get electricity reasonably conveniently and cheaply. I've been accused of misusing statistics to suit my own purpose; this is an accusation that I deny vehemently but without rancor. But I do think that to say that we cannot accept a technology that threatens our lives isn't very helpful.

KOSHLAND: I want to ask one question in general following up on Mr. Sidey's conclusion that as the need rises, the public's perception of how much risk they're willing to take is going to change. Everybody here would probably agree that if we really need energy, siting a reactor in South Dakota would be great, and that if we can impose that on the people of South Dakota it would help the country greatly. Do you think that we're going to come to a stage where the government is willing to impose a reactor in an area over the wishes of the people of that area? Is that something in the near future, or in the far future?

WAHL: I think it's been done many times. There's no question about that. You don't always have everybody in the neighborhood willing to accept the siting of the reactor. That's what the public hearings are about, and generally there are people who come forward and say we don't want this damn thing in our backyard.

Now, they don't always win that public hearing. In fact, they very rarely get their wishes. There are already many cases in which we've, let's say, sited reactors or other facilities, maybe even railroads, for the benefit of the common good of the society over the wishes of a few.

If society were filled with nuclear physicists, the perception would be different. However we're dealing with a world in which most people do not understand how reactors work, do not understand the nature of radiation, and do not really understand what radiation does to their bodies. The siting issue in the nuclear case has to do with who is going to deal with this risk, a risk that is perceived as much more serious by the public than by those in the industry who are familiar with radiation.

Incidentally, I think this reluctance to tolerate an unknown technology is a rational response by the public. I would deal with an escape of certain strange bacteria out of a recombinant DNA laboratory very gingerly, much more gingerly than I would deal with escaped radioactivity. I'm familiar with one and not the other. I think a cautious response to a danger that is unknown to me is a rational response. For the same reason I think it's a rational response on the part of the public to be more wary of radioactivity than would a scientist. Ordinary people don't understand radioactivity; they don't know how to deal with it.

I would do pretty well, I think, in a bad reactor accident. I and others familiar with nuclear matters would know more than the ordinary person about how to protect ourselves, and so, perhaps, we have a different "gut-level" tolerance for nuclear power.

I think that ultimately the question of complexity of technologies and the public's response to complexity are going to be key factors in the choice between technologies.

At this point I want to sneak in a brief response to Dr. Lewis on the usefulness of my criteria for choosing energy technologies. (Before I do that I should say that I respect him very much and I generally respect his use of probabilities, except for tonight when I thought his remarks on probability were inappropriate to the issue.) When I was speaking earlier I neglected to indicate how I think decisions about energy sources should be made. If I were in charge of siting a particular power plant, I would be very careful to make sure that a plant was really necessary before I would agree to site one. I would look critically at industry projections for future electricity demand, and I would look carefully to see if there were not energy efficiency improvements that could be made in the district that would eliminate the need for a new plant of any type. (TVA's experience in eliminating a new power plant by initiating a program to improve the efficiency of electrically heated houses is relevant here.)

Only out of a strong conviction that a power plant is absolutely necessary would I "accept" the risk it would imply. It would only be at that point that I would consider looking at the alternatives. I would be very harsh on unsupported safety claims, not just of nuclear power but also of claims about the alternatives.

BROOKS: I'd like to comment on several points that have been made. First of all, on the question of deaths due to the generation of electricity being tolerable, I agree with Dr. Lewis. I don't think this is a very helpful point. On the other hand, I don't think there is any level of deaths from electricity generation at which we should stop trying to improve the situation. But I don't think we should do nothing until we can guarantee that the fatalities from electricity generation are zero, nor do I think we should spend an infinite amount of money to continue reducing the probability of death from electricity generation to zero. How much would I be willing to spend? The only answer I can give would be at least as much as we spend to reduce the probability of fatalities in other areas of society.

I'd like to subscribe very much to what Joel Yellin said about diversity. In fact, I don't like very much the comparison of nuclear and coal because I believe the best strategy is a mixed strategy, as diverse a mix as possible. First because I think you're safer by and large overall if you have technologies with complementary risks; that is to say, risks that are not likely to be the same under the same circumstances. And second, if you have both technologies in place, then you can shift your emphasis from one to the other as new knowledge appears and new experience is gained. Thus you're not locked into the situation that you got into because you made a prejudgment way back that this was the safest way to go, and then you discovered way down the line that it might not have been the safest. I'm very much a believer in a mixed strategy. I think a system that represents a combination of centralized and decentralized power generation is probably much more desirable than either one or the other by itself.

KOSHLAND: I noted in a recent election in Sweden that the people living near nuclear reactors voted 3 to 1 in favor of them, probably because they had jobs there. Supposing we offered a subsidy to the neighborhood that was going to take the reactor, that there were added financial rewards for the people taking the risk. Do you think that would work, and is it ethical?

YELLIN: The compensation arrangement you suggest is very close to what's done in Japan in their nuclear program. As I understand it, when a reactor site is proposed there, negotiations take place among the utilities concerned, the central government, and local and prefectural governments. In addition, financial arrangements have been made with groups outside of government, such as local fishermen's cooperatives. Within that particular social system, a negotiation and compensation approach seems to work in the sense that, in the majority of instances, reactors have been constructed and electricity produced. Of course, the Japanese nuclear program is by no means free of political controversy, the number of nuclear sites is not large, and reactors are heavily concentrated in three areas relatively distant from the most heavily populated urban centers.[6]

Fishermen's groups have been paid compensation for damage to coastal fishing grounds ostensibly caused by thermal pollution. As for local residents, there appear

[6]See Yellin & Joskow, Siting Nuclear Power Plants, MIT Center for International Studies report C/79-5 (1979), appendix. As of 1978, there were 15 approved Japanese commercial reactor sites and 88 approved U.S. sites.

to be no direct subsidies but there have been indirect subsidies of various kinds, for example, providing a new train station or making special tax payments to local and prefectural governments. With respect to whether subsidies, direct or indirect, are ethically defensible, I don't consider that to be a well-posed question. It is a condition of industrialized society that siting large facilities results in "subsidies," whether implicit or explicit. So I don't suppose one can make a general ethical argument, but on a case-by-case basis ethical issues certainly deserve to be explored.

BROOKS: It's my opinion that we ought to use compensation much more extensively than we do. I think the ideal form of compensation when you could do it would be one in which different communities bid for how much they would take to accept facilities in their vicinity. I don't see anything unethical about that. I think it maximizes the choice and that it's a form of the exercise of freedom of choice.

WAHL: Your question gives me an opportunity to complete an answer to an earlier one. I was very curt when you asked if reactors have been sited over the objections of local residents. I only spoke of the people who object. I think there are by far more people who accept the plants without a lot of concern. The ones who have the concern, after they experience the new neighbor, generally feel it is a good neighbor. I know I could not make that statement about eastern Pennsylvania.

LEWIS: I live in Santa Barbara, California. California is not a state that, for reasons I think we all know, is hospitable to nuclear plants these days. We can't build them. The California Energy Commission wants to site a coal plant 20 miles down the coast from Santa Barbara where I live, and if they do, I want a subsidy.

KOSHLAND: Mr. Sidey, you were talking about the public perception of accidents. Supposing a steady number of people are killed over the years, let's say 200 a year in one type of industry and 2,000 in one accident every 10 years in another. Do you think there will always be an imbalance in the perception of that type of risk?

SIDEY: Well, here you deal with this mass explosion in communication; and I, being a member of it, don't understand it. One of these days we may figure out what we've got here, but up to this point we haven't.

If you had a massive accident with 2,000 dead, the fallout from that would be horrible. I'm talking about psychological impact. It seems to me that with Three Mile Island those of us in kind of the general media first off decided it was of panic proportions and it probably was not. We simply didn't understand it that well; and then, of course, once that had been implanted through television, which dominates the public mind quickly and overwhelmingly, then we dispatched the more thoughtful people who went up and discovered the panic that we had created or added to in that area. If the accident had been larger and more serious, the impact would have been very grave nationally, I think perhaps rightly so. I'm not one to judge that.

We are in this period when I guess we can't measure these things finally. I can't tell you what happens. Shortly after the Three Mile Island accident, over 200 people died in a DC-10 crash in Chicago; it was off the front pages in 3 days, though it was of immense proportions. We've already mentioned the deaths from automobiles and those from the moonshot and all of that.

Here, again, I think it has to do with the crisis atmosphere in the United States and what we perceive as happening to this country, and whether we need or must do these things to get energy. That is made up of so many factors. What would stop that or slow that, I don't know. Surely a massive accident, though, would be a jolt to our nervous system that would be hard to overcome.

KOSHLAND: I'll take questions from the audience now.

HILLEL RASKAS, Educational Consultant: With all due respect, I'd like to ask the panel: Why should we trust the experts? I drive a car and I fly in airplanes; yet, the DC-10 did crash with a friend of mine; the helicopters in Iran for a rescue mission had trouble because of mechanical reasons and failure of personnel to follow all procedures in some cases. Things happen all the time. We can't build cars whose gas tanks don't explode part of the time.

I'm not saying this in a context of pure crisis or pure panic; the point is that nuclear power plants and all the other issues that were talked about either previously or will be talked about will affect people for tens of thousands of years. And so my question, partly to the panel and also just to put in the minds of the audience, is that of a skeptic who simply asks: Why should we trust the experts when we do have all those problems?

KOSHLAND: Who would like to answer that one?

WAHL: I consider myself maybe halfway between a pragmatist and an expert, but let me give you my view of why you should trust the experts. I really believe that you don't have anybody else to trust. Now, that doesn't mean blind trust. No, I'm very serious about that. We have an excellent educational system in this nation that develops experts. We have industries that take those graduates--they're not expert at that point but they're at least trained in the basic techniques of becoming experts--they take those educated people and they continue to develop in an expert atmosphere.

I'll come back to why you can't have blind trust in experts, because I believe that. I don't want blind trust in the nuclear power industry even though I'm a part of it. I have a tremendous amount of respect for what's been done in 25 years, but I want a regulatory commission that has the best expertise in this country to regulate that industry. I think that's very important to our society.

You have to trust the experts. I really believe that you don't have anybody else to trust. Now, not all the experts will agree, but you need to listen to the experts.

BEYEA: I don't think you should trust the experts. Fortunately, the nuclear industry doesn't consider me an expert, so you can trust me.

The issue of when society should defer to experts is a crucial one. To decrease the need for such deference I suggest that we use simplicity as an important criterion in choosing between technologies. I am convinced that we should be moving toward technologies that are simple enough and easy enough to understand that we don't have to trust the experts to declare them safe or acceptable. This is one reason that I want to move away from nuclear power and move toward certain types of solar technologies that are easy to understand and which, therefore, are not frightening and not alienating.

I do not mean to imply that the public should never trust experts. Although scientists and engineers make a great many mistakes they do learn a great deal from the process. Trial and error is the essence of the scientific method. Take the aviation industry for example. When planes crash, people (called experts) go in to find out what happened. They learn why the planes crashed, and they make the next generation of planes better.

I'm absolutely convinced that after five meltdowns the nuclear industry will be able to get the bugs out of reactors and that we will then get relatively safe reactors. However, the question is whether we want to use trial and error methods for this technology.

The public has to learn that experts have something to say, but that expert opinions are not always valid. They tend to be valid when based on a large body of experience. The public should learn to distrust technical opinions about new technologies when those opinions are based on theory, not experience.

JOSEPH McCAIN, International Medical Tribune Syndicate: We're talking about the public acceptability of risks, and since we can say that the public apparently accepts 40,000 to 50,000 deaths a year on the highways, I want to ask if we cannot assume that this discussion will soon become moot in the future as the energy crisis will become worse and the public is going to demand nuclear energy as soon as the petroleum industry is largely dried up, regardless of what the risk is?

SIDEY: You know, when you go back through all of these considerations about energy at this point, you come up to--or at least I do and some others--the principal thing now is our political life, which is the threat from the Soviet Union.

It seems to me that there have been many wise politicians in Congress and around this country who have recognized the risk in going too fast with nuclear energy or indeed in almost all other areas--people who have some good ideas about breaking up some of the industrial giants, about the storage of waste, all of those things.

But we come back to this moment in our national life when we look over to see the Soviet Union having exceeded us in military production. We're not certain whether their appetite is for the Persian Gulf or for much of the rest of the world. And the fact of the matter is that, at least as I interpret the politicians, they see that to maintain a viable economy, which is central to our strength here at home, and to maintain a military machine that hopefully will discourage other aggression, we have simply got to continue rather rapidly the ways we are going at this time, and we see no other alternative.

So I come back to this decision, that it is going to be political. At this point it seems to me it's moving rather quickly in the direction of supply of energy and that takes in nuclear reactors.

LEWIS: I just want to add a couple of points. I think you're right that as the energy crisis that is upon us becomes severe, then discussions like this, if we are really confident that we are talking about an average of one, two, or three lives a year, even if it's not zero, will be lost in the noise.

My concern is that while these are poignant and frightening issues to the American people, we may so disable our ability to move in that direction--it does take 10 years in this country to build a power plant--that we will be unable to respond when we become aware of what our problem is. That's why I think that this kind of discussion is beneficial, because we ought to know as much as we can at the moment about where we ought to be going in the future.

BEYEA: If the public makes a decision to go for nuclear power on an informed basis, then I will accept that decision. I say that because I think the decision to accept a new and risky technology has to be made by the public, not the experts. The important qualifier I add is that the public should be informed about what it is buying.

However, in making decisions about whether or not to use nuclear power, it should be realized that nuclear power is largely irrelevant to the issues that were just mentioned about national security. Nuclear power presently contributes about 4 percent of our total energy supply and about 13 percent of our electricity. It is a rather minor component. We could survive easily by increasing our other alternatives, such as coal power. I think the idea that nuclear power is the savior of the Western world is a little overblown.

It surprises me that the greatest potential for improving our energy situation through improving the efficiency of automobiles and through stopping waste goes largely ignored. The first priority in improving our national security should be eliminating the enormous waste of oil taking place in our inefficient buildings and inefficient automobiles. After we have dealt with oil waste, I will begin to entertain the question of whether in fact nuclear power is necessary to the national security.

FRANKLIN GAGE, Task Force Against Nuclear Pollution: I'd like to note first that it's interesting that it took a member of this audience to mention the two words that say more about nuclear safety than anything the panel described; those words are Price-Anderson.

I would like to ask each member of the panel if you think that nuclear power is so safe, do you support removing the limit on liability for the accidents that you claim will never happen? I wish you would answer this paradox for me, because I have difficulty believing your claims of nuclear safety when we see the industry scrambling to protect its assets while it risks mine and other people's involuntarily.

BEYEA: I don't think you should suggest that every panelist believes there will be no accidents. My subjective, pessimistic judgment is that in fact we will have a large release of radioactivity over the course of the nuclear program.

BROOKS: I guess my problem on the Price-Anderson Act is that the present legislation, as I understand it, is a damned if you do, damned if you don't situation, because the same Price-Anderson Act that limits liability also requires financial responsibility on the part of the companies. I have been told by many people in the industry they would have no objection to the repeal of the Price-Anderson Act if then immediately intervenors would not file and say you can't build a plant because you're not financially responsible if you can't compensate the public, and you don't have enough assets to compensate the public for the maximum credible accident.

WAHL: I believe it's in the interest of the public to have Price-Anderson from the standpoint that there's not a company involved in designing or building or fabricating reactors that is going to be able to provide the same level of coverage that Price-Anderson can provide to the public through the Congress.

GAGE: If the assets of a company are not sufficient to cover this risk, doesn't that say something about this risk? I thought in the free enterprise system the main constraint on reckless activity was financial responsibility for the consequences of that activity. If the companies that are doing this activity cannot assume full financial liability, then does that not say that this is a risk that they should not be imposing on us.

BROOKS: It depends on whose judgment that maximum liability is arrived at. I think most of the companies would be willing to accept the chance, but the question is whether the public has the same evaluation of the chance.

LEWIS: I just want to say one thing lest it be wrong on the record. I did not hear any member of this panel say nuclear accidents will not happen. That's just for the record.

Second, the correlation between the capability of a company and the potential that it may do damage was brought home very clearly to me about a year or so ago when my favorite company that makes sourdough bread in San Francisco had to go out of business because one of their trucks hit somebody. The award in the action exceeded the capitalization of the company, and they went out of business. I don't think that that proved they shouldn't make bread.

KOSHLAND: I'd like to switch to the last question: Are there ways of reducing risks in the future, and if so, what are they?

WAHL: Yes, there are ways. There are a number of ways that have been identified, in fact, in the Kemeny Commission report and the Rogovin report, which both address the Three Mile Island incident. I think you'll find that there is a general endorsement throughout the industry both on the part of the regulators and the regulated that we should make more use of the probabilistic risk assessment that Dr. Lewis talked about earlier that was used for the Reactor Safety Study. While it may not provide absolute numbers of risk, it is a powerful tool from the standpoint of identifying weak spots in systems or in design approaches that can then be given more attention, thereby reducing the risk. I might add that the Advisory Committee on Reactor Safeguards has also supported that. We do feel that we have a powerful tool that is still growing in its use in industry.

It is relatively new to the nuclear power industry from the standpoint of the formalization that has been applied to it in the last few years, but it is finding good acceptance. I think it will be a major tool in improving our ability for reducing the risks. It will probably bring some more consistency to the licensing process in that we'll have a better way to communicate about risks and therefore maybe attack the big question that we've been struggling with here: What's an acceptable level?

The Kemeny Commission has also identified, as has the industry itself, the need for more attention to feedback of operating data regarding malfunction of systems and components. We've not done an adequate job of that in the past, from the standpoint of the formality in which we acquire the data, the way in which we analyze it, and the way in which we feed it back into the systems design.

The industry has set up the Nuclear Safety Analysis Center as a formal tool to provide that support for the industry. In addition to that there's been increased attention on the man-machine interface or the human factor aspect of running one of these plants.

The Institute for Nuclear Power Operation, another formal organization set up by the industry within months after the Three Mile Island incident, is designed to go into these human factors in more detail, to do a better job of training operators, and to be able to systematically provide them with better information upon which to make decisions in times of crises.

These are all ways that we think we can make significant improvements in the operation of the plant. In addition, the NRC has identified many design improvements in the way of instrumentation and information that would be provided to the operators, and many of these have already been made in the plants. In fact I've seen numbers--I'm not expert in these probability discussions--indicating that we think we may have reduced the recurrence of the TMI sequence of events by maybe as high as a factor of 25. That's a step in the right direction, and those are things that we do need to do.

LEWIS: I may help to answer an earlier question, because for this part of the discussion I will appear to be antinuclear, and that will help a little bit to redress the balance of your panel.

I think there is a heck of a lot we can do to improve nuclear safety, and we can probably even save money doing it. It's not all in the area of technical fixes. My personal view is that there have been too many technical fixes in the aftermath of Three Mile Island and that in a sense the nation has been in a state of shock and panic about it. People have sort of felt that they had to do almost anything anybody thought of without using, if you will, the techniques of probabilistic risk assessment to find out if it made sense.

There are many things that people have been talking about for years that somehow seem not to get done. The Kemeny Commission had very few comments to make about technical fixes in reactors, but they came down very, very hard on everybody who was involved in reactors--the industry, the Nuclear Regulatory Commission, the Advisory Committee on Reactor Safeguards, of which I am now a member but was not at the time of Three Mile Island, and everybody involved.

The fact is that some of these techniques are known. They include the techniques of probabilistic risk assessment to identify weak spots in reactors. They include the techniques of looking at prior operating experience to identify weak spots. Contrary to what Dr. Beyea said, they don't have to be core-melts. Every accident or malfunction in a reactor has implications for the safety of the reactor, and what the Kemeny Commission called the mind-set of the industry is really there. I subscribe to that conclusion of the Kemeny Commission. The fact is that the system was not gearing itself in such a way as to improve the safety of reactors. On the issue of operating experience, we all know that Three Mile Island had a precursor, an accident at the Davis-Besse plant, which was very similar in its structure to Three Mile Island. Lots of people noticed this. Reports were written, people said we ought to be sure that this doesn't happen again, yet it happened again. There was an accident at Rancho Seco. You do not read about these accidents in the media because, if you'll forgive me, nobody gets hurt.

The accident at Rancho Seco was extremely informative of an accident mode that is quite threatening to reactors, and people noticed it, but hardly anything was done. Then it happened again in Florida in February, and things are being slowly done.

I think the system has, in my personal view, been so concerned with regulation, as distinguished from safety, that we've gotten into a box in which we don't fix reactors. I understand some of the psychology of that, because the pressure on panels like this and on the NRC is not to make reactors safe; the pressure is to prove that they already are safe.

I'm convinced that, in addition to all the hard things that we could do, there are a lot of easy things we could do. For some reason they weren't done before Three Mile Island in terms of increased responsiveness of the system, and I'm not convinced that they're being done now.

When I look at a regulatory agency that deals with an accident like Three Mile Island, which had perhaps three or four causes, depending on how we haggle about what the causes are, and generates a plan to cope with it that has 200 items in it, I think somebody just hasn't done their homework very well. I think we will have this problem of identifying those things that are important to safety and doing them instead of making plans.

KOSHLAND: Are you suggesting that you need a mechanism for feedback; that the information gained by the accident at one reactor was not fed to the people who were running the other reactors so they could profit from the experience?

LEWIS: Well, this is my personal view. There are a lot of things that need to be done, and don't misunderstand me, things are improving. I believe that we need an institutionalized mechanism for forcing us to learn by experience in the same sense that the National Transportation Safety Board does it for aviation, and given time I could go into that.

BEYEA: I would like to mention some other possible ways of reducing risks from reactors. I'm particularly concerned with improving the safety of existing reactors. I would hope that there would not be a need to build new nuclear power plants. On the other hand, I think a decision to shut down operating plants (given the investment and the problem of choosing benign alternatives) is a much more difficult decision to make. So I've looked very carefully at, and hope to promote, certain ways of reducing the risks at existing facilities.

One method that hasn't come up in the discussion so far, but which is being looked into very thoroughly by the NRC and other people on this panel, is to give reactors some capability to withstand meltdowns. Reactors were never designed to contain a meltdown. They may in fact under certain accident circumstances happen to contain a meltdown--perhaps pressurized water reactors more than boiling water reactors--but they were never specifically designed to do so. The assumption was made that regulatory procedures would keep the meltdown probability so low that reactors did not need this capability.

I think such a view is no longer tenable and that we do, based on Three Mile Island and some other accidents, have to realize that a meltdown has a significant probability. Therefore it would be desirable to give existing reactors some specific capability to withstand a meltdown, something that turns out to be possible. A technological fix, called "vent-filtered containment," provides a way of adding a safety relief valve to a reactor. In accident situations, if it appeared that a catastrophic release was actually beginning or would soon follow, the radioactive gases would be vented through a large filter system, trapping most of the radioactivity before it could become airborne.

There are some problems with adding any new safety device to a complex system. The interaction of the new device with the old safety devices has to be looked at very carefully. But vent-filtered containment is one of the reasonably cheap options that could be backfitted into existing reactors (it might cost $10-20 million, a cost that is very cheap compared to the billion-dollar plant investment). Here is a concept that should receive a great deal of public discussion.

The second option, which is more controversial, certainly within the NRC, is the mitigation of the consequences of accidents through emergency planning to distances greater than are presently considered necessary. The present rough order-of-magnitude distance that the NRC is using for emergency planning is 10 miles. Ad hoc measures would be relied on beyond 10 miles. I think we should do more prior planning. We should not rely on ad hoc measures beyond 10 miles. I think 10 miles is a good target distance for evacuation, but under certain weather conditions I would want to evacuate much farther, perhaps out to 30 miles. Even beyond the evacuation distance, there are some measures that could be taken to reduce the doses and the resultant probability of cancer. Sheltering in buildings is one strategy. Breathing through homemade cloth filters is another.

Finally, there is the somewhat controversial option of stockpiling potassium iodide, a medicine that can reduce certain radiation doses. As I understand it, potassium iodide may not be cost-effective as an emergency measure. I look at the cost of potassium iodide as an insurance premium on an insurance policy. If we never use the medicine (as I hope will be the case), we'll just have to "write off" that expense--an expense, incidentally, that is small compared to the amount of money we spend on regulating nuclear reactors. Many antinuclear people don't like potassium iodide because they feel that it gives the impression that there is a panacea for reactor accidents. I don't want to give such an incorrect impression. I just want to tell you that there are measures that can be taken to add levels of defense beyond what the NRC is presently doing, measures that seem to be reasonably cheap.

KOSHLAND: I wonder if someone would comment on the possibility of reducing risk by, say, having reactors farther away from metropolitan centers. What are the pluses and minuses of that, and should we shut down reactors that are currently close to big cities or something of that sort?

YELLIN: Let me say first that I agree with Dr. Lewis' suggestion that there be an analog of the National Transportation Safety Board that would investigate accidents at nuclear facilities. A provision of that kind is included in Congressman Udall's omnibus nuclear regulation bill.

That would be a constructive step, but it's not the only institutional means for improving safety. The Kemeny Commission, appropriately I think, suggested a number of ways to develop and resolve conflicting views about important safety decisions directly within the regulatory system. Responding to those recommendations, President Carter has appointed an external oversight committee for the NRC. Precisely how it will operate remains to be seen. Its influence may well be positive.

But whether the Kemeny Commission's suggested internal modifications to NRC will be adopted is an open question. The Commission recommended that the Advisory Committee on Reactor Safeguards (ACRS) be authorized to act as party-intervenor in licensing proceedings and that an NRC Office of Hearing Counsel be established. The President has given generalized support to those suggestions, but has declined to implement them and has passed the decision to NRC. That's regrettable, because agencies are naturally reluctant to make internal changes, and that's where progress is needed. External oversight of the technical side of nuclear regulation, whether by Congress, the courts, or "public interest" groups, hasn't been effective.

With all due respect, there are hints--in the lack of specificity of the White House's reply to the Kemeny Commission's recommendations, in the President's grudging public support of the Commission's work, and in the excessively short time the Commission was allowed to complete its task--that the White House was less than enthusiastic about the opportunity to use the Three Mile Island accident to learn how to improve the regulatory system.

Coming to Dr. Koshland's question, it has been the assumption of regulators over many years that major reactor accidents that injure members of the general public are "incredible" events, in view of "engineered safety features" such as containment buildings and emergency core cooling systems. Following Three Mile Island it has become clear that those assumptions were excessively optimistic. At this point, we ought to reexamine the important safety-related decisions that the NRC and AEC made over the last 25 years.

In particular, we would do well to reexamine past siting decisions. In my opinion, it's both unethical and imprudent to site reactors where there is no practical possibility of evacuating nearby residents. We ought to look very carefully, independent of past industry and regulatory judgments, at such sites as Indian Point (which is 35-40 miles up the Hudson from New York City), Zion (which is on Lake Michigan roughly halfway between Milwaukee and Chicago), and Limerick (at which a reactor under construction is 25-30 miles from downtown Philadelphia).

I understand that reexamination of safety issues at those sites is under way and that NRC is considering whether to require additional "engineered safety features," such as controlled containment venting following a meltdown. I favor that particular innovation for all reactors, and perhaps others are advisable, though we'd better be sure that any design change does not add complexity, with minimal improvement in safety. It's important to emphasize that any such reconsideration will be incomplete without serious study of a gradual phaseout of reactors at the least favorable sites.

HERRING: It's been brought out by much of the previous discussions, with which I agree, that there are both human and organizational measures that can be taken to reduce the risk and also technological ones. I'd just like to comment a little more on the technological side.

Dr. Beyea mentioned mechanisms for venting of the containment, i.e., allowing excessive high-pressure gas to escape from the containment building through filters that would remove most, but certainly not all, of the radioactivity rather than running the risk of letting the containment overpressurize itself. I believe that there is a good deal of sentiment in favor of such measures, although these, like all other technological measures, have to be very carefully evaluated using probabilistic risk assessment and so on to make sure that you're not introducing a danger in one place in order to correct one in another. Overall, though, I would not be surprised if the Nuclear Regulatory Commission were to take some action in that direction.

Another technological measure that has not been mentioned--one that some in the nuclear engineering field espouse strongly--has to do with preventing meltdowns by getting at what seems to be the most likely route for meltdowns to occur, namely, the correlated failures of a number of different things. This is the sort of thing that happened at Brown's Ferry. It's the sort of thing that happened at Three Mile Island. A large part of this could be avoided (so runs the argument; I don't claim to be an expert) if there were a dedicated system for heat removal so that one would not have to rely on systems that to some extent overlap in their function or their control with the mechanisms that are used in ordinary operations.

At any rate, my point is simply to say that there are additional technical measures that need to be evaluated, that have some promise, but regarding which it's at the present time a little too early to say whether they'll be completely effective or not.

KOSHLAND: Mr. Wahl, I want to ask another question. You mentioned earlier that the Kemeny Commission report came down heavily on the training of reactor personnel. Since man is far more fallible than machines, could reactors be made much safer if we put into a computer the information from previous accidents?

WAHL: I've had a fair amount of experience with computers, and I do believe that we can take better advantage of computerized analysis, high-speed analysis of accident situations. I think the reference you make to putting feedback into a computer relates more to being able to take this data that we have available from many, many plants and by using the computer to quickly analyze it and tell us what it all means.

I think there's fairly good consensus that we need to, from the standpoint of displaying information to operators, run some of this through the computers so that it can do some of the thinking for them. But I'm pretty strongly in favor of doing a better job of training operators to understand the problems that can occur with maintaining cooling to the reactor, and that's not just for safety systems. Many of the heat removal systems that we have in the plant just for normal operation are many magnitudes larger than the safety systems, and we really don't believe that these more frequently lower-grade accidents are going to happen due to an earthquake or tornado or some natural catastrophe like that. These systems will in fact be available to help us cool the core. That was true in TMI, and I think it was true at Brown's Ferry.

The point I would make relative to the computers is, yes, we can make better use of them. I believe we can make better use of miniaturized instrumentation--cathode ray tube displays of graphical information, which allow a human to understand much more quickly what is really going on. Graphics is a very powerful tool. The British have done a better job of using that in their nuclear plants than we have, and we need to take a page out of their book. I guess I would still, in spite of doing all those good things with the machines, opt for doing just as much in training the operators. The nuclear navy has had great success in the rigorous training of operators.

KOSHLAND: Have the submarine reactors had a better record than commercial reactors basically?

WAHL: I think I could say yes. I don't really know. I don't know of the minor malfunctions because the data are not really available to the public. But their record of reliability and strategic maneuverability over long distances with no operating problems, to my knowledge, speaks for itself.

BEYEA: Well, I think it's very difficult to make useful comparisons of reactors in nuclear submarines with commercial reactors. Submarine reactors are much smaller than commercial reactors. The basic problem I see is that the safety information is classified. Two nuclear submarines have gone down. That doesn't make me feel too confident about unsupported safety claims. Until the information about these sinkings is declassified, until a record of all malfunctions is released, I don't think we can use the nuclear submarine situation as an example of safe reactor experience.

KOSHLAND: I want to ask Mr. Sidey one question in regard to the information. On the interaction of the public with science, would you like to assess the role of the media and the role of scientists? I don't think scientists have been perfect in this kind of situation; a sort of highly emotional, highly technical area.

SIDEY: I think that probably most Americans have faith that we are improving and this discipline will do much as aviation and others did. I think we in the media feel much the same. But I do confess that those of us who write about politics and general decision making at the highest levels of government are ignorant in this world. When you meet a crisis like Three Mile Island that rises up to that level, we are suddenly confronted with the problem of writing rationally about it and we don't do very well at it. We don't pay much attention to the details, like this whole matter of improving or cutting down risks. We tend to drift away; bigger issues dominate us.

I assume there are technical people in the mass media today who write on these things, but I do confess that I seem to see them less and read them less all the time as the political problems seem to get greater and deeper. I'm not sure that we do a particularly good job of talking about what can be done, or even presenting the numbers that we've talked about here, what the ratios are. We tend to respond, I would guess, much like politicians in many ways.

I would judge that we could do a great deal simply by paying more attention, being more aware, and just trying to listen a little better and urge improvement. I think, though, by and large, that we have quite a faith in scientists and technology, and we would believe that they are making good progress. Perhaps we misplace our faith; I'm not sure.

KOSHLAND: I think scientists have a shorthand that is basically a jargon and a convenient way of conversing with each other because we know what rads and rems and curies and so forth are. It is frequently difficult, and particularly in a crisis, to rethink this language and make it understandable to outsiders. I think perhaps both sides have to help a little bit. Now we will take questions from the audience.

N.H. SAUBERMAN: I'm an engineer, and my remarks are addressed to a fellow engineer, Mr. Wahl. It seems to me that this whole discussion regarding the risks inherent in nuclear energy may be a bit irrelevant and is merely another way to justify the acceptability of nuclear energy as a commercially viable alternative to other means of power generation, such as fossil fuels. I say that in all sincerity because I believe that the main problem concerning nuclear energy, and which will have to be addressed sooner or later, is not really made up so much in the risks as it is in the failure to close the nuclear fuel cycle. Until some way is found by which we can successfully dispose of our nuclear wastes, the discussion regarding risks is a bit premature.

I would like to ask my fellow engineer whose honesty I really admire to answer that question.

WAHL: Well, I guess I would agree with you that we do need to get on with the business of solving that problem. I think it is solved technically, but we do have some political problems in deciding how we as a society are going to site the disposal plants, that type of thing. It's a question of whose backyard you're going to put it in.

GLORIA DAVIS, York, Pennsylvania: We live halfway between Peach Bottom and TMI, and thank you, Mr. Sidey, but we have had our share of psychological jolts, and we hope we don't have any more.

A new insurance pool for the nuclear industry has been formed, and ostensibly it is to cover the terrific costs of both the replacement power and the cleanup in an accident like the one at TMI. Anyone who is familiar with Price-Anderson knows that that is a government-subsidized insurance program; in other words, the taxpayers are paying for that.

Now along comes this new insurance pool. In yesterday's Washington Post there was a news item that Virginia Electric and Power Company would be going before the Public Utilities Commission to petition that the cost of paying this insurance be included in their operating expense.

Again this turns it around and puts it on the back of the ratepayers when and if there is an accident of that caliber. My question is--I think I know the answer: If the reactors can be made agreeably safe, and if the possibilities of these accidents are so remote, why will the utility industry not accept full responsibility for paying for the cleanup, paying for the risks that are involved? Why must we again accept the risk and pay for the damage?

YELLIN: I think that any utility in the country faced by "one-time" costs, including the cleanup costs you ask about and the costs of replacing power from a disabled reactor, would opt to pass them on to its ratepayers.

Under our economic system I don't really see how, in the end, either the general taxpayer or the ratepayer can avoid being burdened for a major share of those costs. In the extreme case, when the utility is forced into bankruptcy, electricity will still be needed. Unless state legislatures or Congress intervene and place the burden on the general taxpayer, the ratepayers will be charged to repair the equipment, buy power elsewhere, or construct new generating facilities.

KOSHLAND: I can answer that question in a brief way because I spent the last year on sabbatical in Boston, where when one of the nuclear reactors was shut down, the cost of the added fuel oil was passed on to the ratepayers immediately. I'm afraid the ratepayers are going to end up paying in the long run, no matter what.

DAVIS: Well, would I be out of line to ask whether you think this is entirely fair? One gentleman cited the instance of a food processor having to go out of business because he was not sufficiently insured and he was sued for something or other.

I think you have the equivalent here. You have an industry that thrives on profit, as most industries do--and I am not against this, I like profit as much as anyone else--but, by the same token, when something happens I don't think you can expect other people to jump in constantly and bail you out. I just don't think that's the way to go.

YELLIN: I agree it would not be wise to allow utilities to operate nuclear reactors without bearing any of the risks of financial loss if an accident should occur. Some of that burden will fall on the ratepayers, as you've seen. And some may fall on the general taxpayers via the Tucker Act[7] or, though in part that's up to Congress, via the Price-Anderson Act. But there surely will be a financial burden on stockholders too, though it may not be as large as you'd like. I understand that General Public Utility (GPU), which is the ultimate owner of the Three Mile Island facility, has suffered financially as a result of the accident. Two dividend payments have been missed, the price of the stock has

[7] See Duke Power Co. v. Carolina Env. Study Gp., 98 S.Ct. 2620, 2641 n.39 (1978).

fallen substantially, and though the New Jersey and Pennsylvania public utility commissions have allowed GPU to pass replacement power costs on to the ratepayers, they have ruled that the company is responsible for any uninsured losses due to damage to the plant. One would have to say that other utilities now have considerable motivation to avoid being involved in similar cicumstances, and that's as it should be.

BROOKS: I'd like to make two remarks. In the first place, it's customary in all businesses to consider the payment of insurance premiums as a cost of doing business and to include this in the cost. I don't see why this should suddenly be different in the case of public utilities.

The second point is that I think there's a misunderstanding. There is no subsidy, although there may be in some people's minds an implicit subsidy involved in the Price-Anderson Act. In fact, so far as I am aware, the premiums paid by the companies under that act have accumulated a considerable reserve.

Now, of course, there is an implicit subsidy in the fact that if a payout was ever required, then of course the taxpayers would foot the bill; but so far the taxpayers have not. It has not cost the taxpayers anything.

ROBERT S. McADAMS, York County, Pennsylvania: I want to discuss the word "acceptable." Semantically, it does not mean much until you say acceptable to whom, acceptable by whom. To me the radioactive inventory at Three Mile Island or Peach Bottom, which could, according to the WASH-740 update, contaminate an area the size of Pennsylvania and cause $17 billion worth of damage, is unacceptable.

I believe that I am being disenfranchised on this issue by federal expertise. I want to know how this issue is going to be resolved. If it is not acceptable in anyone's backyard, then it is not acceptable.

WAHL: First of all, I would respond by saying that I'd like to assure you that I believe that the Nuclear Regulatory Commission and the industry will in fact remove that waste as safely as we humanly know how. I guess we have to say that that leaves some element of risk or doubt. And what we're talking about tonight is how we can best accept those risks.

We don't live in a risk-free world, and while I believe that the amounts of radioactive material at TMI, at Peach Bottom are serious matters, I also believe the industry takes them very seriously, and I think that the record to date indicates that we take them seriously. We support that attitude.

I get upset because we seem to be getting an implication in the media and from the public that we don't take that business seriously. We've taken it seriously for 25 years, and that's why we have the safety record we do, and I want to assure you we're going to continue to take it seriously. I'm sure that won't give you any peace of mind, but that's the only response I can give.

BEYEA: I think the decision as to whether or not nuclear power is to be accepted has to be made at the ballot box. It is now a political decision.

ALLEN BRODSKY, Nuclear Regulatory Commission: First, I'd like to thank the National Academy of Sciences for these meetings. I think they're very important as public discussions. I'm sorry I got up so late and am taking the last question. I would like to recommend that more time be given for everybody to ask questions because people come here at great expense. I don't think we'll be that much more tired if we spend another half hour, so I'd like to ask for the people who follow me the chance to ask a question.

I'm a former associate professor of health physics at the University of Pittsburgh and professor at Duquesne University where I taught radiation physics, health physics, biostatistics, and epidemiology. My present job does not involve me directly in making analyses of reactor safety, but speaking as an individual because I am concerned about the health of people--it's been my career for 30 years--I'm concerned about my children and the environment. I'm also concerned about what will happen to this society if we don't make rational decisions by utilizing our resources to stay alive and survive in this world.

First , I'd like to review a quick scenario about TMI, and I'd like to ask some questions that have been touched on by the speakers. Did the Kemeny report actually come up with a conditional probability that, given there is a meltdown, a significant amount of fission products would be released to the environment in a power reactor accident such that we really would have the situation we're all worrying about?

The second question is, if such a probability is believed to be finite, why hasn't anyone mentioned taking the usual engineering approach of a pilot test? We have had many pilot tests of H-bombs, which are very destructive. We didn't seem to worry about H-bombs putting a lot of activity into the upper atmosphere.

I want to mention that less than 10^{-6}, less than one millionth of the radioactive iodines in the reactor at TMI, got out of containment and out to the environment. I made some calculations of my own based on a 1965 paper, which is calculated to be very conservative on the side of safety. My calculations were that if all of the fission-product inventory in the TMI reactor were released to the containment building just like the iodines and these are not volatile fission products by and large and certainly not as volatile as iodines that at most you would have 15 rem at the site boundary.

I would like to ask the important question then: if this is the case, has the important probability been calculated that you will have a higher release than that in the Kemeny Commission report?

YELLIN: There is a most interesting analysis of this by a Battelle-Columbus Laboratory group.[8] They explored the question whether if things had happened a little differently there could have been a major release at Three Mile Island. They also investigated what would have happened if the Three Mile Island containment building had been built according to other existing designs.

As I understand the results, though I have not explored the calculations in detail, if the pressure-operated relief valve (PORV), the key component in the accident, had been open for 1 more hour, additional damage would have occurred in the core, and a complete meltdown is an open possibility.[9] The NRC Special Inquiry Group (Rogovin group) concluded, on the basis of these results and other considerations, that the Three Mile Island reactor"was probably within about 30 to 40 minutes of having a substantial fraction of the fuel

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[8] Wooton, Denning, Cybulskis et al., Analysis of the Three Mile Island Accident and Alternative Sequences, NRC consultants' report NUREG/CR-1219 (Jan. 1980).

[9] Ibid., pp 5-8 to 5-11.

liquefied or molten at the time of the PORV block valve closure. . . ."[10] The Battelle group also found that under certain assumed circumstances following meltdown, a failure of the containment building could have occurred.[11] There is considerable uncertainty about the physical processes that would be involved in such a failure, and I would hope that research into containment failure following meltdown is pursued.

Second, the Battelle group found that other existing containment designs could well have failed, due to pressure created by the hydrogen deflagration that occurred in the Three Mile Island containment, if they had been in place. This includes the ice condenser design in use at the TVA Sequoyah reactor, which has a particularly low design pressure. It also includes the BWR Mark III containment.[12]

The Battelle calculations, and the discussion in Volume II of the Rogovin report, suggest that Three Mile Island was considerably more serious than a reader of the Kemeny Commission report and Volume I of the Rogovin report would suppose.

(Note: In the comment that follows, Dr. Herring correctly points out that the Kemeny Commission reached conclusions at variance with those of the Battelle group. The analysis of alternative accident sequences made by the Commission staff is not as extensive as the analyses performed by the Battelle and Rogovin groups. This is not surprising, since less time was available, and the Commission's resources and manpower were limited. The Battelle analysis had not been completed at the time the Kemeny Commission made its report and so was not considered there.)

[10] NRC Special Inquiry Group, Three Mile Island (Jan. 1980) vol. II, pt. 2, pp 536, 563-64. The PORV was closed manually 2 hours, 20 minutes into the accident.

[11] Battelle report, Sec. 6.

[12] Ibid. Sec. 8.2. The design pressures of the ice condenser and Mark III containments are 12 psig and 15 psig, respectively. The Three Mile Island hydrogen deflagration produced a measured pressure pulse of approximately 28 psig, but the spatial pressure distribution within the containment is unknown, and different local pressures may have actually occurred.

HERRING: It should be mentioned that the Kemeny Commission itself commissioned a staff study on alternative event sequences to consider the possible consequences of a number of additional mishaps that might have taken place, might conceivably have taken place at Three Mile Island. As I recall, the conclusions of that study were that there was no single additional equipment failure or human failure that would have led to core-melt, that multiple such failures might conceivably have led to core-melt, but that if there had been a core-melt, there would in all probability not have been a major release of radioactivity, though there might have been a slightly larger release than what occurred.

BEYEA: Which study are you going to believe? The Rogovin study states that had the pressure-operated relief valve not been bypassed when it was, significant core damage would have resulted in another hour with a high probability of core-melt. However, I agree with you that even if there had been a core meltdown at TMI, there may not have been breach of containment. It would have depended on what happened to the cooling system and whether or not sufficient cooling could have been maintained to prevent overpressurization.

Although there is some room for optimism with larger-volume containments such as the one at TMI, I am very pessimistic about the containment holding following a meltdown in a boiling-water reactor or in the ice-condenser system mentioned by Professor Yellin.

DAVID STEINBOCKER: I'm a concerned citizen from Blacksburg, Virginia, and let me ask something a little off the subject.

Last night on "60 Minutes" they were talking about how the politicians are all for busing but none of their schoolkids are going to the inner-city high schools. You know, the politicians during the Vietnam War, none of their kids were over there fighting. I don't think any of the pro-nuclear people have their families living in North Anna, Calvert Cliffs, Three Mile Island, Indian Head, wherever. How can we as citizens who aren't calling the shots give you guys the benefit of the doubt, and does this seem fair, that you guys are legislating this and that and whatever, and it's not directly involved in your own personal life or none of your family members are involved?

KOSHLAND: How many people would live on Three Mile Island is the question.

BROOKS: I would say categorically that I am perfectly willing to live in the vicinity of a nuclear power plant and have my family live in the vicinity of a nuclear power plant without any hesitation. It just happens that I don't have a job in the vicinity of a nuclear power plant.

BEYEA: Even though I am a nuclear critic, I think you're being a little harsh on the nuclear industry. It's my experience that people in the industry, as well as the people who are regulating the industry, honestly believe that the dangers of nuclear power and radiation are not as great as the critics believe.

I happen to disagree with their assessment, but my general impression is that they are not being hypocrites. Furthermore, given the amount of money that's at stake (hundreds and hundreds of billions of dollars), the industry reponse to attack has been relatively gentle and based, apparently, on the belief that their arguments are correct and need only be given wider publicity for the public to come around.

SIDEY: I would challenge virtually every premise that you laid down in that question. I don't know what "60 Minutes" did last night, but I can't imagine that they suggested that. I've known many of the people in this town who worked hardest for integration of schools whose children have been in such schools. Indeed, I would judge the city of Chicago, which gets a great deal of its energy from nuclear plants, must have a good number of people in it who probably support nuclear energy. I would also add that I know many people whose children went to Vietnam, some of whom were killed, who had much to do with debating the war, who were for it, who were against it.

So, I would find those oversimplistic statements, if you will, said simply.

KOSHLAND: I think we'd better turn to some concluding statements. I'm sorry I can't include everyone, but we have to end this sometime. Maybe I'll just ask the panel to go from one end tothe other. You don't have to speak, but I would like you to make any summary remarks or any new points that you think have not been covered.

HERRING: I would like to make a remark with regard to the general state of public information and the responsibility both of the citizen and of the news media. I think that there are a few very simple things that one can do to try to keep things in perspective. I mentioned some of them earlier.

I think that whenever you are presented with something that is supposed to be a risk or that you think may be a risk, you try to get from your source, or if you are a reporter try to ferret out, the numbers describing it and how these numbers compare with other numbers measured in the same units that are relevant to more familiar situations. Let me give an example.

The other day I saw in a local newspaper a banner headline on the second page about a radioactive gas release from Three Mile Island. It just happened that the fine print of the newspaper mentioned the magnitude of that release. Now, it mentioned it in units that might well be meaningless to the average reader, but the reporter could perfectly well have asked how this compares with what was emitted in the main accident last year. If that number had been given, the headline would have obviously been nonsense, because it was millions of times smaller. This is something that almost anybody can do.

LEWIS: The only thing I really deplore about the great nuclear debate is the amount of polarization in it, which makes it very, very difficult for people to serve in a constructive forum in which they try to preserve the nuclear option for the United States.

People often take the view that anything you do to preserve the nuclear option is automatically bad. I obviously don't subscribe to that position. I don't know if it was Horace Greeley--I have a funny feeling I'm giving him a quotation that belongs to somebody else--but somebody once said it's a pleasure to be against something because you don't have to know very much, and there's a little bit of an element of that in the nuclear debate.

In my observation over the years, things are getting better. The press is getting better. The critics are getting better, and I think even the pro-nuclear people are getting better. So there is probably a little bit of hope, just a teensy bit.

YELLIN: I believe the country would benefit if safe and reliable reactor operation could be assured and if the nuclear power industry were stabilized. It's an open question whether we have the political will and the technical ingenuity to reach those goals. The challenge is to work with goodwill to succeed and, if the problems aren't solvable, to admit it and apply the same energy and enthusiasm that went into the nuclear power program to other means of producing energy, especially to energy conservation.

WAHL: If you had any doubt about where I stand, you won't when I get through. I want to make a statement in support of the Nuclear Regulatory Commission. I've dealt with that agency since the mid-1960's. There's been a lot of criticism of the NRC over the years, especially when it was known as the AEC.

I think it's important that we in this society believe that we have a qualified scientific organization regulating the use of nuclear power. I believe that it is basically that. I believe it needs some improvements. I don't think anybody in the industry would argue that.

We do in fact have a major resource in this nation in the form of the Nuclear Regulatory Commission, which has a tremendous backlog of experience. It may need some fine-tuning, but more than that it needs positive support from the leadership in this town and the public, and we'd better get on with the job of providing it or we're going to lose what capability we do have.

BEYEA: I think that we have to realize that all energy technologies have risks associated with them and that our social goal should be to reduce steadily those risks, not to declare them "acceptable." Furthermore, because there are a series of value judgments that have to be made in ranking energy technologies, the choice of energy policy is basically a political decision and should be recognized as such. (Hopefully, such decisions will be made on an informed basis.)

I think that in making energy policy decisions, whether choosing nuclear, solar, fossil, or conservation technologies, we have to shift from an absolute criterion of acceptable risk to a relative criterion involving the ranking of the alternatives available. The NRC has an impossible job, as it's now set up, to try to devise politically acceptable safety criteria for nuclear power on an absolute basis.

One major criterion we should use in ranking alternative strategies is health and safety. If we have no large releases of radioactivity over the course of the nuclear program, then nuclear power will turn out, as I have said previously, to be a relatively benign source of energy. However, if we have one large accident, then I think the harmful side effects of nuclear technology will catch up with the harmful side effects of coal-burning and will dwarf the harmful side effects associated with the other alternatives. Since I expect at least one such large release to occur in the next 30 years, I have concluded that solar and conservation alternatives are more benign than nuclear power.

I must say that I see no great movement in Washington toward a serious solar and conservation strategy. As a result I am forced to temper my own personal choices on energy policy in light of certain larger issues--issues whose importance may overshadow the nuclear and coal risks mentioned before. In ranking technologies in widespread use today, it is necessary to consider the risk of nuclear war from the proliferation of nuclear weapons, the risk of war in the Middle East over oil supplies, and the risk of long-term climatic change from continued reliance on fossil fuels.

Although these larger issues may be important in tempering concern over health and safety risks from conventional technologies, the Nuclear Regulatory Commission is not the place to deal with them. Such trade-offs represent political decisions and should be made in Congress.

Another criterion that should be kept in mind in ranking energy technologies has to do with their social impact. I think we should move toward technologies that are easy to understand, technologies that will not alienate ordinary people because of frightening complexities. I hope, incidentally, that we do a good job in the way we go about choosing or rejecting nuclear power--a better job than we've done so far--so that we set a good example for the future. Nuclear power is not the only case we're going to have to face up to in which a risky and complex technology has the potential to affect our lives dramatically.

BROOKS: I don't have much to add. I would emphasize that I think the discussion of nuclear safety ought to be focused much more on how to improve it than on proving that the current technology is safe. I think one of the problems has been that in the recent past too much attention was focused on the largest conceivable accident and too little attention on the intermediate severity of accidents that are much more probable. I think that is one of the principal lessons of TMI.

SIDEY: I would say that I think that in this town frequently our own special interests, particularly now, make us forget something called national interest. It's a rather battered and forgotten concept. I believe that it's made up of many things surely the quality of life, those things we consume, clear air, clean water. The safety of our products is part of that, surely. But there are other things, and they have to do with the nature of our system, which up until now has given us freedom of action. And then, of course, our national security is a central consideration.

I would hope that as this debate, which will be governed by time and world events, goes on we do keep that in mind, that finally decisions have to be made in what we call the national interest.

KOSHLAND: I'd like to close with a couple of comments. First of all, I'd like to thank the panelists. They are very distinguished and very busy people. If I have made some misestimate in relation to one of the skeptics who turned out not to be as skeptical as some of the audience had expected, it is, I think, a reflection of the fact that these people are all picked with a little background and a reputation for knowing a great deal in the field. I don't cross-examine them or know exactly what their political views are ahead of time.

Assembled here are at least some of the people who are among the outstanding leaders in this area. I am very grateful to them for attending this Forum. I am extremely grateful to the audience for participating in a discussion so complex. I think that our society is faced with not just this decision but with a series of decisions on the borderline of science and society that will not be easy for either side to get through.

I would like to reassure Harold Lewis. I have a slightly different attitude because I think that where there is a great deal of emotion in an issue, it means that a lot of people care. I saw a bumper sticker in California that said, "I am neither for nor against apathy."

I think that summarizes the worst that could happen in a society. Where we're going may depend somewhat on attitude. I have heard that the definition of an optimist is one who says "This is the best of all possible worlds," and the pessimist says, "I'm afraid you're right."

I think we can all look at the same data and disagree. But as long as groups like this can get together and share opinions in a rational and intelligent way, we're probably in good shape.