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ABSTRACT

According to this guide, the major goal of this minicourse, developed for secondary and adult education, is to have the student gather pertinent information relative to the generation of electrical energy and to draw his own conclusions concerning the need for this energy supply. If in his mind such a need exists, he should make a judgment as to the methods by which the energy should be produced. The job of the teacher is to "tell it like it is" and then to encourage the student to make his own judgments based on the evaluation of this information. Each chapter of this teacher's guide corresponds to a chapter in the text. There are five sections in each chapter dealing with behavioral objectives, suggested activities for that chapter, audiovisual aids, references, and selected readings to provide background material for the teacher. At the end of the teacher's guide is a decision-making model to help the reader analyze the information he has received. There are three appendixes: the first concerning laboratory safety rules for working with radioactive substances, the second containing names and addresses of environmental action organizations, and the third an achievement test. (BT)

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A Teacher's Guide for the Environmental Impact of Electrical Power Generation:

Nuclear and Fossil

A Minicourse for Secondary Schools and Adult Education

Prepared under contract AT(40-2)-4167
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PHILOSOPHY OF THE PROGRAM

The major goal of this minicourse is to have the student gather pertinent information relative to the generation of electrical energy by either nuclear or conventional means, and to draw his own conclusions concerning the need for this energy supply. If in his mind such a need exists, he should make a judgment as to the methods by which the energy should be produced--by burning fossil fuels, by nuclear processes, or by a mixture of both types. He must be made aware of the advantages and disadvantages of each method of electrical generation without undue emphasis being placed on one method by the teacher to bias his judgment. In short, the job of the teacher is to *"tell it like it is"* and then to encourage the student to make his own judgments based upon an evaluation of this information.

We urge you to use varied teaching techniques which will involve the student in the active acquisition of knowledge, and to avoid as much as possible teacher-centered methods in which the learner plays a passive part. These student-centered activities should include individual studies of some aspects of the problem, seminar-type meetings, committee reports, debates, the use of field trips and resource persons, and laboratory experimentation.

The educational objectives, suggested activities, and other pertinent material are presented for each unit. We ask that you feel free to modify the activities to fit your class needs, so long as these activities are designed to achieve the objectives of that unit.

PURPOSE OF COURSE

In an era when the requirement for additional sources of power is growing at an ever-increasing rate, and concern for the protection of our environment is rightfully coming to the fore, it is imperative that an unbiased, straightforward, and objective view of the advantages and disadvantages of the methods of generating electrical power be made available to our schools.

The development of this minicourse has been partially supported by the Division of Nuclear Education and Training of the U.S. Atomic Energy Commission and produced under the direction of the Pennsylvania Department of Education. It was written and compiled by an independent committee drawn from educators, engineers, health physicists, members of industry and conservation groups, and environmental scientists.

This course is an effort to describe the cost-benefit ratio of the various methods of generation of electrical power.

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PREFACE

Generation of electrical power has provided a vital link in the everyday life of almost every member of the human race. Recent ominous warnings, however, regarding potential detrimental effects of by-products of wide scale power generation and distribution networks have made headlines in the news media. While students in our classrooms may not express as much enthusiasm for the scientific and engineering principles behind power generating facilities as their teachers, they have great interest in environmental protection problems. Thus a discrepancy has been generated between the benefits and hazards of providing a source of the *'good things'* in life. A wise teacher recognizes the potential for stimulating interest and learning inherent in the presence of a *cognitive discrepancy* [a discrepancy between what a person predicts should happen and what actually happens]. Science teachers often attempt to stimulate their students by carefully drawing their attention to apparent discrepancies in nature to spur information-seeking, problem solving, and cognitive learning.

This minicourse attempts to capitalize on the discrepancies heightened by the news media. It attempts to serve in two ways. First, it provides information relative to power generation which may be useful in reducing the discrepancy. Second, it attempts to maintain a certain level of discrepancy by not providing a comprehensive list of answers; instead it provides some information which may be useful in formulating such answers.

Out of this argument stems the first *"how to"* recommendation for this minicourse. Prior to beginning the minicourse,

HAVE EACH STUDENT FORMULATE A LIST OF QUESTIONS HE MAY HAVE ABOUT ENVIRONMENTAL PROTECTION PROBLEMS ASSOCIATED WITH ELECTRICAL POWER GENERATION

Ask him to check off the questions as they are nswered and add more questions as they are raised. A reasonable goal is to end up with a longer list than he started with.

The minicourse is designed to be flexible to permit its most meaningful application by the teacher. As such there are numerous alternative ways it can be used.

As an Integral Part of a Science Course

As an Optional, Nonrequired Part of a Science Course

As an Independent Study Unit in an Individualized Approach

As a Springboard for Further Study Into Other Areas of Environmental Protection

As a Basis for an Adult Information and/or Education Course

INTRODUCTION TO THE TEACHER'S GUIDE

Each chapter of this teacher's guide corresponds to a chapter in the minicourse text. There are five sections in each chapter.

The first section of each chapter consists of behavioral objectives for that chapter. A behavioral objective is a statement which describes student observable behavior or products of student behavior. Science advances by making valid inferences on the basis of observed phenomena. So, too, it is extremely difficult to determine the amount and extent of learning that has taken place without making valid inferences based on observable acts, such as test performance. A test provides a limited amount of observable products from which to infer the unobservable process of learning. A comprehensive set of behavioral objectives provides a wider and thus more valid basis for describing the act of learning. Behavioral objectives can be a great aid to learning. But how do you use them with your students?

If your experience with behavioral objectives is limited, read recent literature in education about behavioral objectives.

Objectives in the file or mind of the teacher are essentially locked away from the students. This fosters student dependency on the teacher and results in the game of guessing what objectives the teacher is going to place on the next examination. Both of these situations are highly inefficient. Therefore the first thing you need to do with the objectives of the course is to communicate them to the students. Reinforce this behavior by constructing tests around these objectives.

Most educational activities are followed by some form of evaluation to estimate the amount of learning that has occurred. Test items have been written for this minicourse and appear in Appendix III. These test items have alternative ways of being used. Use them to (1) evaluate the learning of each student on each of the objectives; (2) evaluate the learning of each student relative to the others in his class; (3) let the students interpret their degree of learning from the test. The latter course of action may be used when you wish to encourage independent functioning on the part of your students.

The evaluation of the test items is necessarily limited to basic terminology and concepts of power generation and environmental protection. In a larger way, the questions raised by the inquiring mind are extremely difficult to evaluate. In addition, there are many questions which do not have definitive answers. It is extremely important to recognize this in the classroom activities. It is also imperative to remember that while many questions raised by students do not have definitive yes or no answers, there is a way to determine whether a student's answer is valid or not. Does his answer or solution (1) violate respected assumptions of known facts; (2) demonstrate logical inconsistency with other parts of the solution and known facts; (3) violate all common sense? Finally, a most necessary requirement is that of demanding accountability from the student. Can he back up his solution or answer with evidence, either of an empirical or authoritative nature? The teacher should become schooled in the asking of questions like, *"What is the basis for your assertion?"*

The second section of each chapter is a list of suggested activities for that chapter. These activities, plus others which you may construct, are designed to aid you in making your instruction more student-centered.

All teachers at some point in their careers assume that teaching is lecturing. If he just presents a lecture lucidly describing the essentials of a concept, the listeners will be *"taught"*. Of course, presenting the information should include the appropriate voice inflections, projection techniques, and gesturing to dramatize the information, and *"lucidly"* usually implies that the listeners can clearly understand the information being presented.

To say lecturing is categorically bad is bad in itself. But lecturing has serious drawbacks which should cause us to consider alternatives. For example, it is difficult, if not impossible, to deliberately select and present the exact combination of words which will communicate the proper message. Secondly, even when this criteria is met, the learner may (1) have brought into the session with him all the content that was lectured; (2) not have heard the words in the context in which they were spoken; (3) have had experiences opposite to those stated by the lecturer.

Finally, lecturing either directly or indirectly encourages student dependence upon the teacher and discourages practice in independent student thinking.

If your objective is to have students be able to repeat or recognize certain facts, regardless of their truth or accuracy, lecturing is a highly efficient method. If, on the other hand, you seek to promote the ability of learners to synthesize or evaluate information, to demonstrate their ability to take a position with respect to several plausible alternatives, and to provide evidence (hopefully scientific and empirical) for his position, then use questioning techniques as opposed to lecture, as much as possible.

To guide your question-asking verbal behavior in the classroom, the following categories should be studied and practiced. These are taken from Robert B. Ribble and Charles B. Schultz, "*Social-Substantive Schedule,*" Mirrors of Behavior, Vol. 12, Philadelphia: Research for Better Schools, Inc., 1970. An audio tape of your classroom will provide a basis for checking how many of these behaviors you are actually using. Teachers invariably grossly overestimate the amount of questioning and underestimate the amount of telling that transpires in their classroom.

1. *Checking:* asks the student to recall or find previously encountered material.
   St: Are these three batteries hooked up all right?
   T: What cautions did your instructions point out?

2. *Exploring:* asks the student to try another idea or add to what he has said or done.
   St: It says to make sure the batteries must all face the same way.
   T: What else do you think would be important?

3. *Pursuing:* asks the student to support his statement.
   St: Oh, it also says to be sure the needle swings up.
   T: Where did you find that statement?

4. *Eliciting:* asks the student to make an assertion.
   St: Right here in frame 16-14.
   T: I see. What do you think will happen if the cells are hooked in parallel?

5. *Translating:* ask if a paraphrased version of the student statement is accurate. [Note: (a) The student must know he may answer either *"yes"* or *"no"*; otherwise the statement tends to be coercive. (b) A good paraphrase eliminates one or more of the possible interpretations of the student statement.]
   St: Not as much electricity will flow.
   T: Do you mean that the needle will deflect less?

6. *Supporting:* tells the student that his performance is acceptable. This response should be used to build the student's self-confidence in his own performance. Hence, right answers should not be the prime target. Instead, student performance should be weighed in terms of his previous results, techniques, hypotheses, and models.
   St: Yeh, that's what it did when the battery needed charging.
   T: Sounds reasonable. Let me know how your prediction turns out.

7. *Focusing [informing]:* presents additional information. This techniques should be used sparingly since the student is supposed to obtain most of his information from performing the exercises. Normative information, examples, or reasons for a procedure are most easily justified.
   St: Is this OK?
   T: I believe that your set-up is close enough to permit some readings.

8. *Directing:* suggests a procedure for the student to follow. Acceptance of the suggestion should be a student option.
   St: What will happen if I use thinner copper wire around the carbon?
   T: Why don't you try it and compare your results with John and Pete?

For other suggested activities besides those given in this guide, see Energy and Man's Environment, an elementary through secondary interdisciplinary activity guide available from Energy and Man's Environment, 2121 Fifth Avenue, Seattle, Washington, 98121.

The third section of each chapter is a list of audio-visual aids. Most of them may be borrowed at no charge. These come from widely-varying sources, and they may not all be suitable for a given age or educational level. It is therefore important that you preview any you plan to use.

The fourth section of each chapter is a list of references. Some are booklets which can be ordered. You may also wish to check the list of references in the appendix of the minicourse text.

The final section of each chapter contains selected readings to provide background material for the teacher.

At the end of the teacher's guide is a decision-making model to help the reader analyze the information he has received. This also appears as an appendix to the minicourse text. Finally, there are three appendices, the first concerning laboratory safety rules for working with radioactive substances, the second containing names and addresses of environmental action organizations, and the third an achievement test.

CHAPTER I

THE DEMAND FOR ELECTRICAL ENERGY

A. OBJECTIVES

1. The student will discuss reasons for the increasing electrical energy demands in the United States.

2. The student will list the appliances which consume electricity in his own home. From the table provided, he will calculate the total annual kilowatt-hour consumption for his place of residence and the per capita kilowatt-hour consumption for members of his family.

3. The student will discuss the population projections and estimated power needs for the U.S. through the year 2000.

B. ACTIVITIES

1. Have students discuss the role which electricity plays in supporting our current standard of living and adaptations which we would be forced to make if the availability of this energy supply were seriously curtailed.

2. Hold a class debate: *"Is pollution necessary? Can we live in a pollution-free society?"*

3. Calculate electrical consumption in the students' place of residence by a listing of all home electrical devices and use of the tables of consumption listed in the text.

4. Have a group discussion of which home appliances could be discarded to reduce electrical consumption.

5. Interpret population projection charts to determine the most probable population growth in the U.S.

6. Discuss *"Will recycling reduce electrical consumption?"*

7. Consider the following situation: Flood, high winds, or some other unusual event has severely damaged your source of electrical power. You are to form an advisory committee and set up priorities, since electricity will have to be rationed. What groups should be represented on this committee? (e.g., city government, hospital, factory, etc.) Determine priorities such as who will get power, who will not, and to what degree.

8. Make a collection of cartoons related to power generation or the energy crisis, and make a bulletin board display. Include other items as you see fit.

9. Present the following problems to any or all of the students, with or without time for them to prepare answers or possible solutions. Inform the students that they just became involved in the situation.

   Ask: What is your reaction? What are you going to do about it? What should you do about it?

   a. Electrical power has been rationed due to recent damage by violent weather conditions. Your best friend's home (or Aunt Effie's) continues to utilize total air conditioning in spite of warnings to the contrary. The brown-out seriously hinders certain equipment from being fully utilized at the local hospital.

   b. You have just been notified that a new power plant is to be located right on the site of your present home. You have an opportunity to purchase a similar home elsewhere, still convenient for all purposes. The price is right, but the new neighborhood is heavily populated with minority groups, most of which are of a different color.

C. AUDIO-VISUAL MATERIALS

1. *"The Energy-Environment Game,"* a simulation dealing with society's demand

for energy and its effect on the environment. Edison Electric Institute, 90 Park Avenue, New York, New York, 10016

2. *"Environmental Health: Energy and the Environment,"* a teaching kit including records and filmstrips prepared for Southern California Edison Company by H.R.A., Inc., P. O. Box 3036, Granada Hills, Calif. 91344

3. *"Nuclear Power and the Environment,"* 1969 16 mm sound, 14 min., color. Takes up the problems that stem from the growing demands for electricity in the U.S. The film discusses the great care taken in studying and controlling the effects of nuclear power plants on the environment.

D. REFERENCES

1. *"The Search for Tomorrow's Power,"* National Geographic, November, 1972, pp. 650 ff.

2. *"Nation's Energy Crisis,"* 3-part series of articles, New York Times, July 6, 7, 8, 1971.

3. *"Managing the Power Supply and the Environment,"* Report of the Federal Power Commission's National Power Survey Task Force on Environment, July, 1971. Federal Power Commission, Washington, D.C., 20426.

BACKGROUND INFORMATION FOR THE TEACHER

Sunday Patriot-News, Harrisburg, Pa., August 20, 1972.
Diplomatic Perils of Importing Fuel Oil A Reality

ENERGY CRISIS: STRAIN ON ALL FUELS, LIMITS TO ALL

by Jean Heller
Associated Press Writer

WASHINGTON (AP) – In the past several years, energy crisis has become a household term. It signifies steamy summer days without air conditioning, frigid winter nights without heat or light, rising utility and real estate costs and a lot of unanswered questions.

Blackouts, brownouts – and recently in Michigan something called a tanout – have become a way of life in much of the nation during periods of severe weather.

Why?

The simple answer is that not enough clean coal, fuel oil and natural gas are available in the country to meet consumers' demands and many electric utilities don't have the dependable generating capacity to meet peak needs.

"We've got trouble, trouble, trouble, with a capital T and that rhymes with E and that stands for Energy," Hollis M. Dole, the Interior Department's assistant secretary for mineral resources, told a House subcommittee recently.

"We are beginning to feel the pinch on energy in certain forms," Dole said. *"This condition of scarcity will widen as time goes by to include an Assn. of Homebuilders estigory of energy."*

AN ASSOCIATED PRESS study of the nation's energy crisis found:

–During July's heat wave, demand for electricity along the East Coast far exceeded electric utilities' capacity for supply. New York City and parts of Rhode Island and Massachusetts temporarily were blacked out. A heavy demand in Michigan caused a tanout, a deliberate reduction of from 1 to 5 per cent in generator power output.

–A Federal Power Commission survey at the beginning of the summer showed that the Southeast and West Central Areas of the nation did not have sufficient reserve electrical generating capacity to meet unexpected demands or equipment failures.

–In many parts of the nation, including Washington, D.C., and Chicago, natural gas supplies were so low that indefinite moratoriums were placed on sales to new customers. The possibility exists that if the nation suffers a severe winter, gas service to some commercial and industrial customers will have to be cut off in order to maintain service to residential customers.

–Most of the nation's coal supply cannot be used because of stringent air-pollution laws and not enough fuel oil currently is available in the nation to fill the gap.

–Electric utilities, paying ever-mounting prices for fuel, are passing on those increases to consumers. Wholesale electric rate increases pending at the FPC jumped more than $20 million during the second quarter of the year.

–In areas where new gas sales have been curtailed, housing projects awaiting service are standing idle. A spokesman for the National Assn. of Homebuilders estimates this factor costs a builder about $100 a month on an average $28,000 home, a cost passed on to buyers. Moreover, the cost of installing an oil heat system in an average home is between $500 and $600, another home cost add-on.

So, how did we get into this situation in the first place, and how do we get out?

We got in because the nation has not yet learned how to combine progress and conservation and make it work. It appears the only immediate way out is a growing, and possibly dangerous, dependence on foreign fuel imports.

"The current energy crisis can probably be attributed to the tensions and adjustments resulting from attempts to achieve a proper balance between the duty to protect and conserve the natural environment and the equally valid obligation to meet

the growing energy demand necessary for preserving and improving the total quality of human life," said Aubrey J. Wagner, chairman of the nation's largest electric utility, the Tennessee Valley Authority.

"It's not anybody's fault, really," said Ralph Williams, an Interior Department energy specialist and Dole's staff assistant. *"It's just the way the whole darned thing went together. It all fell on us at once."*

One of the principal factors is a series of new environmental laws which restrict the use of dirty fuels.

Of the three fossil fuels – coal, gas and oil – only gas is completely clean. Coal, especially, is high in sulfur content, making it useless in areas which have stringent air-pollution restrictions on sulfur emissions. That means all urban, industrial areas.

Since coal accounts for somewhere between 70 and 85 per cent of the nation's fuel reserve, a huge reservoir of energy has all but been eliminated from the market, at least until an economically feasible way is found to burn coal cleanly.

Fuel oil, much of which can meet environmental standards, is not in as short supply as it was several years ago, but it costs far more than other fossil fuels.

In addition, oil production in the United States has reached its peak with no drastic upswing in sight so that fuel oil alone, which amounts to only 5 to 10 per cent of every barrel of refined crude oil, never could fill the coal gap.

AS A RESULT, the immediate burden has fallen on natural gas, which is cheap and clean.

But in the past few years, gas producers haven't been exploring for new supplies, claiming government regulation of prices doesn't provide a big enough profit margin to encourage the high-risk business of exploration.

It has been estimated that in 20 years the demand for natural gas will be 1 1/2 times all the gas discovered in the nation's history. Yet the number of producing wells drilled in the country dropped by more than one half from 1955 to 1968.

In 1960, the nation had a 20-year supply of natural gas in reserve. By 1970, that reserve had fallen to 13 years. Now it's 11.3 years. The nation is using up the reserve faster than new supplies are being found. All current reserves are committed for some specific future use.

Until recently, the Federal Power Commission set ceilings on the price natural gas producers could charge interstate pipeline companies. In time of plentiful supplies of gas, the ceilings were set low.

As rates of inflation grew, producers' costs for equipment and labor steadily closed in on profits because the FPC allowed few price-ceiling hikes. Gradually producers stopped looking for new gas supplies because, they said, with 80 per cent of all new wells coming up dry, the FPC ceilings didn't allow enough capital to finance high-risk exploration.

LAST MONTH, the FPC announced it was lifting price restrictions and would allow gas to find its own price level. The action, expected for some time, was greeted with chagrin by consumer groups, who claim the FPC fell for an industry trick.

The FPC does not collect its own data on gas reserves, relying instead on a survey conducted by the American Gas Assn., a professional representative of gas producers. Critics charge the AGA and producers misrepresented gas reserves just to force prices up, an allegation the producers and the AGA deny vehemently.

Whatever the truth, the FPC's action may indeed spur new gas exploration, but locating and producing new supplies require a three-to-five year lead time, and nobody is very optimistic about any quick solutions to the shortage problems.

"We're unable yet to gauge the effects of the ruling," said Charles Krautler, a spokesman for the Washington Gas Light Co. *"Even if it helps it will take several years to develop new supplies."*

"We're very much taking a wait-and-see attitude on this thing," said Robert Wilson, an official of Peoples Gas Light and Coke Co. in Chicago, *"It's possible, I suppose, that this will free up some gas, but I haven't heard anybody express much optimism."*

Wilson and Peoples has a waiting list of 3,349 customers, many of them big commercial and industrial users, which seek enough gas to supply 191,000 average single-family homes.

WHAT OF NUCLEAR energy, once touted as the solution to power problems of the 70s and beyond?

The first nuclear generating plants went into operation in the early 1960s. By the middle of the decade there was rising discontent over air and water pollution. The Atomic Energy Commission began predicting that nuclear plants were the environmentally-sound wave of the future.

Electric utilities seemed to agree. In 1966, 20 new nuclear plants were ordered. In 1967, another 30 went into the planning stages. But the following year, problems began. A shortage of specialized equipment, parts and trained personnel developed. On construction sites, crews had difficulty in assembling parts and keeping them operable.

And conservationists began raising objections and occasionally filing law suits over plant sites and possible dangerous heat and radiation emissions.

As problems developed, new plant orders fell to 21 in 1968; to seven in 1969. As of August 1972, 28 nuclear plants were in operation, 49 were in various stages of construction and 67 were still on the drawing boards.

IN THE MIDST of all this, the nation's over-all demand for electric power is doubling every 10 years and per capita demand is growing five times faster than the population. The nation has become so dependent on electric power that human muscle now accounts for less than one per cent of the work done in the nation's factories.

Ten years ago, electric utilities had the capacity to generate 30 per cent more power than customers demanded. By 1970, the figure had dropped to 15 per cent, a level barely the minimum needed to cover unexpected demands or equipment failure.

This summer, some areas of the country couldn't meet that minimum.

The FPC's summer power supply survey indicated that the Southeast and West Central areas of the nation had only an 11.1 and 11.6 per cent reserve, respectively, at the beginning of summer.

The Northeast, plagued by power problems, had a barely-comfortable 17.9 per cent reserve, but that's an average. In New York City, for example, the reserve was under 11 per cent, and power problems have plagued that city all summer.

In the Southeast region, the Miami area was getting through the summer on a prayer, with a reserve of minus 2.1 per cent. The Cleveland municipal electric utility was even worse, with a minus 8 per cent reserve.

"We have a kind of chain reaction," said Williams. *"We feel the environmental restrictions will continue to crowd coal out of the market. As coal is forced out, that will bring pressure on alternate fuels. Nuclear power is late. Gas is already past its peak. So the demand that was met by coal is going to have to be met by oil. And domestic oil production has fallen off.*

"So I think that all the increase in energy demand in the United States is going to have to be met by imported oil" he said. *"For the most part this is going to be Middle East oil. We're going to have to try to figure out how much oil we can produce and how much more is going to be needed and fill that gap by letting foreign oil in."*

THE IMPORT quotas, set out during the 1950s, were intended to protect the United States from international extortion to prevent the nation from becoming so dependent on the cheap Middle Eastern oil that Arab nations could use the dependency to whipsaw the country during an international political crisis.

Energy experts agree that easing import quotas now could put the United States in a vulnerable position. But, they say, at the moment there is no other choice.

"We've got trouble, trouble, trouble, with a capital T and that rhymes with E and that stands for energy." So says Hollis M. Dole, the Interior Department's assistant secretary for mineral resources.

The trouble often includes dimming lights, stalled air conditioners on summer days, no heat on winter nights, increased utility costs-households signs of the nation's growing energy crisis.

NEWS RELEASE - Bureau of Public Affairs
Department of State Office of Media Services

April 1972

LECTURE: INTERNATIONAL REALITIES OF THE ENERGY CRISIS

Following is the text of a lecture given recently by Dr. Chauncey Starr at the U.S. Department of State in Washington, D.C. Dr. Starr, founder of the American Nuclear Society, is Vice President of the National Academy of Engineering, a member of the President's Task Force on Science Policy and a member of the Office of Science and Technology's Energy Panel.

Also participating in the presentation was a panel of three other distinguished scientists: Dr. Robert A. Bell, Dr. Ralph E. Lapp and Dr. Gordon J. F. MacDonald.

The presentation was one in a series of science lectures sponsored by the State Department.

In view of the national interest in the energy crisis, we are sending you the text of this lecture because we think it may be of particular use to you as background information.

International Realities of the Energy Crisis

"Between now and 2001, just 30 years away, the U.S. will consume more energy than it has in its entire history. By 2001 the annual U.S. demand for energy in all forms is expected to double, and the annual worldwide demand will probably triple. These projected increases will tax man's ability to discover, extract and refine fuels in the huge volumes necessary, to ship them safely, to find suitable locations for several hundred new electric-power stations in the U.S. (thousands worldwide) and to dispose of effluents and waste products with minimum harm to himself and his environment. When one considers how difficult it is at present to extract coal without jeopardizing lives or scarring the surface of the earth, to ship oil without spillage, to find acceptable sites for power plants and to control the effluents of our present fuel-burning machines, the energy projections for 2001 indicate the need for thorough assessment of the available options and careful planning of our future course. We shall have to examine with both objectivity and humanity the necessity for the projected increase in energy demand, its relation to our quality of life, the practical options technology provides for meeting our needs and the environmental and social consequences of these options."

The above quotation is taken from a paper I prepared more than a year ago. It describes the nature of the continuing problems we face – and which have recently reached public attention in the form of the *"energy crisis."* The term *"energy crisis"* has served as a convenient layman's umbrella for encompassing a wide variety of society's concerns with the energy situation. Because these do not have a common solution, it is important to examine them separately and to clarify the several issues we face.

The *"crisis"* designation tends to be misleading, because it implies that quick-fix emergency steps should be taken to cure situations which have developed over many years. In fact, there are no quick fixes. Further, the practical realities of the situation have not yet required an immediate national *"crisis"* response by applying true emergency measures – such as energy rationing and cessation of energy consuming activities.

The fact that pressing localized issues have arisen should give us concern, both as indicators of widespread inadequacies and as they may portend more serious things to come. To use a medical analogy, the patient may have aches and pains, but can still do a day's work and live normally – the situation doesn't justify hospitalization now, but could get worse if remedial treatment is neglected.

In like manner, the most pressing energy need is for a coherent and long-range program to plan and manage our national and international energy systems. It takes 10 to 20 years to significantly alter the trends of these huge systems. Waiting until the situation becomes intolerable must now be recognized as intentionally planned neglect – a societal irresponsibility difficult to condone.

Our national and international energy systems consist of a complex of interlocked activities, including fuel resources (most notably the fossil fuels – coal, oil and gas), the distribution of these fuels

either by pipeline, truck or tanker, the distribution of electricity generated from these fuels, and finally the many end uses of energy.

Energy is consumed for residential purposes, for transportation, by the manufacturing industry, and in sundry other ways. All activities of any energy system have some environmental impact. For example, the development of fuel resources gives rise to land use and esthetic issues. The distribution of these fuels involves transportation risks both to the public and to our ecology.

The conversion of these fuels into either electricity or into their end functions – such as automobile transportation, industrial operations, and the like – creates air polluting effluents and waste heat. In addition to these more obvious environmental impacts there are secondary by-products from energy systems that are not as directly visible to the public, but which are also important societal costs – such as fires, explosions and accidents.

The current public focus on the energy crisis arises primarily from a few immediately visible near-term events. First, because of the occasional shortages and malfunctions of the electricity delivery system, which cause dramatic blackouts and brownouts in spot areas, the public affected has a discomforting anxiety about the reliability of supply. The *"crisis"* nature of this issue tends to be very localized in place and time. The great majority of our population have no difficulty with getting electricity on demand.

The second near-term issue is that related to urban air pollution. However, air pollution arises from a great variety of sources, many of an industrial nature not directly related to the energy systems. The contribution to air pollution which arises from the generation of electricity is significant, but usually only a modest part of the total. Most notably the use of petroleum products for private and public motor vehicles is a major source. These two items, the continuous delivery of electricity and urban air pollution are generally the stimuli for the public attention to energy issues.

The continuous delivery of electricity to meet demands, without the penalties of brownouts or blackouts or other failures, has always been the traditional objective of the electric utility industry. In order to accomplish this, the industry has anticipated a decade ahead the growth in demand for electricity, so as to schedule the construction of power generation and distribution facilities to meet such foreseen needs.

Electric utilities have also tried to maintain a sufficient surplus of generation capacity to provide a reserve for unexpected breakdowns of equipment, maintenance and other causes of disruption. In the past several years the normal anticipatory planning of the electrical industry has gone askew because of conditions not anticipated at the time when the original commitments for future plants and equipment were made. These unanticipated issues have arisen from many sources, but perhaps the two most important are the first recently restricted availability of suitable fuel and second the new environmental criteria for power plant performance.

The traditional fuel for power plants has been the fossil fuels – coal, oil and gas. Coal, while an abundant mineral in the United States, unfortunately produces the largest overall environmental impact. The mining operations, underground and strip mining, involve social costs associated with safety and land use which are quite substantial and require very large remedial investments. In addition, coal contains a large number of foreign elements, including sulphur compounds, which are environmental pollutants.

The result has been that while the demand for coal has continuously increased for power production purposes, its use creates problems which have yet to be solved satisfactorily. In particular, the ability to remove the sulphur contamination from the coal, either prior to its use or after its discharge as a gas in the power plant stacks, requires the commercial development of new technologies only now undergoing pilot plant trials.

The available indigenous oil in the U.S. has not been sufficient to meet our needs. Because of the slow development of both our onshore and offshore oil reserves, we have become one of the great importers of oil. Oil, like coal, contains sulphur which generally requires either removal prior to combustion or in the power plant stack gas. Naturally low sulphur oil is available in relatively small amounts.

The recent environmental restrictions on oil drilling on the continental shelf (because of the possible leakages into the marine environment), and the concern with the ecological impact of oil pipelines all have tended to slow down or inhibit the full exploration and development of oil resources.

Natural gas is the least contaminated form of fossil fuel and is therefore in great demand for power plant use. It is also in great demand for industrial and domestic use, because of the ease with which it can be transmitted and distributed and the simplicity of combustion equipment. For complicated reasons, including pricing policies, natural gas has been mostly a byproduct of oil development. At the present time there appears to be an insufficient reserve of natural gas in the United States to permit continued expansion of its use. Thus, this most environmentally acceptable of all the fossil fuels is also the most limited for the future.

For all these reasons the utility industry recognized some years ago that the unique *"clean air"* characteristics of nuclear power would make it a very desirable addition to the available technical options for the generation of electricity. For almost two decades the utility industry has actively supported nuclear power development, and underwritten the higher costs of the first stages of commercializing nuclear power.

The rate at which nuclear power has entered into the production of electricity is however disappointingly less than that which was expected by the utilities. The initial delays were associated with establishing the reliability needed for commercial operations. More recently these plants have been delayed by the intervention of various public groups fearful of their potential environmental impact.

These interventions are primarily serving as a means of public education and communication concerning the relative safety of nuclear power. Unfortunately, the associated delays, sometimes extending for several years, have had a serious impact on reducing the planned expansion of nuclear power availability.

Thus, as a result of the combined effects of an inadequate supply of environmentally suitable fossil fuels to meet expanding requirements, the time needed for technical development of anti-pollution devices to permit use of available coal and oil, and delays in the authorization for nuclear power plants, we face a near-term situation where the generating capacity of our national electricity system does not contain everywhere an adequate reserve for meeting unique peak demands and providing protection against unexpected power plant failures.

There are many regions of the country where these issues have not been pressing. Unfortunately, there are many urban areas that have had a large expansion of electricity demand, and in these the margin of reliability has been so reduced that even minor malfunctions or unusual weather conditions can create electricity shortages with considerable public discomfort and, in some cases, public hazards.

Such problems can only be avoided by administrative removal of unproductive delays and interferences, and by the most efficient use of the available resources of fuel and power generation facilities. Because it takes a decade or more to bring new technical developments or new fuel systems into operation in our energy system, it is not likely that these near term pressures will be rapidly removed by technologies still in the process of development.

The availability of energy has always been of basic concern because of the intimate relationship of energy to our societal development. It has become a major public issue only in the past several years, and will probably always remain with us as a primary consideration in the future. Basically our society cannot function without energy in various forms. We utilize it for elemental physical comfort by heating and cooling, we utilize it to run our industries, and we use it for recreational purposes.

All these uses have always had some impact on the environment. As our per capita use has grown in the past several generations, and as our population has grown and also concentrated in large urban areas, these environmental impacts have become sufficiently severe that we now must begin to develop either better energy technology or some limitations on energy use, or both. It must be recognized that there is no form of energy which may be used without some environmental impact.

The issue is not one of *"good or bad"* but one of balancing the beneficial aspects of energy use against its undesirable environmental effects. As a nation we are presently engaged in developing a socially acceptable balance between these two issues through public debate, technical and scientific research, and through empirical trial and error. This development of a sound social philosophy for the use and control of energy, so as to maximize the public good, may be one of the most important national issues of this decade.

Long-range planning of our national and world-wide energy systems must start with some estimate of future energy demands. A conception of the future may come from a simple extension of historical trends, or may be developed from a more sophisticated analysis of changing life styles and their impact on end-use needs.

Since 1900, the average per capita energy consumption in the world and the U.S. has doubled every 50 years, with some short term perturbations. There appears to be small likelihood that this long-term trend of increasing per capita use will change in the next several decades.

In spite of increased public concern with the impacts of such a growth, there is actually very little that can be done pragmatically to limit it – other than direct scarcity or rationing – because of the intimate connection between the life styles of peoples, their aspirations, and their energy supply.

The future need for energy in societal development is of two broad types, one characteristic of the highly developed sections of the world and one typical of the underdeveloped portions. During the past two centuries the industrialized nations of the world significantly increased their energy use in order to sustain their population growth and to improve the condition of their people.

It is likely that in the next century the per capita energy consumption in these advanced countries will approach an equilibrium level, first because the quality of life for the majority of the population will be less dependent on increased energy use, and second because environmental constraints will make energy more costly and thus encourage increased efficiency of its end use. The hoped-for population equilibrium in advanced nations will also lead to an eventual leveling-off of total energy need for these countries.

While it is possible that the future creation of socially desirable high-technology energy consuming devices may maintain a continuously growing energy demand, nevertheless, the realities of resource economics will probably create a trade-off ceiling on energy demand. Only the development of new energy resources (such as fusion) which are both low cost and extensive can lift such a ceiling. Even so, the availability of investment capital – a manmade resource – may limit such growth.

For the underdeveloped part of the world, which contains most of the world's population, the situation is quite different. These peoples are still primarily engaged in maintaining a minimum level of subsistence. They have not as yet had available the power resources necessary for the transition to a literate, industrial, urban, and agriculturally advanced society. Historically such transitions have always involved both an increase in population and an increase in per capita energy consumption. We are seeing this now in most of the underdeveloped countries. So, the inevitable population growth, combined with an increased per capita energy use, could result in an enormous worldwide energy demand.

A capsule example of what can occur is provided by Puerto Rico. It is being shifted to an industrial economy from an agrarian sugar economy by the planned investment of foreign capital. In 1940 the annual electricity consumption was about 100 kwhrs per capita, comparable to India's present usage. By 1950 this had been more than doubled to 220 kwhrs per capita. By 1968 this had increased to 1800 kwhrs per capita. This is an average doubling time of about 7 years. (By comparison, the U.S. consumption in 1968 was about 7200 kwhrs per capita with a present per capita doubling time of about 12 years. Now, in 1972, the U.S. level is about 8800 kwhrs per capita.) Puerto Rico is, of course, a unique case of accelerated economic development, but the 20-fold increase in per capita electricity consumption is nevertheless startling.

At present the U.S. consumes about 35 percent of the world's energy. By the year 2000 the U.S. share will probably drop to around 25 percent, due chiefly to the relative population increase of the rest of the world. The per capita increase in energy consumption in the U.S. is now about 1 percent per year. Starting from a much lower base, the average per capita energy consumption throughout the world is increasing at a rate of 1.3 percent per year.

It is evident that it may be another century before the world average even approaches the current U.S. level. At that time the energy gap between the U.S. and the underdeveloped world will still be large. With unaltered trends it would take 300 years to close the gap. By 2000 the world's average per capita energy consumption will have moved only from the present one-fifth of the U.S. average to about one-third of the present U.S. average. Of grave

concern is the nearly static and very low per capita energy consumption of areas such as India, a country whose population growth largely negates its increased total production of energy.

If the underdeveloped parts of the world were conceivably able to reach by the year 2000 the standard of living of Americans today, the world-wide level of energy consumption would be roughly 10 times the present figure. Even though this is a highly unrealistic target for 30 years hence, one must assume that world energy consumption will move in that direction as rapidly as political, economic and technical factors will allow. The problems implied by this prospect are awesome.

Increasing per capita income is an essential for increasing the quality of life in underdeveloped countries, and this requires energy. It has often been suggested that because of its environmental impacts, energy use be arbitrarily limited everywhere. This requires the same type of societal decision that would be associated with arbitrarily limiting water supply or food production.

Given the objective of providing the people of the world as good a life as man's ingenuity can develop, the essential role of energy availability must be recognized. With the same motivation that causes the agronomists to seek an increased yield per acre, it is the function of technology to make energy available in sufficient amount to meet all essential needs, and with sufficiently small environmental impact as to ensure that the benefits outweigh all the costs.

Because even in the industrial societies the per capita use of energy in large amounts is only a century old, and in most of the world it has not even started, we have both a growing need and an opportunity to develop long-range plans for optimally supplying this essential aid to world-wide social development.

One can better appreciate the energy problem the world faces if one simply compares the cumulative energy demand to the year 2000 – when the annual rate of energy consumption will be only three times the present rate – with estimates of the economically recoverable fossil fuels.

The estimated fossil fuel reserves are greater than the estimated cumulative demand by only a factor of two. If the only energy resource were fossil fuel, the prospect would be bleak indeed. The outlook is completely altered, however, if one includes the energy available from nuclear power. As has often been stated, nuclear fission provides another major resource – with the present light water reactors about equal to the fossil fuels, and with the breeder reactors almost 100 times as much

There is no question that nuclear power is a saving technical development for the energy prospects for mankind. Promising but as yet technically unsolved is the development of a continuous supply of energy from solar sources. The enormous magnitude of the solar radiation that reaches the land surfaces of the earth is so much greater than any of the foreseeable needs that it represents an inviting technical target.

Unfortunately there appears to be no economically feasible concept yet available for substantially tapping that continuous supply of energy. This somewhat pessimistic estimate of today's ability to use solar radiation should not discourage a technological effort to harness it more effectively. If only a few percent of the land area of the U.S. could be used to absorb solar radiation effectively (at, say, a little better than 10 percent efficiency), we would meet most of our energy needs in the year 2000. Even a partial achievement of this goal could make a tremendous contribution.

The land area required for the commercially significant collection of solar radiation is so large, however,that a high capital investment must be anticipated. This, coupled with the cost of the necessary energy-conversion systems and storage facilities, makes solar power economically uninteresting today. Nevertheless, the direct conversion of solar energy is the only significant long-range alternative to nuclear power.

The possibility of obtaining power from thermonuclear fusion has not been included in the listing of energy resources because of the great uncertainty about its feasibility. The term *"thermonuclear fusion,"* the process of the hydrogen bomb, describes the intereaction of very light atomic nuclei to create highly energetic new nuclei, particles and radiation. Control of the fusion process involves many scientific phenomena that are not yet understood, and its engineering feasibility has not yet been seriously studied. Depending on the process used, controlled fusion might open up not only an important added energy resource but also a virtually

unlimited one. The fusion process remains a possibility with a highly uncertain outcome.

It has been proposed that tapping the heat in the rocks of the earth's crust is feasible, and if it is, this could be important. At present, the initial probing of this source has not yet been tried – so its pragmatic availability is yet uncertain.

It is clear from all such studies, that for the next century mankind is unlikely to run out of available energy. Instead, the important issue is whether the increasing cost of energy (including environmental costs) will become a major handicap to world-wide societal improvement. Just as an increasing cost of water with increasing usage might limit the development of an area, the same could apply to the use of energy in various parts of the world.

Within nature's limitations man has tremendous scope for planning energy utilization. Some of the controlling factors that enter into energy policy depend on the voluntary decisions of the individual as well as on government actions that may restrict individual freedom. The questions of feasibility, both economic and technical, depend for their solution on the priority and magnitude of the effort applied.

The time scale and costs for implementing decisions, or resolving issues, in all areas of energy management have both short-term and long-term consequences. There are so many variables that their arrangement into a *"scenario"* for the future becomes a matter of individual choice and a fascinating planning game. The intellectual complexity of the possible arrangements for the future can, however, be reduced to a limited number of basic policy questions that are more sociological than technical in nature.

Dr. Starr referred to a table, not reproduced here, showing a partial list of the controlling factors which enter into energy planning. He continued:

As shown, the only parameters under our control which can alter the nature and trends of near-term energy systems are a limited number of individual and governmental choices – life style and value oriented rather than technological in nature. An individual choice of energy device (home heating, for example) can be made and implemented with a time constant of about a year. A choice by a societal unit (location of a power station, and effluent regulation, for example) takes about a decade to make and implement. Thus, the full effect of such societal decisions often doesn't develop until more than a decade has passed.

In the technological domain of new economically acceptable energy devices we are really working for the next generations, rather than our own. Even nuclear power, which was certainly supported by government as enthusiastically as any technology in history, has taken 25 years to establish a commercial base – and still hasn't made a real impact on our energy supply.

Of all the energy needs projected for the year 2000, nonelectric uses represent about two-thirds. These uses cover such major categories as transportation, space heating and industrial processes. The largest energy user at that time will be the manufacturing industry, with transportation using about half as much. Transportation is illustrative of the possibilities in societal planning. The automobile is responsible for almost half of the world's oil consumption – and a corresponding part of its air pollution. Except for the airplane, the private automobile is the most inefficient mode of using energy for travel.

For passenger travel, railroads are 2 1/2 times as efficient as autos and 5 1/2 times as efficient as airplanes. Buses are 4 times as efficient as autos. For freight, railroads are 3 1/2 times as efficient as trucks and 55 times as efficient as airplanes. Clearly, to reduce energy consumption an extensive nationwide network of railroads, with local bus service, is far superior to an automobile road network. Unfortunately, the world-wide trends have been diametrically opposite, and the human preference for personal mobility have reinforced such trends.

Finally, contrary to much public comment, the development of new speculative energy resources are investments for the future, not a means of remedying the problems of today. Unfortunately, many of these as yet uncertain and undeveloped sources of energy are often misleadingly cited publicly as having a great promise for solving our present difficulties. In addition to their technical uncertainties, many of these speculative sources are likely to be limited in their contribution, even if successful.

Unfortunately, the attraction of *"jam*

tomorrow" may persuade us to neglect the need for *"bread and butter"* today. Because of the very long time required for any new energy device to become part of the technological structure of our society, these speculative sources could not play a major role before the year 2000. The quality of life of the peoples of the world depends upon the availability in the near future of large amounts of low cost energy in useful form. This being the case, we must plan an orderly development and efficient use of the resources available to us now, and these are primarily fossil fuels and nuclear fission.

Given this situation, what are the possible impacts on U.S. relations with foreign countries? Because of our present limitations on the use of high sulphur coal, and the present unavailability of more natural gas, a rapid shift to oil is now underway, because oil can be found with low sulphur or can be desulphurized.

There is no emergency remedy except rationing. Because roughly half our oil goes to transportation, this is the likely area to be controlled, not electricity. U.S. oil production can be increased only fractionally even if all internal controls are removed.

If the politically distasteful course of rationing is not taken, our 1970 foreign oil purchase of $5 billion will become $10 billion in 1975, and $15 billion by 1980, at which time half our oil consumed will be foreign. For perspective, these dollar outflows may be compared with the total U.S. annual capital investments of less than $100 billion. I will not dwell on the international monetary consequences.

It should also be remembered that increased fuel cost means increased cost of goods, reduced foreign sales, and worsened trade balance. The foreign relations issue is, of course, aggravated by the increasing dependency of the U.S. on the oil producing nations without a balancing dependency on their part. The international tensions so produced can lead to consequences of the most serious nature – a variety of scenarios can be imagined.

A parallel situation exists in Western Europe, and both France and Germany have embarked on the construction of oil storage facilities to provide at least three months reserve. (The U.S. now has a 2-3 week stored supply.) The recent North Sea discoveries will help but not solve this problem. These countries are also developing pipeline connections to the USSR and Eastern European oil fields. Western Europe and the U.S. may end up in conflict for limited world resources.

For the U.S., the Canadian supplies are attractive, but both trade barriers and lack of incentives have made this a slowly developing course. Perhaps we should offer the D_2O (heavy water) for their oil. The Canadians have no reason to be concerned with our problem and may be viewing it with some skepticism, as do many foreigners.

After all, the environmental issues that have engendered our situation have a very dubious rationality. The public health causality relations which are the reputed origin of our pollution standards are not, in fact, based on demonstrable or credible risk-benefit analyses. They are instead judgmental levels set primarily for esthetic or comfort purposes, with health benefit marginal at best. This is not likely to create international sympathy.

Although the near-term U.S. situation has no quick fix, the intermediate term (post 1980) has several optional aids. Offshore drilling, for example. This is much less polluting than tanker imports, and given time could probably meet much of our needs. Of course, we must resolve the issue of the *"law of the sea"* if we wish to exploit the resources beyond the three mile limit. Another option is to ease the environmental and esthetic constraints and reactivate coal mining, and this may occur when the public realizes the situation. Another is speed up coal desulphurization, gasification and liquefaction, and the recovery from oil shales and tar sands. These take both the development of commercial technology and much capital.

In the very long term (post 2000) we have the *"clean air"* option of nuclear power. The abundance of uranium and the fast breeder gives us potentially ample energy. Obviously, the rate at which nuclear power comes on the scene is dependent in the U.S. on public acceptance. It should be pointed out that this issue does not exist in most foreign countries. As a consequence, we may be buying foreign reactors eventually.

We must recognize and resolve the several very basic trade offs between environment, life styles, personal freedoms, amenities, international tensions, high energy cost and high cost of goods, public health, personal income, and allocation of national

resources – and perhaps others. The issue may be as basic as national security vs. social costs.

For example, based on my perceptions of the alternates, I would very much rather accept the minimal risks of large scale nuclear power than the already evident risks of international tensions from foreign oil. These issues are so important, and the energy systems so ponderous and slow to change, that our national planning must be based on a comprehensively developed long-range insight rather than a fickle public emotion and short-term political expediency. Let us hope it is.

CHAPTER 2

MEETING THE DEMAND FOR ELECTRICAL ENERGY

A. OBJECTIVES

1. The student will describe the production of an electrical current and relate this to the generation of electrical power.

2. The student will identify the current methods of generating electricity, some possible alternative methods, and the limitations of each in meeting our energy requirements.

B. ACTIVITIES

1. Have the students use a hand-operated generator to produce sufficient energy to light a small incandescent bulb. This generator might then be operated by a model steam engine, producing, in effect, a miniature power generating system.

2. Using iron filings with horseshoe and bar magnets, demonstrate the magnetic lines of force by sprinkling iron filings on a piece of heavy paper placed over the magnet.

3. Conduct a field trip to a nearby power plant.

4. Allow the students to *"mess around"* with Oersted's loops. Can they devise ways to increase the amount of electricity they can get from this apparatus?

5. Get a speaker from your local utility to discuss electrical generation.

C. AUDIO-VISUAL MATERIALS

1. *"World Behind your Light Switch,"* 1966, 16mm sound, 28 min. On transmission of electricity. Bonneville Power Administration, U.S. Department of the Interior, P. O. Box 3621, Portland, Oregon, 97208.

2. *"Intertie,"* 1969, 16mm sound, 28 min. On transmission of electricity. Same source as Number 1 above.

3. *"Electric Power Generation in Space,"* 1967, 16mm sound, 26½ min. On solar cells, fuel cells. NASA--order from NASA Regional Film Library serving your state.

4. *"Birth of an Era,"* 1954, 16mm sound, 27 min. On hydropower. U.S. Army Engineer District, 200 E. Julian Street, P.O. Box 889, Savannah, Georgia, 31402.

D. REFERENCES

1. *"The Search for Tomorrow's Power,"* National Geographic, November, 1972, pp. 650 ff.

2. Following are the names of seven chapters from the book Mineral Facts and Problems. One copy of up to 10 of these chapters may be requested in booklet form on official stationery from U.S. Department of the Interior, Bureau of Mines, Publications Distribution, 4800 Forbes Street, Pittsburgh, Pennsylvania, 15213.

   "Anthracite"
   "Bituminous Coal and Lignite"
   "Energy Resources"
   "Natural Gas"
   "Petroleum"
   "Shale Oil"
   "Uranium"

3. *"Power and Progress,"* a booklet on general facts about electricity. Single copies available from Edison Electric Institute, Public, Employee and Investor Relations Division, 90 Park Avenue, New York, N.Y., 10016.

BACKGROUND INFORMATION FOR THE TEACHER

Energy: The Squeeze Begins
by James H. Krieger, Chemical and Engineering News, November 13, 1972.

Like a meteorite, the "energy problem" has fallen on the national scene, and tremors threatening to become shock waves are spreading out in all directions. Scientists, technologists, industrialists, and government officials are gathered around, probing here, sampling there, trying to determine what it is, what it means, and what to do about it.

One conclusion can be reached: The energy problem represents change. Although its complexity makes the problem difficult to grasp in its entirety, its existence means that "things" will no longer be the same. Actions taken in response to the problem–whatever they ultimately may be- will affect in ways large and small–and at this point mostly unknown–not only the energy industry but all industry, commerce, and the man on the street.

The reason lies in the role of energy in the economy of the U.S. The U.S. economy, especially as it has developed over the past quarter of a century, is based on the profligate use of cheap energy. Whatever the outlook for availability, the future seems to hold no place for cheap energy. Thus, cost increases coupled with sporadic unavailability at least in the short term strikes at one of the assumptions that has infused the very fiber of the American economic system.

Already prices of fossil fuels have begun to rise. In 1967 oil was going for about $3.00 per barrel, natural gas for 15 cents per 1,000 cu. ft. (at the wellhead), and coal for $5.00 per ton. Today, prices have reached about $3.50 per barrel for oil, 45 cents per 1,000 cu. ft. for natural gas, and more than $7.00 per ton for coal. There seems little basis for assuming that this is other than the beginning.

Changes that will be wrought by actions to overcome the energy problem will be wide ranging and deep. How fuels are produced, the way power is generated, the forms in which energy is used-the whole technology of energy–will be most directly affected.

Secondary effects will also ripple outward. Rising costs and unavailability of energy in certain forms could affect industrial consumption patterns. Chemical producers' raw material supply patterns could change markedly. Consumption patterns of products whose price tags include a substantial portion for production energy could undergo large shifts. Automobile design could be affected, as could architectural practice and building construction.

But however wide and deep the changes might be, they likely will not come overnight. The energy situation is too complex, involving economic, technological, environmental, political, and, indeed, diplomatic aspects. Moreover, there is no overall coordination or energy policy for the U.S., at least as yet. As a result, actions likely will be taken piecemeal.

Just a few short years ago, nothing could have been simpler than energy supply. Need more electricity? Build another generating station and dig more coal. Need more gasoline and fuel oil? Drill some more wells and increase refinery capacity. Need more natural gas? Drill for that and build a pipeline.

What happened was that increasing demand and a newly erupted environmental concern met on a collision course. As the ensuing strains and stresses caused people to take a closer look at the energy system, hoping that a little doctoring would relieve the pressure, they found that the energy situation was not what everyone thought it to be, save possibly for a few cranky doomsayers As the layers of assumption, myth, and misconception were peeled back, the view that emerged was decidedly unsettling.

Natural Gas shortage

First to gain attention was natural gas. An especially heavy upsurge in demand caused by growing environmental limitations on high-sulfur coal and oil put heavy pressure on the fuel. It became evident that the U.S. was running out. Not enough was being found, and, in 1968 for the first time revisions and additions to reserves were less than the volumes of gas produced and purchased.

Recent years' data aren't encouraging. Data reports by the U.S. Bureau of Mines show that, indeed, marketed production of natural gas has increased each of the past five years, reaching 22.5 trillion cu. ft. in 1971, compared with 18.2 trillion cu. ft. in 1967. Production has pretty much kept pace with consumption. However, proved recoverable reserves, although fluctuating, have tended downward, standing at 278.8 trillion cu. ft. in 1971, whereas they were 292.9 trillion cu. ft. in 1967.

The ratio of proved recoverable reserves to consumption tells the story. The ratio has steadily declined from 16.1 in 1967 to 12.3 in 1971.

The natural gas industry lays the blame for this state of affairs at the Government's doorstep. Low wellhead prices forced on producers by the Federal Power Commission, the companies say, not only held down capital generation required for the exploration necessary to discover new wells, but eroded incentive to invest available funds. In any event, FPC is now letting prices rise, although in the opinion of the industry not fast enough.

Capital and incentive aside, how much natural gas is there to be found in the U.S.? Perhaps as good an estimate as there is comes from the Potential Gas Committee, a group of some 150 members from the transmission, production, and distribution segments of the natural gas industry. In addition, government observers work with the group. The committee, backed by the American Gas Association (AGA), the Independent Natural Gas Association of America, and the American Petroleum Institute (API), and sponsored by the Colorado School of Mines, prepares a biennial report of the potential supply of natural gas in the 48 contiguous states and Alaska. Since work committees are privy to private information on a confidential basis, the studies should be as good as any estimates available.

In short, the committee's latest report showed that, as of Dec. 31, 1970, the ultimately discoverable volume of natural gas in the U.S. stood at 1,178 trillion cu. ft.—made up of 257 trillion cu. ft. classed as possible, and 534 trillion classed as speculative. In the previous report for 1968, estimates showed a total of 1,227 trillion cu. ft. with 260 trillion classed as probable, 335 trillion classed as possible, and 632 trillion classed as speculative. The committee notes the potential supply is constantly changing as new reserves are discovered and proved, as economic and operating conditions change, and as prospects are condemned by the drilling of dry holes.

Definitions are important. They often lie behind the confusion and controversy over differing results of various studies. "Potential supply," as used by the committee, means "that prospective quantity of natural gas yet to be found and proved by all wells which may be drilled in the future under assumed conditions of adequate but reasonable prices and normal improvements in technology." In other words, assessment of potential supply doesn't take into account radically different economics or breakthroughs in production technology.

"Probable" is that future supply from known accumulations and new pool discoveries associated with existing fields. "Possible" is that supply from new field discoveries associated with productive formations and "speculative" is that supply from new field discoveries associated with formations not previously productive.

Estimates by the committee do not include "proved recoverable reserves," which by AGA definition include those amounts of natural gas and natural gas liquids which analyses of geologic and engineering data demonstrate with reasonable certainty to be recoverable in the future from known oil and gas reserves under existing economic and operating conditions. It is the AGA estimates of proved recoverable reserves that are reported by the Bureau of Mines.

Despite definitions, however, and the differing estimates of various studies, one conclusion stands out: The U.S. seems destined to run out of natural gas—not at some hazy, far-distant time, but in the foreseeable future.

Oil reserves limited

What then about oil? To some extent, the situation with oil parallels that of natural gas. Crude oil production in the U.S., according to Bureau of Mines data, increased to about 3.5 billion barrels in 1971, compared to 3.2 billion barrels in 1967. But demand has shot up from 4.5 billion barrels in 1967 to 5.5 billion barrels in 1971.

Meanwhile, proved reserves have hovered about the 30 billion barrel mark. As a result, the ratio of reserves to demand had dropped from 7.0 in 1967 to 5.9 in 1969. In 1970 the American Petroleum Institute-which compiles the figures and defines proved reserves as the crude oil that may be extracted by present methods from fields completely developed or sufficiently explored to permit reasonably accurate

calculations-added some 10 billion barrels of reserves from Alaska's North Slope to the U.S. data. This addition brought reserves to some 39 billion barrels and boosted the ratio of reserves to demand to 7.3. But even at that, the ratio was below the 7.6 for 1965.

Oil production has suffered from environmentalist actions. Fears of oil spills from offshore drilling and of ecological damage from proposed Alaska pipeline construction have contained efforts aimed at increasing production.

The slack has been taken up with imports, and imports of crude oil and refined products have both been increasing rapidly. In 1967 they were about 21% of domestic demand. In 1971, according to Bureau of Mines data, imports had risen to just under 25% of demand, and for the first six months of this year, they ran at 27%.

There is a large amount of oil remaining to be discovered in the U.S., according to estimates. In 1970 the National Petroleum Council reported results of a study that indicated some 436 billion barrels of crude oil discoverable in the entire U.S., including the continental shelf and slope. Of this, 141 billion barrels would be recoverable at known rates of recovery. The discoverable oil adds to 388 billion barrels estimated by the American Petroleum Institute to be known oil-inlace , of which 117 billion barrels would be ultimately recoverable (86 billion barrels of it have already been recovered).

Such figures, although large, are hardly comforting. If the known and discoverable oil is recovered at current rates, the total adds up to a supply of only some 30 years at current rates of consumption.

Plenty of coal

The other fossil fuel on which U.S. energy supply currently depends is coal. Coal, in many ways, symbolizes one major energy problem for the short term: plentiful supply of fuel, but too polluting or in the wrong form or the wrong place.

There is plenty of coal in the U.S. awaiting the mining machines. According to the latest U.S. Geological Survey estimates, as of January 1, 1967, 3.2 trillion tons of remaining resources--bituminous coal, lignite, and anthracite-were in the ground at levels of 0 to 6,000 feet overburden. Some 200 to 390 billion tons of it can be considered identified and recoverable. But coal is solid, thus not as easily or economically transported as fluid gas and oil.

Moreover, of the fossil fuels, coal has come most heavily under the environmental gun. When city ordinances and state and federal regulations limiting sulfur content of fuels began to proliferate, it was coal that bore the brunt of the regulations, although oil was affected, too. Most of the coal in the East is high-sulfur coal. There is plenty of low-sulfur coal in the West, but it is not economical as a supply for the East. Also, coal is being hit hard by environmentalists' attacks against strip mining, a technique that is growing in proportion to underground mining.

For these and other reasons, such as new federal safety regulations that have forced the closure of some mines, production and consumption of coal, the most plentiful fossil fuel in the U.S., have declined. According to Bureau of Mines figures, production of bituminous coal and lignite in 1971 was 552 million tons, about the same as in 1967, although production has surpassed 560 million tons in the interim. Consumption in 1971 was 495 million tons, higher than 2967's 480 million tons. But during that period, consumption has risen to considerably more than 500 million tons. Exports have been fairly steady for the past few years, reaching 57 million tons in 1971.

Even as energy people were becoming aware of potential problems with fossil fuel shortages, environmental consciousness was gathering force. One of the early environmental targets was the sulfur dioxide generated by burning high-sulfur coal or oil from heat or for generating electricity. Bans on sulfur content of fuels exacerbated the already touchy supply situation with natural gas by forcing a switch by many users from coal and oil to natural gas.

Meanwhile, the promise of nuclear energy loomed as a way out of the environment - vs. - energy problem, at least for electricity. It's clean, and by supplying a larger and larger share of demand growth, it could over a period of time relieve some of the pressure on fossil fuels. But advocates of nuclear power hadn't reckoned with the concerns of environmentalists. Actions by the latter group have effectively slowed the nuclear option for the short term.

Nuclear plant orders had begun to fall off in the late 1960's, when construction costs for nuclear

plants rose sharply, making fossil-fuel plants more economical. But rising costs of fossil fuel turned the economics around at the end of the decade. Possible fuel shortages and environmental problems associated with fossil-fuel plants added incentive. As a result, nuclear plant orders took off, with 14 units ordered in 1970 and 20 in 1971–following only seven orders in 1969. So far, 24 units have been ordered in 1972.

By the fall, 31 units totaling some 15,000 Mw. had operating licenses. But 33 more units totaling more than 28,000 Mw. have operating licenses pending. There are also 16 units with construction permits, 37 with construction permits pending, and 35 on order but not yet at a licensing stage. All told, the 152 plants add up to nearly 132,000 Mw.

Original schedules for many of the plants have been greatly stretched out. Hearings for various licenses by the Atomic Energy Commission, state agencies, and other groups–once nearly routine–have become battlegrounds for environmentalists concerned about radiological safety, plant siting, and thermal pollution.

Commonwealth Edison in Illinois found earlier this year, for example, that construction permit review for its new Zion station took twice as long as that for its older Dresden facility. Such licensing delays, coming on top of construction-related delays. have put many nuclear plants well behind schedules originally set to have the plants ready in time to meet anticipated demands.

Even without environmental issues, the early glowing image of conventional nuclear plants as almost limitless power suppliers has been tarnished a bit by a close look at reserves of uranium needed for fuel. By current estimates, there are some 270,000 tons of triuranium octoxide (U_3O_8) recoverable at $8.00 per pound. Beyond that, recovery costs rise and would ultimately be reflected in higher power costs. Because without technological advance, such as breeder reactors, nuclear plants could have consumed a cumulative total of as much as 2 million tons by the year 2000, the economics of conventional nuclear energy from light-water reactors are not very bright for the long term.

In short, the domestic energy supply outlook over the short term leaves much to be desired: inadequate supplies of oil and gas: coal in the wrong form or prohibited from use; nuclear energy projects delayed to where they won't be ready in time or in high enough volume to take up the slack for electrical power generation.

Energy demand rising

This deficient domestic supply is arrayed against an inexorably climbing demand for energy in the U.S. Numerous studies of energy demand have been made, and most point to accelerating growth, although, to be sure, most are predicted on supply being available and don't often take into account the effects that rising prices or plain unavailability might have on that demand.

One of the better studies of historical growth in energy consumption was issued this past September by the President's Office of Science and Technology. Prepared for OST's energy policy staff by Stanford Research Institute, the study examines trends in energy consumption from 1960 to 1968.

Total energy consumption in the U.S., SRI finds, increased from 43.1 quadrillion Btu in 1960 to 60.5 quadrillion Btu in 1968, for a compounded growth rate of 4.3% per year. Industrial consumption, the largest market, in 1968 accounted for 41.2% of the total for that year and had grown at a rate of 3.9%. Transportation consumption at 25.2% of the total had grown at a 4.1% rate; residential, at 19.2% of the total, at a 4.8% rate; and commercial, at 14.4% of the total, at a 5.4% rate.

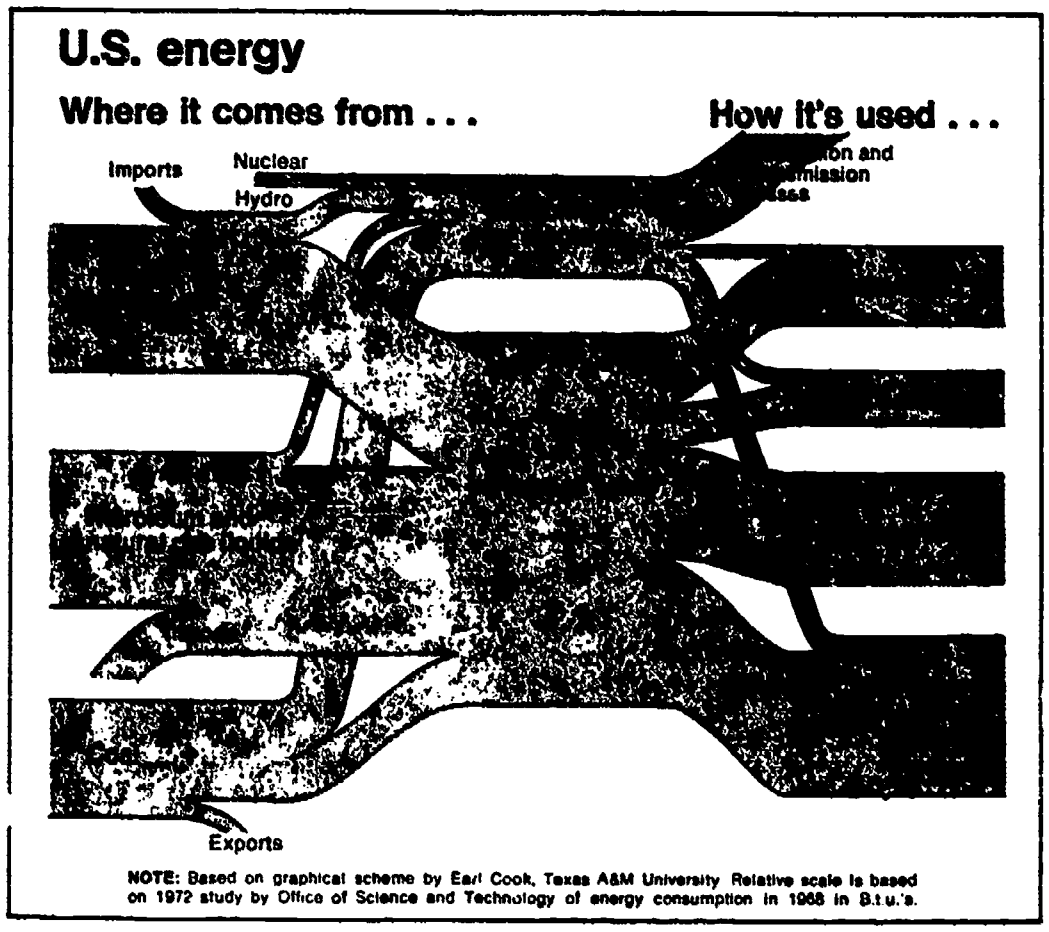
SRI finds that trends in energy consumption were smooth between 1960 and 1968. The institute also notes in the study's introduction that, based on data for 1969 and 1970, "There is every indication that the same basic trends have persisted through 1970," and probably continued through 1971.

Energy consumption in the U.S. has thus increased 50% between 1960 and 1970. Will this rate of growth continue to be sustained? Can it?

No letup in sight

Chase Manhattan Bank, for one, sees no diminishment in sight. In a report on the outlook for energy in the U.S. to 1985, the bank's energy group notes that per capita use of energy has doubled within the past 30 years. And, the group says, "Evidence that it will continue to grow at even a faster rate is unmistakable."

The evidence usually amassed in studies of



NOTE: Based on graphical scheme by Earl Cook, Texas A&M University. Relative scale is based on 1972 study by Office of Science and Technology of energy consumption in 1968 in B.t.u.'s.

near-term energy demand is that of population growth, demographics, and rising standard of living. In all three areas, the trends point toward heavy growth in energy demand.

Although the birth rate has been declining in the U.S., it is nevertheless running at about 2.5 children per woman. The Bureau of the Census figures that, assuming current levels of fertility continue, the rate of population increase will be between 240 and 255 million. By 2000, it will approach 280 million. By itself, population growth should expand energy demand, even if per capita consumption were to hold steady.

But there is no reason to believe per capita consumption will hold steady. Rather, the evidence points to a rapid increase. Near-term demographics intensify plain population growth, as far as energy is concerned.

The Census Bureau estimates that one third of the total population increase between now and 1985 will be in the 25- to 34-year age group. There will be an additional 27 million people who will be in their twenties, thirties, and early forties, compared to an increase of only 2 million in the number of people between 45 and 64. It is the young age group in which most marriages, household formations, and births–and the attendant need for goods and services requiring energy–take place. Consequently, energy demand from this source can be expected to increase considerably, raising per capita energy demand.

Moreover, per capita consumption of energy correlates closely with standard of living, as exemplified by gross national product. If the U.S. achieves its social goal of a continuing rise in standard of living for more and more of its citizens, per capita consumption of energy will rise. Also, attempts to improve quality of life through environmental control will add additional per capita.

Chase Manhattan figures that because of these various factors, per capita demand for energy will not only increase but accelerate. By 1985 per capita demand in the U.S. will be nearly two thirds greater than in 1970.

Overall, the bank estimates U.S. energy demand in 1985 is likely to be twice as large as that in 1970. The average annual growth rate for that period, it estimates, will be 4.5%. This compares with the 4.3% growth rate determined by SRI for the 1960-68 period.

One of the most significant energy studies, and the one most often referred to in energy discussions, is that undertaken by the National Petroleum Council, an officially established industry advisory board to the Secretary of the Interior. The study, published in 1971 under the title "U.S. Energy Outlook: An Initial Appraisal 1971-1985," was carried out by NPC at the request of the Interior Department. Despite cautions urged by NPC throughout, it is often misinterpreted.

The NPC study was made as something of a baseline projection against which to judge actions and policies that might be taken. NPC cautions that, as such, the study is not a forecast of what NPC thinks will happen. Rather, based on certain assumptions, it is a set of projections to be used as reference points, "reflecting an optimistic view of what might happen without major changes in present government policies and economic parameters."

NPC has surveyed the entire energy supply/demand scene. It finds:

. U.S. energy comsumption growing during the 1971-85 period at 4.2% per year, with electric utilities consumption growing at 6.7% per year, nonenergy uses at 5.4%, transportation at 3.7%, residential and commercial at 2.5%, and industrial at 2.2%.

. Domestic supplies dropping from 88% of U.S. consumption in 1970 to about 70% in 1985. Growth rate during the period would be 2.6%.

. Oil imports in 1985 accounting for 57% of total petroleum supplies and 25% of total energy consumption, most of the new imports coming from the Eastern Hemisphere.

. Dependency on natural gas imports rising from 4% in 1970 to more than 28% in 1985, assuming the availability of foreign supply.

. Domestic coal supply, including exports, increasing from 590 million tons in 1970 to 1,071 million tons in 1985, if manpower and transportation are available and if sulfur dioxide control technology is commercially proved.

. Nuclear power supply increasing from 23 billion kwh. in 1970 to 2,067 billion kwh. in 1985, if delays are overcome, supplying 48% of total electric power requirements in 1985.

Energy sources other than oil, gas, coal, and nuclear contributing only 3% of energy requirements in 1985.

Capital outlays for resource development, manufacturing facilities, and primary distribution in the U.S. totaling about $375 billion over the 1971-85 period, not counting costs for petroleum marketing, gas, and electricity distribution, and development of overseas natural resources needed to satisfy U.S. import requirements.

New facilities

In discussing implications of the appraisal, the study notes the enormous additions of new facilities that would be required during the 1971-85 period under existing social, political, and economic conditions. For example, importing the petroleum products needed would require more than 350 tankers, each of 250,000 deadweight tons–for which new terminals would have to be developed, since the U.S. currently has no ports equipped to receive such tankers. About 10 million barrels per day of new domestic refining capacity would be required, involving construction at about 2.5 times the rate of the past decade. Importation of 4 trillion cu. ft. of LNG annually by 1985 would require building 120 tankers, each having a maximum capacity equivalent of about 790,000 barrels–not to mention liquefaction plants, terminals, regasification plants, and storage facilities. Western coal reserves and transportation for the coal would have to be developed, along with expanded development of underground mines in the East and Midwest. And nuclear power would have to reach a capability of bringing 30 1,000-Mw. plants on line each year from 1980 through 1985.

NPC has thus set dimensions to the energy problem. It is now analyzing changes in industry and government programs and policies and changes in economic conditions that would lead to an increase in indigenous energy supplies, enhancement of the environment, maintenance of U.S. energy supply security, and increased efficiency in production and use of fuels through research and development.

In the face of what appears to be an approaching supply/demand imbalance of serious proportions, various piecemeal actions are being taken and numerous proposals being made. Some of the actions involve importation of liquefied natural gas (LNG) and production of substitute natural gas (SNG). Meanwhile, energy industry voices have been calling for government action on pricing, offshore lease sales, oil import policy, environmental protection demands, and similar issues.

Imported LNG

At least 17 applications for importation of LNG have been received by the Federal Power Commission, most for short-term projects of less than two years. Three, however, are long-term projects and are currently awaiting FPC or court adjudication of FPC-imposed pricing conditions. The three involve Distrigas, Eascogas, and the El Paso project including Columbia LNG, Consolidated System LNG, and Southern Energy Co.

If the regulatory way is cleared, Distrigas plans to import up to about 15.4 billion cu. ft. of Algerian LNG per year for 20 years from Alocean, Ltd. The LNG tanker *Descartes* would transport the LNG to terminals at Everett, Mass., and Staten Island, N.Y., for resale to domestic utilities, primarily for peak shaving.

Eascogas LNG, Inc., jointly owned by Public Service Electric and Gas Co. of New Jersey and Algonquin Gas Transmission Co., has plans for importing LNG at an equivalent average of 593 million cu. ft. per day for 22 years for base-load supply. Transported from Algeria by a five-ship fleet, the LNG would be brought to terminals at Staten Island, N.Y., and Providence, R.I.

The El Paso project, first of the long-term base-load projects to file with FPC, involves two operations. Columbia LNG Corp. and Consolidated System LNG Co. plan to import the equivalent of 650 million cu. ft. per day to a terminal at Cove Point, Md. Southern Energy plans to import an equivalent 350 million cu. ft. per day to a Savannah, Ga., terminal. The LNG would be bought from El Paso Algeria Corp., a wholly owned subsidiary of El Paso Natural Gas Co., and transported by a fleet of nine tankers. However, the project last month ran into serious difficulties with environmentalists who object to construction at the Cove Point site.

If regulatory decisions and environmentalists' attacks don't scuttle the projects before they get under way, they are likely to be just the beginning for imported LNG. Last month, for example, it was disclosed that an international group of companies, involving Iranian, U.S., Japanese, and Norwegian concerns, plans a project to supply LNG from Iran to the U.S., Japan, and South America.

And early this month, natural gas negotiations of U.S. companies with the Soviet Union surfaced to reveal what could, if brought to successful completion, amount to one of the biggest trade deals ever made (see page 4). Tenneco, Inc., Texas Eastern Transmission Corp., and Brown and Root, Inc., are jointly negotiating with the U.S.S.R. to bring 2 billion cu. ft. of gas a day from Siberia to the U.S. East Coast. Expecting an agreement to be reached before the end of the year, the companies say it would cover the sale of Soviet gas over a 25-year period.

The Tenneco group is also negotiating to bring 2 billion cu. ft. of gas from Siberia to Japan and the U.S. West Coast. For this gas, the Tenneco group is in competition with another combine made up of El Paso Natural Gas and Occidental Petroleum Corp. Whatever agreements result must undergo scrutiny and approval by various U.S. government agencies.

According to preliminary estimates by FPC's Bureau of Natural Gas, disclosed in late September by FPC chairman John N. Nassikas at the Third International Conference on Liquefied Natural Gas, held in Washington, D.C., LNG imports to the U.S. could reach some 2 trillion cu. ft. by 1980 and 4 trillion cu. ft. by 1990. At that volume, LNG would, according to the estimates, be supplying 6% of domestic demand in 1980 and 9% in 1990.

SNG projects

LNG projects are just one area of recent activity. In view of impending natural gas shortages, companies have rushed to make proposals for projects that would turn out SNG. More than 30 such projects have been proposed. Most would be based on naphtha feedstock, some on natural gas or petroleum liquids. Some involve fuels refineries, which would also produce fuel oil. A couple of projects would use coal.

Actually, only a few of the SNG projects are under way, mostly those involving domestic or Canadian feedstocks. Columbia LNG Corp., for example, is building a 250 million cu. ft. per-day plant at Green Springs, Ohio, and Consumers Power Co. is building a 100 million cu. ft. per-day plant at Marysville, Mich., both based on natural gas liquids from Canada. Also under way are plants for Boston Gas Co. at Boston (40 million cu. ft. per-day) based on propane; Public Service Electric & Gas Co. at Livingston, N.J. (20 million cu. ft. per-day), based on light petroleum liquids; Brooklyn Union Gas Co. at Brooklyn, N.Y. (50 million cu. ft. per-day), based on domestic naphtha; and Algonquin SNG, Inc., at Freetown, Mass. (120 million cu. ft. per-day), also based on domestic naphtha. All of these should be on stream by the end of 1973.

A couple of other plants are planned to be on stream in 1974. But for the most part, the projects that would be based on imported feedstocks are held up pending ruling on the imports. At stake are enough SNG projects based on imported naphtha that, if all were built, would put heavy pressure on world naphtha sources and almost certainly create a price increase that would affect petrochemical producers using the feedstock.

Domestic resources

Apart from some action on LNG and SNG, commercial-scale activity aimed at increasing domestic resources is slight. There is, however, a lot of talk. Industry voices from the oil, coal, and gas sectors increasingly call for government policy actions that they feel would stimulate needed activity. Capsuling the thrust of most of the arguments, the American Petroleum Institute last month filed a statement with the Senate Committee on Interior and Insular Affairs, which, in response to a series of questions raised by the committe, made recommendations in seven areas:

. Create a stable investment climate, by reducing the uncertainty created by perennial threats of adverse changes in tax, import, and regulatory policies.

. Establish tax incentives that stimulate exploration and development of new domestic reserves.

. Continue availability of public lands for mineral development; larger and more frequent sales of offshore leases; and recognition of growing energy needs in actions establishing marine sanctuaries and withdrawal of public lands from leasing.

. Terminate wellhead natural gas price regulation as rapidly as possible.

. Establish specific environmental goals through the governmental process with private industry

responsible for the methods, means, and techniques used to achieve goals given public endorsement.

. Retain a flexible system of quantitative restrictions on oil imports.

. Implement government policies that will encourage the private sector to engage in research and development of synthetic fuels, including oil from oil shale.

Regulation of wellhead prices for natural gas sold in interstate commerce is particularly nettling to producers, especially since gas sold intrastate, which isn't regulated, sells for much more. But it seems unlikely that natural gas price regulation will be eliminated anytime soon.

FPC did take steps in August to ease the price-ceiling pressure on natural gas by issuing new regulations. Previously, producers were limited to area rate ceilings of 26 cents per 1,000 cu. ft. or less. With the new procedure, producers, under certain conditions, may submit to FPC contracts negotiated at higher than regulated prices, and if FPC considers them to be in the public interest, certification will be granted. Immediately, FPC was hit with petitions from several consumer organizations and the matter may go to court.

The move by FPC is apparently about as far as the commission can go in decontrolling prices. Significantly, FPC commissioner Rush Moody, Jr., last summer called for decontrol by Congress through an amendment to the Natural Gas Act. It is beyond FPC's statutory power, he noted, to decontrol wellhead prices. However, it would take some doing for such an amendment to move through Congress.

Oil importation is an area fraught with government concern over maintenance of a strong domestic petroleum industry, coming imbalance in forms of energy, delays in development of domestic synthetic oil facilities, and lack of sites for new refinery operations. Only minor policy changes have been made lately. Perhaps, with the election over, other changes will be forthcoming.

Levels of imports were modified twice during 1972, increasing allocations of crude petroleum and finished product import quotas to meet increased demand. The Government feels its most recent allocation provides some flexibility in supply, since it allowed for borrowing import quota from 1973 for use in the last quarter of 1972.

Offshore leasing, another area of industry concern, seems to be opening up. In September, the Interior Department proceeded with a lease sale of 78 tracts on the outer continental shelf off the coast of Louisiana, following postponement of almost a year due to court challenges by environmentalists. Last month the department issued a final environmental impact statement on the sale of oil and gas leases for 135 more tracts of outer continental shelf land off Louisiana coast. Further, Interior has developed a five-year leasing schedule providing for two large lease sales each year.

Whatever one's opinion on the Government's policies or industry's desires, the various disorganized actions and proposals in the energy area point up one of the most serious problems of energy in the U.S.: No one is in charge.

At the federal level, there is a hodgepodge of agencies and offices dealing with energy. For some, their connection with energy is obvious: Bureau of Mines, Federal Power Commission, Geological Survey, Environmental Protection Agency, Office of Coal Research, and the Atomic Energy Commission, for example. With growing imports of fuels affecting U.S. balance of payments, the Treasury Department plays an increasingly significant role in energy policy–as it does also with any changes in taxation policy. Increasing dependence on foreign sources for fuel brings the State Department into the picture. Antitrust concern over energy company monopolies falls to the Justice Department. The Department of Transportation is heavily involved through transportation policies–for example, those involving mass transit and auto design. Any energy conservation program aimed at housing and commercial building construction would involve the Department of Housing and Urban Development. Searching for long rangeanswers through research and development brings in the National Science Foundation.

Congress is no better off. Senate committees, House committees, and joint committees charged with responsibility for different areas of energy abound.

The result of such a divided approach is a plethora of activities at the national level which are often independent, sometimes at cross purposes. No overall coordinating body or authority exists, let alone one that would set directions.

"The best minds this nation has to offer should be brought together by Government and locked in one room and the key thrown away" until a national energy policy emerges. "It is possible that no one will ever emerge from the room, but if they do, we will have an energy policy around which we can shape our nation's future." This particular call for a national energy policy was sounded last month by C. Howard Hardesty, Jr., executive vice president of Continental Oil Co., in addressing the Independent Natural Gas Association of America. Although more colorful than most, his plea typifies the widespread feeling of need for such a policy.

An energy policy

Actually, momentum toward a policy seems to be building steadily. President Nixon, for example, has proposed an administration reorganization to create a Department of Natural Resources–although bureaucratic resistance to change being what it is, the concept has barely moved off dead center. Many in the industrial and technical communities look to a study of the national energy problem currently being prepared by the President's Office of Science and Technology to set directions (C&EN, Oct. 2, page 4). But until the study is completed, possibly early in 1973, it remains questionable as to whether it can provide a focus for a national energy policy.

The most recent action in the executive branch came last week when the Interior Department announced that it is creating an Energy Board within the department to provide a focal point for coordinating programs and exchanging information relating to a national energy policy. It will not only work within the department but will interact with other interests in national energy policy matters.

Meanwhile, Congress is stirring with activity along policy lines. The Senate Committee on Interior and Insular Affairs is in the midst of a two-year National Fuels and Energy Policy Study, headed by committee chairman Henry M. Jackson (D.-Wash.). In August, Sen. Jackson called for establishment of a centralized agency to coordinate energy data gathering, analysis, and forecasting. The Senate Commerce Committee has held hearings on bills to create an Energy Policy Council. The House Committee on Interior and Insular Affairs is also investigating the energy situation. And study of energy research and development activities and needs is proceeding under a Task Force on Energy of the House Committee on Science and Astronautics, Subcommittee on Science, Research, and Development.

Nongovernment groups are getting involved in the policy area as well. An example is the Energy Policy Project (EPP), established last May by the Ford Foundation to make a comprehensive analysis of national energy policy problems. EPP is headed by S. David Freeman, former head of the energy policy staff in the Executive Office of the President. It has a board of advisers made up of academic leaders, public administrators, executives from the energy industries, and representatives from consumer and environmental movements.

EPP is placing priority on five major areas: quality of life, energy and life styles, efficiency and conservation, international outlook, and development of scenarios of the future. In August EPP awarded a grant to Washington-based Resources for the Future, Inc., to analyze future energy supply patterns, assuming a continuation of current growth rates in energy consumption and different energy supply sources. Another grant has gone to the National Resources Defense Council, a public-interest law firm, to study energy policy decision-making in the Federal Government. Last month a service contract went to Boston consulting firm Data Resources, Inc., to develop an empirical model of the energy sector of the U.S. economy.

Any energy policy making body that finally emerges will have a problem of astounding complexity to deal with. For perhaps the main feature of the U.S. energy system is its complexity.

The energy problem changes depending on whether it is viewed in terms of short range, medium range, or long range. Each requires understanding of the interplay among resources, reserves, production, distribution, pricing, demand, capital generation, and a host of other factors. The scene shifts depending on whether the focus is local, national, or international. And how to mix into all of this the interplay of forces technological, environmental, and political?

Research workers at Massachusetts Institute of Technology are one group that is trying to grasp the complexity, or at least to gain some insights into it. In computer studies, they are attempting to develop models of the U.S. energy system that would account

for the complex interrelationships of the many variables to see how the system would react over time to various changes.

A somewhat similar project is being carried out by Data Resources, Inc., through its EPP contract. The empirical model of the energy sector of the U.S. economy that the firm is developing will be an extension of an econometric model of the U.S. economy it has already developed and has in operation. Incorporating world supply and demand, the energy-sector model will distinguish among the principal primary and secondary sources of energy and cover exploration, production, distribution, consumption, storage, and pricing. In this way, it can be used to support the EPP economic analysis work.

It would make matters a good deal simpler for the U.S. if it could consider its energy problems in isolation. But as a country with 6% of the world's population consuming a third of the world's energy, it cannot escape the reality of its position. What the U.S. does regarding energy affects the rest of the world, and what the rest of the world does affects the U.S.

It seems inescapable that one thing the rest of the world will be doing will be increasing its own energy demands–perhaps drastically. It will be doing so in both industrial and developing countries.

Thus, the U.S. is not alone in its concern about adequate energy supply. "We cannot wait until the lights in Europe literally go out," said a European Economic Community official last month in calling for an EEC energy policy (C&EN, Oct. 30, page 10). As communication from the European Commission to the Council of Ministers recently put it, "The community's key problem in the energy field is to ensure adequate supplies in a market displaying greater uncertainty than in the past."

With its current six member countries, EEC will probably consume in 1972 nearly 1 billion metric tons of coal equivalent of energy. With increasing demand and coming expansion to nine countries, its energy consumption is expected to reach 2 billion metric tons of coal equivalent by 1985. Some 70% of the fuel needs then would be imported, com[illegible]red with 63% in 1971.

Further pressure on world energy resources will likely come from the developing countries. Energy demand rises rapidly in an industrializing country. It seems self-evident that rising aspirations of the people in those countries will rapidly increase per capita demand for energy. Although in 1985 or even 2000 per capita consumption in developing countries will probably be minute in proportion to that in the U.S., the staggeringly greater population will put sizable dimensions on absolute demand.

Thus, the almost certainly rising world energy demand and the expectation that the U.S. could be importing as much as 18 million barrels of oil alone in 1985–more than 50% of domestic demand–raises serious national security implications regarding dependence on foreign sources. Political or economic forces could threaten imported supplies, and with such a heavy dependence on imported oil, U.S. bargaining power would not be particularly strong.

Trade deficit

There are further implications. Speaking at the recent Third International Conference on Liquefied Natural Gas, deputy assistant secretary of Commerce for resources Stanly Nehmer noted that the U.S. 1985 balance of payments deficit for fuels has been projected at $25 to $30 billion, some 10 times higher than the present payments deficit for fuels. Until recently, Mr. Nehmer points out the U.S. did not have to be overly concerned about the role of fuel in its balance of payments, something that Japan and the countriesof western Europe had to worry about.

Considering the strain put on the international economic system by the current deficit in U.S. balance of payments of a few billion dollars, what would be the effect of a balance of payments deficit of the size projected for 1985? "How does the international economic system manage the addition of a substantial increase in the U.S. fuel payments deficit on top of a growing volume of imported fuels by these other industrialized countries?," Mr. Nehmer asks.

Still another implication was brought out last summer in an address to the American Chamber of Commerce in London by John G. McLean, chairman and chief executive officer of Continential Oil Co. Growing purchases of crude oil by the U.S., he noted, coupled with those of other consuming countries in the non-Communist world will create a major new center of financial power in world money markets.

In the 15 years from 1970 to 1985, total funds

flowing to the 11 countries making up to Organization of Petroleum Exporting Countries (OPEC) could amount to as much as $500 billion. Most of the countries, predominantly Arab, aren't yet ready to absorb new funds of this magnitude within their own economies. A result, Mr.McLean says, is that a large amount of the revenues will move into the short- and long-term money markets in ways, and with impacts, that are difficult to predict. One possibility is that the OPEC countries could become large equity holders in the financial institutions and industrial companies of the U.S., western Europe, and Japan.

Technological solutions

When the critical energy situation became clear, people began to look for technology to come to the rescue. And indeed there is quite an array of new energy technology waiting in the wings to be developed or put to use. Some of it, SNG-from-oil processes, for example, is already coming into play as short-range solutions are sought. More will be emerging in the medium range. The long range will undoubtedly see a national energy technology far different from what it is today.

However, whether new technology related to energy sources can come on strong enough soon enough to really resolve the shortage problems is far from definite. It may be that the directions energy use takes in the future will hinge more on technologies that are now seemingly peripheral to the central issue and on changes in societal life style.

Meanwhile technological efforts are proceeding on a broad front. For the medium term, the technological solutions most widely heralded fall primarily in the category of fuel-to-fuel conversion. Hopes for the medium term and beyond also turn strongly to the new nuclear technology embodied in the breeder reactor. Geothermal energy could supply some localized help. Also in the medium term, hydrogen will probably begin to make itself felt as an energy carrier in the system. In the longer term, options will most likely increase to include thermonuclear, solar, or other unconventional forms of energy.

Coal gasification

In fuel-to-fuel conversion, development emphasis is currently on coal gasification. The U.S. is rich in coal, which represents more than three fourths of known fossil fuel reserves. Since natural gas is in shortest supply, effort has been placed on developing economical methods of producing pipeline quality, or high-Btu, gas from coal.

Research and development on a number of high-Btu coal gasification processes has been under way for some time by private and industrial groups, mostly at a low level of effort. In 1960 the Office of Coal Research was formed in the Department of the Interior and, among its various programs, began to fund work on coal gasification. At that time, utilizing coal was the primary concern. When the energy problem shifted the program's focus to the products, coal gasification was given a big boost.

In 1971 OCR and the American Gas Association reached agreement to administer and fund jointly a Government/Industry Coal Gasification Program. Under the program, gasification research on three OCR pilot plant projects will accelerate, and research leading to preliminary design of a demonstration plant will be started. Funds for the program are being provided two thirds by Government and one third by industry at a rate of $30 million per year for four years. The program will specifically advance three projects: Hygas, the CO_2 acceptor process, Bi-Gas.

The Hygas process, developed by the Institute of Gas Technology, first under AGA sponsorship and then with OCR support, is furthest along. It consists basically of a two-section gasifier, in the second section of which coal reacts with a mixture of synthesis gas and steam provided by an electrothermal gasifier operating on char from the hydrogasifier.

A pilot plant incorporating the Hygas process began operating in Chicago late in 1971. Operated by IGT, the unit has capacity to process 75 tons of coal per day, producing 1.5 million cu. ft. of pipeline gas. IGT and engineering firm Procon, Inc., also have under way a project sponsored by AGA to design a demonstration plant with a capacity of 80 million cu. ft. per day of gas (a commercial plant would produce about 250 million cu. ft. per day).

The CO_2 acceptor process, developed by Consolidation Coal Co. under joint sponsorship with AGA since 1964, operates by circulating calcined

dolomite through a fluidized bed of lignite char, the dolomite reacting with carbon dioxide from the gasification reaction to liberate heat, which sustains the endothermic carbon-steam reaction. A pilot plant using the CO_2 acceptor process was completed at Rapid City, S.D., early in 1972.

The Bi-Gas process resulted from development work of Bituminous Coal Research, Inc., under OCR sponsorship. It is a two-stage gasification process, in which char swept out with the product gas is returned to the bottom section of the gasifier, where it is completely gasified under slagging conditions by reaction with oxygen, producing both the synthesis gas for the upper gasifier section and the heat needed for the reactions. A pilot plant utilizing the Bi-Gas process is being built at Homer City, Pa.

Meanwhile, the Bureau of Mines has been doing its own gasification development, which has resulted in the Synthane process. In this process, coal moves through a three-zone gasifier that incorporates fluidized beds. Lummun Co., under contract to the Bureau of Mines, has been designing a Synthane pilot plant, planned for the bureau's Bruceton, Pa., research complex.

Work on the four main U.S. gasification processes is moving ahead rapidly. Last month, an OCR contract went to C. F. Braun & Co. to provide engineering support in the evaluation of all OCR gasification projects and to aid in selecting the best process and preparing a preliminary design for a demonstration plant. OCR's goal is to have a demonstration plant sometime after 1976 so that privately built commercial plants could be ready soon after 1980.

A large number of other government and private projects are moving along at a much lower level of activity and not nearly so far ahead in development. One example is an OCR-sponsored project at the University of Wyoming on direct conversion of coal-steam systems to hydrocarbon gaseous and liquid fuels in a single-stage reactor employing a multiple catalyst. On the private side, just last month General Electric revealed work resulting in, among other developments, a way to use inert bulk diluting agents to reduce swelling and caking of coals in a unique fixed-bed gasification reactor.

Despite all of the development activity, however, domestic gasification technology may not be the first put to commercial use. A number of studies of possible gasification projects are being made by gas and coal companies, and indications are that the German Lurgi process will likely get the first nod. El Paso Natural Gas, for example, has proposed a $250 million plant in New Mexico to supply 250 million cu. ft. per day of pipeline gas. With FPC approval, the project could get under way shortly.

Low Btu processes

With processes for making high-Btu gas (about 900 Btu per s.c.f.) at the leading edge of coal gasification development, more attention is also being given to production of low-Btu gas (below 200 Btu per s.c.f.). Such a gas is ideal as gas-turbine fuel, and, indeed, it is the prospect of its use in generating electricity by the combined gas turbine/steam turbine cycle that is providing incentive for process development. High-sulfur coal can be used in air gasification processes and the resulting gas cleaned of sulfur and supplied to power stations as fuel.

OCR is in the process of finalizing low-Btu gasification contracts with five companies, having issued letter contracts in September. Westinghouse Electric Corp., Gilbert Associates, Inc., Pittsburgh & Midway Coal Mining Co., Air Products and Chemicals, and Combustion Engineering will be involved in projects ranging from engineering studies and evaluations to small-scale experimental work.

Still another area of coal gasification activity has to do with underground gasification. A number of countries have experimented with the concept off and on for some 100 years, but the technique has yet to be shown to be economically feasible. About a year ago, Arthur D. Little, Inc., prepared a study of underground coal gasification for the Bureau of Mines that found justification for new development activity but within a limited scope.

Last month the Bureau of Mines began underground gasification experiments in cooperation with Union Pacific Corp. Holes are being drilled in a 30-foot-thick bed of coal 400 feet below the surface in a deposit near Hanna, Wyo. The solid coal will be fractured by injecting water under high pressure. Combustion will then be started by inserting a propane burner down a central borehole and air will be supplied from the surface. Successful underground gasification could reduce mining costs and hazards and provide a low-Btu gas for power generation.

Fuel-to-fuel conversion encompasses not only gas from coal but oil from coal, and development work on processes in this area is progressing as well. OCR has had an active coal liquids program since the early 1960's. A pilot plant to test out Project Gasoline-based on a process developed by Consolidation Coal was built at Cresap, W. Va., in 1967. However, mechanical problems prevented totally successful operation. Since 1970 the plant has been shut down, now pending possible conversion to test out the feasibility of producing low-sulfur fuel oil from high-sulfur coal.

Project COED (char-oil-energy-development)--a process developed by OCR in conjunction with FMC Corp. for multistage, fluidized-bed pyrolysis of coal to char, oil, and gas--has been carried to pilot-plant development at Princeton, N.J. Among other OCR projects in liquids is a solvent-refined coal process developed by Pittsburgh & Midway Coal Mining Co. A pilot plant for this process is now under construction at Fort Lewis, Wash. The process, in which coal is dissolved in a heavy aromatic solvent under moderate hydrogen pressure and the solution filtered to remove ash and insoluble organic material, and then fractionated to recover solvent, produces a low-sulfur, low-ash product either as a hot molten liquid or solidified.

Apart from coal, tar sands and oil shale have held promise for some time as sources of oil. Large oil shale deposits lie in the Piceance Basin of northwestern Colorado, the Uinta Basin of Utah, and the Green River Basin of Wyoming. The Interior Department estimates that high-grade deposits in the three states contain some 600 billion barrels of oil. Moreover, the retorting technology required is simpler than the technology needed to get oil from coal, since the hydrogen-to-carbon ratio of shale oil is higher.

In June 1971 the Interior Department disclosed plans for a proposed program to permit development of a small part of the oil shale resources on federal lands, which make up more than 70% of land containing high-grade shale. The program would involve public and industry participation in selecting up to six oil shale tracts, two in each of the three states, to be offered for lease by sealed, competitive bonus bids. Interior last week wrapped up public testimony on a draft environmental statement issued in September in connection with the oil shale leasing project.

But the promise of oil shale has been--and may be--elusive. And to some extent coal suffers from the same problem that has helped to prevent oil shale from being commercially exploited. Indeed, when oil shale or coal conversion technology makes it to the point of being commercially feasible, the problem might well wipe a good bit of the luster from these materials as sources of fuels to plug the energy gap. Quite simply, the problem is that enormous amounts of material must be moved for processing.

Take oil shale, for example. The shale contains from 25 to about 100 gallons of oil per ton of shale-say, 35 gallons per ton, as a reasonable average figure. After retorting and processing, this amount converts to 0.8 barrel of synthetic crude oil per ton of shale. In 1971 imports of crude oil alone (not counting refined products, which were even higher) amounted to some 660 million barrels. Thus, to provide synthetic crude oil in the amount imported in 1971 (let alone what might come in the future) would require shale supplied to plants at a rate of 1,570 tons per minute--or, at 75 tons per car, 21 railroad cars of shale every minute around the clock. And the spent shale would also have to be disposed of after processing.

Or take coal. If a commercial gasification plant were to have a conversion rate similar to that of the Hygas pilot plant, it would turn out synthetic natural gas at a rate of 20,000 cu. ft. per ton of coal, the equivalent to natural gas in heating value of about 18,000 cu. ft. per ton. Just the three LNG import programs of Distrigas, Eascogas, and El Paso, if implemented, would bring some 620 billion cu. ft. of gas per year. For this amount to be produced by gasifying coal would require somewhat more than 34 million tons of coal per year--equivalent to 6% of coal produced in the U.S. in 1971. If projections pegging imports of LNG at 2 trillion cu. ft. per year by 1980 are realistic, the amount of coal required to replace that imported LNG would reach 110 million tons--nearly 20% of 1971 production.

Coal gasification will undoubtedly become a commercial reality. And some day shale oil will likely be feeding into the U.S. energy system. But it would seem an unreasonable hope that either could become a really significant factor in taking up the projected energy deficit for quite some time.

Hydro and geothermal power

Looking to other in-place sources of energy-hydroelectric power and geothermal power-little but localized aid seems likely in the

immediate future. Although more hydroelectric power can be developed, the relatively few remaining sites indicate that this source will become a decreasing percentage of national energy needs in the U.S. Chase Manhattan Bank, in its study, for example, estimates that hydroelectric power will drop from the 15% of electricity generated in the U.S. in 1970 to probably less than 8% in 1985.

Geothermal sources are something of another matter–strong potential, but, so far, only potential. Activity in the geothermal area is increasing, however, and a better idea of how this source fits into the future U.S. energy picture should be forthcoming.

A number of geothermal operations are being carried out in several countries in the world - for example: New Zealand, Italy, and the Soviet Union–but only one operation exists in the U.S. Since 1960, Pacific Gas & Electric has been generating electricity using geothermal steam from an area north of San Francisco called the Geysers and now has a total capacity there of 184 Mw.

In 1970 Congress passed the Geothermal Steam Act with the purpose of stimulating geothermal resource development. The act provides authority for leasing of such resources on federal lands. Federal expenditures alone on geothermal investigations have increased from less than $20,000 in fiscal 1968 to some $2 million in fiscal 1972. The U.S. Geological Survey to date has classified some 1.8 million acres of land as known geothermal resource areas, all in western states.

For all their seeming simplicity, geothermal sources are not without problems. Corrosive hot water must be handled, and turbines operated at low temperatures. Moreover, there exist the environmental problems of drilling noise, release of noxious gases, and the possibilities of land subsidence and increasing seismic activity. Thus, despite its promising potential, goethermal development is only beginning and currently can be classified at best as a medium-term energy source.

Fast breeder reactors

Many hopes for the medium term and the future stretching beyond are pinned on new nuclear technology in the form of the fast breeder reactor. Conventional light-water reactors utilize only the scarce and expensively separated uranium-235 isotope. As a result, their use of uranium ore is inherently inefficient and they are able to recover less than 2% of the energy potentially available in natural uranium. Nuclear authorities have calculated that with expected growth in nuclear power and using only light-water reactors, the low-cost uranium resources in the U.S. would be used up in less than 30 years.

The fast breeder, on the other hand, is able to recover some 70% of the energy potentially available in natural uranium. It is fueled with plutonium and uranium-238. Plutonium produces more neutrons from fissioning than are consumed in the process. The excess is absorbed by uranium-238 to produce more plutonium, leaving a net gain. By thus using all the abundant uranium-238 in natural uranium, the breeder can vastly extend uranium resources.

Moreover, a light-water reactor requires 171 tons of uranium per million kw.-years, making the cost of electricity sensitive to the price of uranium. However, since the fast breeder requires only 1.3 tons of uranium per million kw.-years, making the cost of electricity relatively insensitive to uranium price, the breeder can economically use high-cost uranium, further extending the nation's uranium resources.

With this rationale as stimulus, the Atomic Energy Commission has rapidly accelerated its breeder development program. Although work on several breeder types continues (and which types are best remains a point of some contention), AEC has placed its chips on the liquid-metal-cooled fast breeder reactor (LMFBR) on the basis that only enough money for a demonstration plant of one type would be available and the LMFBR shows the most promise at this point.

Between government and industry funds, $500 to $700 million should be available for a breeder demonstration plant program. And AEC and the nuclear industry have embarked on a program aimed at a demonstration plant by 1980. In January AEC revealed that Commonwealth Edison will be project manager and engineering manager for the demonstration plant and that the plant will be constructed and operated by the Tennessee Valley Authority and located within the TVA system.

In March two corporations to be involved in the breeder program were set up, Breeder Reactor Corp. (BRC) and Project Management Corp. (PMC). BRC has a 17-man board representing both investor-owned and consumer-owned utilities, plus Edison Electric

Institute, American Public Power Association, and National Rural Electric Cooperative Association. It will provide senior counsel, manage financial contributions, and serve as liaison with utilities. PMC has a five-man board representing Commonwealth Edison, TVA, and BRC, and will be responsible for overall design engineering and construction of the demonstration plant.

In 1968 AEC, through a contract with Westinghouse Electric, began work on a fast-flux test facility at Hanford, Wash., scheduled for 1974 operation. It will be used to test fast breeder fuels and materials, providing a typical fast breeder environment.

Barring some breakthroughs, the other forms of primary energy most often considered to have strong potential-thermonuclear power and solar energy–can only be termed long range. Research in both of these areas is building up, but neither of the areas has seen any demonstrations of technological feasibility, let alone economic. So, the techniques show promise, but it is a promise even more remote than others.

In sum, the emerging shape of energy technology over the next few decades will likely find coal gasification moving into the mix, perhaps as early as the late seventies, but not in significant amounts for some time. Oil-from-coal and oil-from-shale will probably come along later, but again, probably not in highly significant amounts at first. Some geothermal energy could be providing local help, perhaps within a decade. With successful development, the fast breeder reactor could start playing an accelerating role in the middle eighties.

The shape of future U.S. energy technology lies, however, not only in development of primary sources; it is also latent in efforts aimed at better energy conversion. Central station fossil-fueled power plants, for example, are an area of strong potential development. Successful development of the combined gas-turbine/steam-turbine cycle, magnethohydrodynamics, new combustion technology, fuel cells, and other techniques could alter priorities elsewhere, influencing the primary energy mix of the future.

Hydrogen fuel economy

One of the strongest influences on future energy technology and utilization-indeed, on day to-day living habits and practices–could well be an energy storage concept that has sprung suddenly into prominence during the past few years. It is the hydrogen fuel economy (C&EN, June 26, page 14). In the energy system foreseen, hydrogen, unlike fossil fuels, would not be a primary source of energy but a carrier with vast flexibility.

A number of considerations point toward use of hydrogen in the future energy system. As a fuel, it burns cleanly, the primary combustion product being water. It thus has little impact on the environment. It would be easily transportable in the existing natural gas pipeline system, and could be stored locally for use in power generation. It could, in fact, replace fossil fuels in all combustion uses.

The key to a hydrogen system lies in rapidly growing nuclear power generation. With large coastal nuclear plants, some of the electricity generated would be used to produce hydrogen, most likely by electrolysis of water, although other schemes are under consideration.

Already, economic analyses of hydrogen systems are being made, one indication of the seriousness with which energy people view hydrogen. In September, at the Seventh Intersociety Energy Conversion Engineering Conference in San Diego, one such analysis was presented by Tempo General Electric Co. Research Center (C & EN, Oct. 2, page 33). The system analyzed, called Eco-Energy System (EES), isn't now economical compared to existing systems under the various technological alternatives analyzed. However, the research group feels that improvements in the subsystems making up EES can make it economically competitive and ecologically superior within 20 years.

A large-scale changeover to hydrogen as an energy carrier would have wide ranging effects. For example, autos would be designed to use hydrogen as a fuel. Studies already performed for the Environmental Protection Agency have shown that present internal combustion engines can be converted to hydrogen use without great difficulty. Households would also use hydrogen as a fuel for cooking and other activities involving combustion. In the final analysis, use of hydrogen depends to a large extent on society's overcoming what has been called the "Hindenburg syndrome." However, proponents of hydrogen feel that hydrogen, if properly handled, is as safe as is natural gas today.

While various energy groups are debating the shape of energy systems–including the use of hydrogen–for the future, growing recognition of impending shortages today and of rising costs of energy has created the beginnings of an energy conservation consciousness. One indication: full-page ads this fall in the **Wall Street Journal**, in which Owens-Corning Fiberglas points out that with proper insulation in all houses in the U.S., more than 20 billion gallons of oil or more than 1 trillion cu. ft. of natural gas could be saved every year. Obviously, Owens-Corning believes, or hopes, that someone is open to the message.

Another example of an early energy conservation consciousness is symbolized in a program initiated by PPG Industries Foundation. The foundation has invited 10 leading schools of architecture from the 10 largest metropolitan areas in the U.S. to compete for a $25,000 grant to improve the education of students in subjects relating to energy conservation as it affects construction and building operation. A requirement of the competition is that the engineering department at each school must be involved in preparation of proposals. Award of the grant will be made early in January.

In September the Office of Emergency Preparedness issued a staff study undertaken to suggest programs that would either improve on the efficiency with which energy is consumed or minimize consumption of energy while providing the same or similar services. The study outlines a wide range of short-, medium-, and long-term conservation measures that can be taken in the four major consumption areas–transportation, residential and commercial, industry, and utilities.

The study finds that the most significant additional energy conservation measures are installation of improved insulation in both new and old homes and the use of more efficient air conditioners; a shift of intercity freight from trucks to rail, intercity passengers from air to rail and bus, and urban passengers from autos to mass transit; and introduction of more efficient industrial processes and equipment. The study recognizes that not all measures might be acceptable or would be implemented, but it estimates that if all suggested measures were taken, demand could be reduced by the equivalent of 7.3 million barrels per day of crude oil within 10 years.

If an energy conservation consciousness should spread, there could be considerable effects in living habits. Such effects coupled with forced changes due to shortages or high prices and other changes due to new technology promise a quite different energy system for the U.S. in the future.

Much depends on whether and what national energy policy emerges. But at this point, any changes that can be envisioned seem likely to affect mainly supply and utilization patterns. They would seem likely to jar the consumption growth curve only a bit. Growth in demand for energy seems inexorable.

CHAPTER 3

NUCLEAR POWER PLANTS

A. OBJECTIVES

1. The student will describe in general terms the process of fission. He will include the concept of the chain reaction as a necessary phenomenon for the continuation of the process.

2. The student will list and describe the functions of the major components of a nuclear reactor. Major components mean fuel assembly, moderator, coolant, control rods, and shielding.

3. The student will compare the various reactor types in terms of the cooling systems utilized.

4. The student will describe the concept of the breeder reactor, and the types of breeder reactors.

5. The student will describe the safety features of reactors, including natural safeguards and engineered safeguards.

B. ACTIVITIES

1. Have your students construct a model nuclear power station.

2. Arrange for a tour of a reactor facility near you. Do not merely plan for a day away from school, but make certain that your students are well prepared for the trip, and that follow-up activities are conducted when you return.

3. Conduct mock hearings relative to licensing of an imaginary power reactor in your school district. Divide your class into groups representing the utility company, the Atomic Energy Commission, the state regulatory agency, and a *"watchdog"* conservationist group. Discuss the situation from all aspects. (Refer to Nuclear Power and the Public, pages 124-134. See reference in Section D of this chapter.)

C. AUDIO-VISUAL MATERIALS

1. *"Atomic Power Today: Service with Safety,"* 16mm sound, 28½ min. A 15 minute abridged version is also available. U.S.A.E.C. Film Library, Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee, 37830.

2. *Tomorrow's Power-Today,"* 16mm sound, 5 1/2 min. U.S.A.E.C–see Number 1 above.

3. *"The Experimental Boiling Water Reactor,"* 16 mm sound, 30 min. U.S.A.E.C.–see Number 1 above.

4. *"Power Unlimited,"* 16mm sound, 12 1/2 min., U.S.A.E.C.–see Number 1 above.

5. *"A Breeder in the Desert,"* 16mm sound, 29 min., U.S.A.E.C.–see Number 1 above.

6. *"The Piqua Nuclear Power Facility,"* 16mm sound, 23 min. Animated comparison of various power reactor types. U.S.A.E.C.–see Number 1 above.

7. *"Dresden Nuclear Power Station,"* 16mm sound, 15 min. U.S.A.E.C.–see Number 1 above.

D. REFERENCES

1. From the "Understanding the Atom" series, a complete set of which may be obtained free by teachers by writing to U.S.A.E.C., P.O. Box 62, Oak Ridge, Tennessee, 37830.

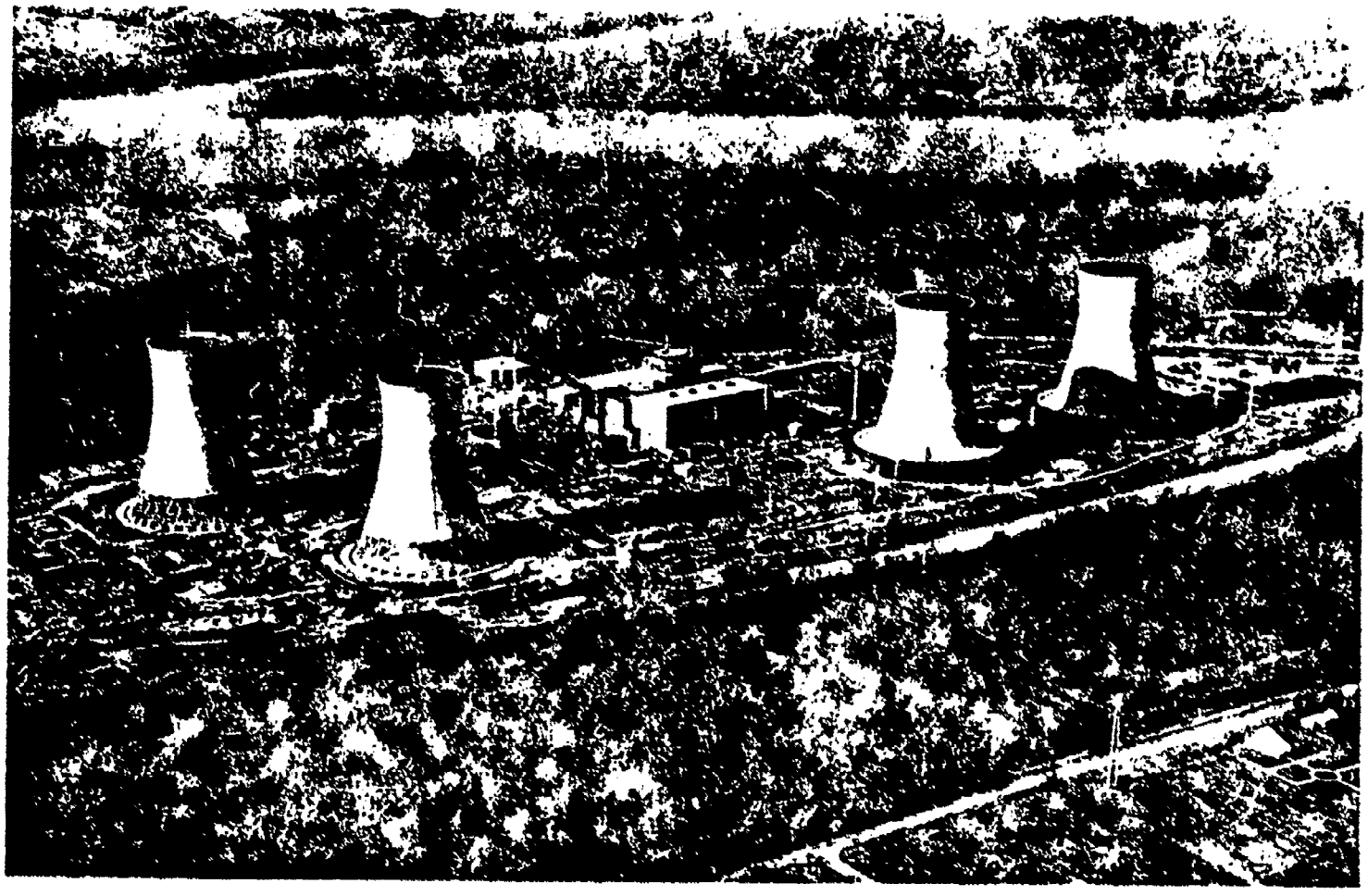
   "Nuclear Power Plants"
   "Nuclear Reactor"
   "Plutonium"
   "Research Reactors"
   "SNAP: Nuclear Space Reactors"
   "Breeder Reactors"

2. Nuclear Power and the Public, Harry Foreman, editor, University of Minnesota Press, Minneapolis, Minnesota (1970).

3. *"The Four Big Fears about Nuclear Power,"* Ralph E. Lapp, The New York Times Magazine, Feb. 7, 1971.

4. *"More Energy from the Atom--But Will It Come in Time?"* U.S. News and World Report, Feb. 19, 1973.

Three Mile Island Nuclear Station now under construction



Met-Ed's Three Mile Island Station complex, under construction, will center around two 169-foot containment structures of prestressed concrete. The vessels will house the nuclear reactors, water pumps and four 73-foot high steam generators.

The turbine buildings, next to the containment vessels, will be as high as 10-story office buildings and will house the 209-foot long turbine-generators. Together these immense pieces of equipment ultimately will produce more than 1,730,000 KW of electricity, the end product of Three Mile Island Station.

The tallest structures of Three Mile Island will be the four 372-foot natural draft cooling towers. Here, water from the steam condensers will be cooled and recirculated. These cooling towers use the same cooling water over and over. The only water taken from the river will be that needed to make up for evaporation. The very slight amount of water returned to the river from these towers will not exceed the river temperatures. Cooling towers eliminate thermal pollution.

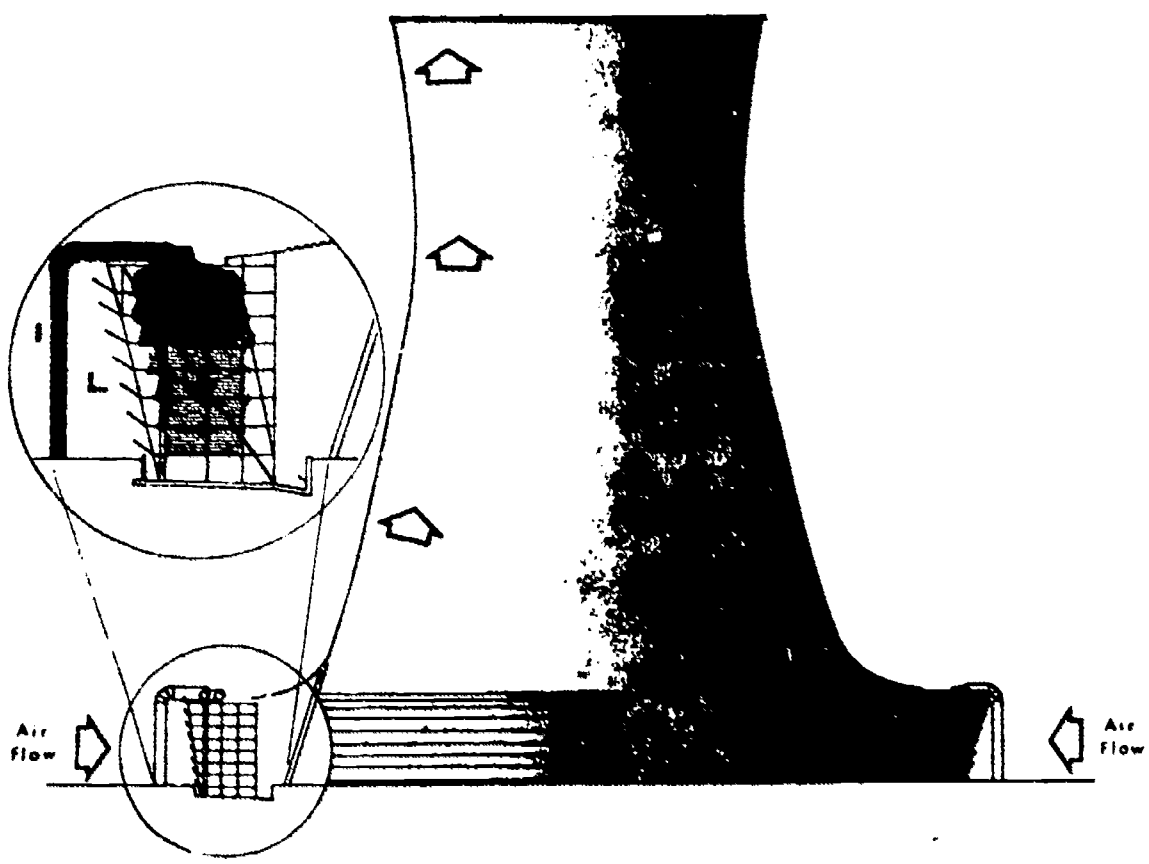
The Heat Goes Up and Away!

During this period of mounting concern about our environment, there has been considerable discussion about the amount of heat that nuclear plants could add to our waterways. Popular public terminology for this problem has become "thermal pollution." This is not pollution as we normally think about it; it is the addition of heat to the water, which changes the ecology, or natural balance of nature, in the stream.

At Three Mile Island, we are not presenting this problem. We are not adding heat to the Susquehanna River, because we are using cooling towers to cool the water used in the nuclear plant. We installed these 37-story towers at a cost of some $15-million to totally protect against affecting the river temperature.

Since the reactor water is one enclosed system and the water from the condenser to the cooling towers is in another enclosed system, the river water is not "polluted," nor is its temperature affected. As the water in the cooling tower is cooled, some of it evaporates and leaves the top of the tower as water vapor, the same principle as when you see vapor from your breath on a cold day.

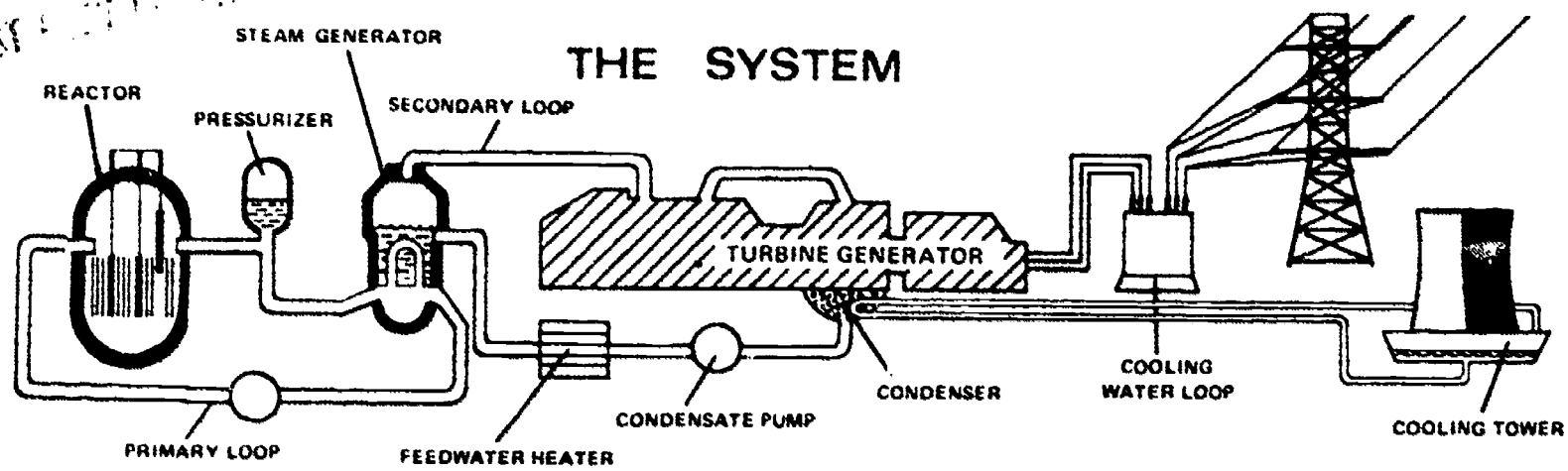
The 372-foot-high natural draft cooling towers at Three Mile Island will stand as servants of life, present and future. As gigantic as they are, they really are very simple machines, especially when compared with the complexity of the other parts of the station. The "what" and the "how" of these devices are explained briefly in the diagram below.



The hyberbolic natural draft cooling towers at Three Mile Island are, in effect, huge chimneys which, for most of their 372 foot height, consist of a reinforced concrete shell. The more complicated part of each structure is contained in the bottom 40 feet—the portion shown encircled in the cut-away above

The hot water enters through the **inlet (I)** at the top of the crossflow **water cell** completely encircling the base of the tower. Air flowing through **louvers (L)** and up through the giant tower, cools the **water (W)** as it trickles down through the cross-flow filling.

The cooled water is then returned to the plant for re-use in condensing the steam exhausting from the turbines.



The main difference between the system for generating electricity at Three Mile Island and at one of Met-Ed's modern coal-fired stations, such as Titus or Portland, is the heat source.

The purpose of the reactor is to produce heat. The reactor is the nuclear "furnace." Instead of burning coal, gas or oil to produce the heat to make the steam that turns the turbine generators, heat is produced by the splitting or fissioning, of atoms in a special uranium fuel. It is called a reactor because of the chain reaction within it.

Three Mile Island's pressurized water reactor replaces the boiler and furnace used in conventional stations. But the steam-electric portion of both types of stations is basically the same. And the end product, electricity, is identical.

At Three Mile Island, the heat produced by the fissioning of the atoms in the reactor, heats the water in the primary loop (see diagram above) to 600° under 2,185 lbs. per square inch of pressure. Pressure prevents boiling.

The pressurized water will be pumped through the heat exchanger, or steam generator. Here the heat will be transferred to water in the secondary loop, converting it to steam at 570° F and 910 lbs. per square inch of pressure.

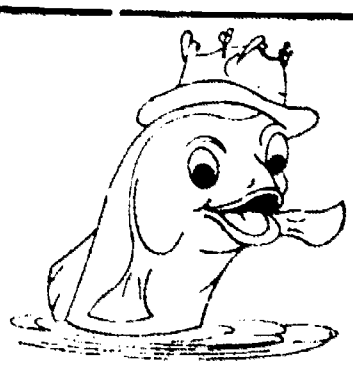
The steam produced in the steam generators surges against the turbine blades, causes them to spin at the rate of 1800 revolutions per minute and turns the connecting generators. This produces electricity at 19,000 volts on Unit No. 1 and 22,000 volts on Unit No. 2. Transformers in the substations step this up to 230,000 volts and 500,000 volts for instantaneous transmission.

Having spent most of its heat and pressure in the turbine, the steam in the secondary loop is cooled and converted back into hot water in the condenser, and recirculated through the steam generator for another cycle.

The water from the condenser, that was used to cool the secondary loop, passes through an outside circuit to the natural draft towers, where it is cooled before it is returned for re-use in the condenser. It is the closed circuit nature of this condenser cooling water system which permits it to operate at maximum efficiency with a minimum of heat transfer to the Susquehanna River.

Trained Personnel

To insure efficient and proper operation, Met-Ed is conducting an extensive training program for the personnel who will maintain and operate the Three Mile Island station. The one-year course consists of theory and classroom work which prepares the employees for their duties at the station. Additional on-the job training was afforded some of our personnel at the Saxton Nuclear Experimental Station and other nuclear facilities. Some must also pass the Atomic Energy Commission's operator's test.



Ecology

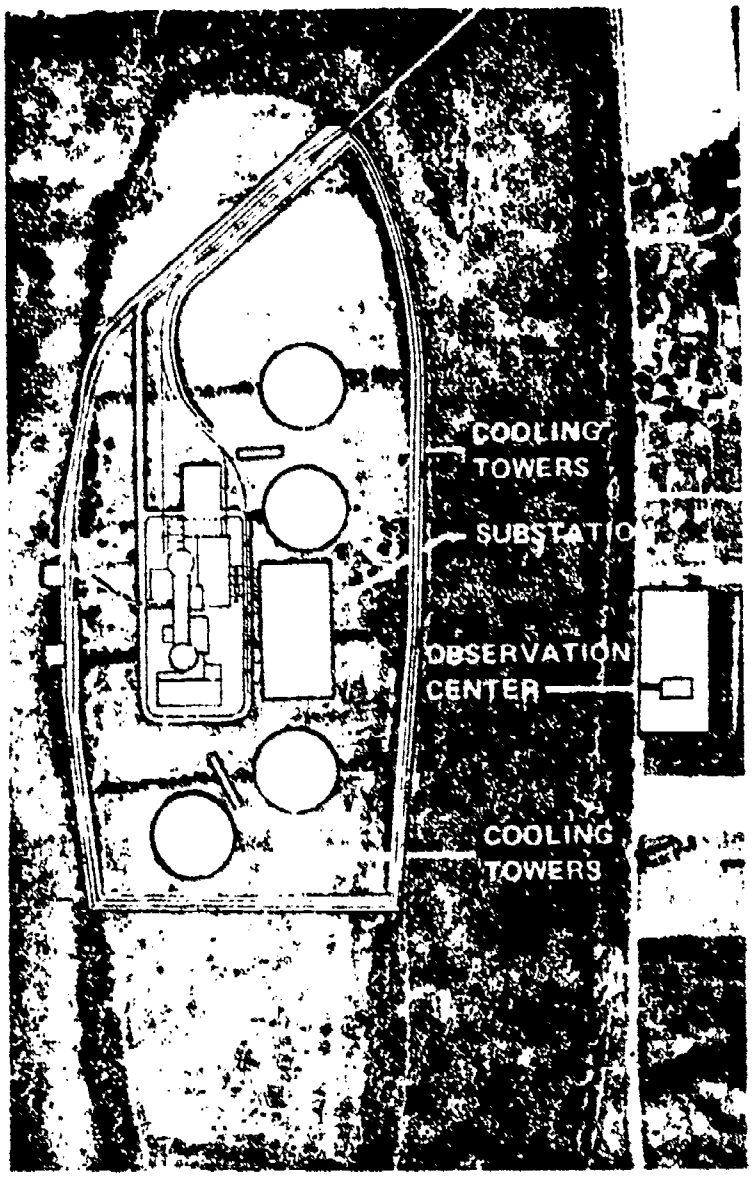
Three Mile Island Nuclear Generating Station will not only provide the electricity so necessary for the continuing advancements of our technological society, but will also help to conserve our natural resources and protect against the problems of pollution which now plague our environment.

For centuries America has enjoyed an abundant supply of natural fossil fuels which we have used to heat our homes and produce electricity. New deposits are becoming more difficult and more costly to find and develop. Since these supplies are not inexhaustible, nuclear fuel must figure increasingly in our nation's power needs. Our supplies of nuclear fuels are virtually limitless and thus afford us the greatest potential power source for the future. Three Mile Island station will be a giant step forward in the preservation of our natural fossil fuel resources.

The greatest problem our nation faces in the coming decade is that of air pollution. As good neighbors, Met-Ed, Jersey Central and Pennsylvania Electric have been conducting, for many years, an active research program to develop more efficient methods of air pollution control. Through the installation of precipitators, more than 99 per cent of the particulate matter (flyash) is removed from combustion gases in conventional generating plants. But nuclear generating plants offer an even better solution. Because nothing is burned in a nuclear plant there is no smoke, no flyash and no fumes that could add to the already serious air pollution problem.

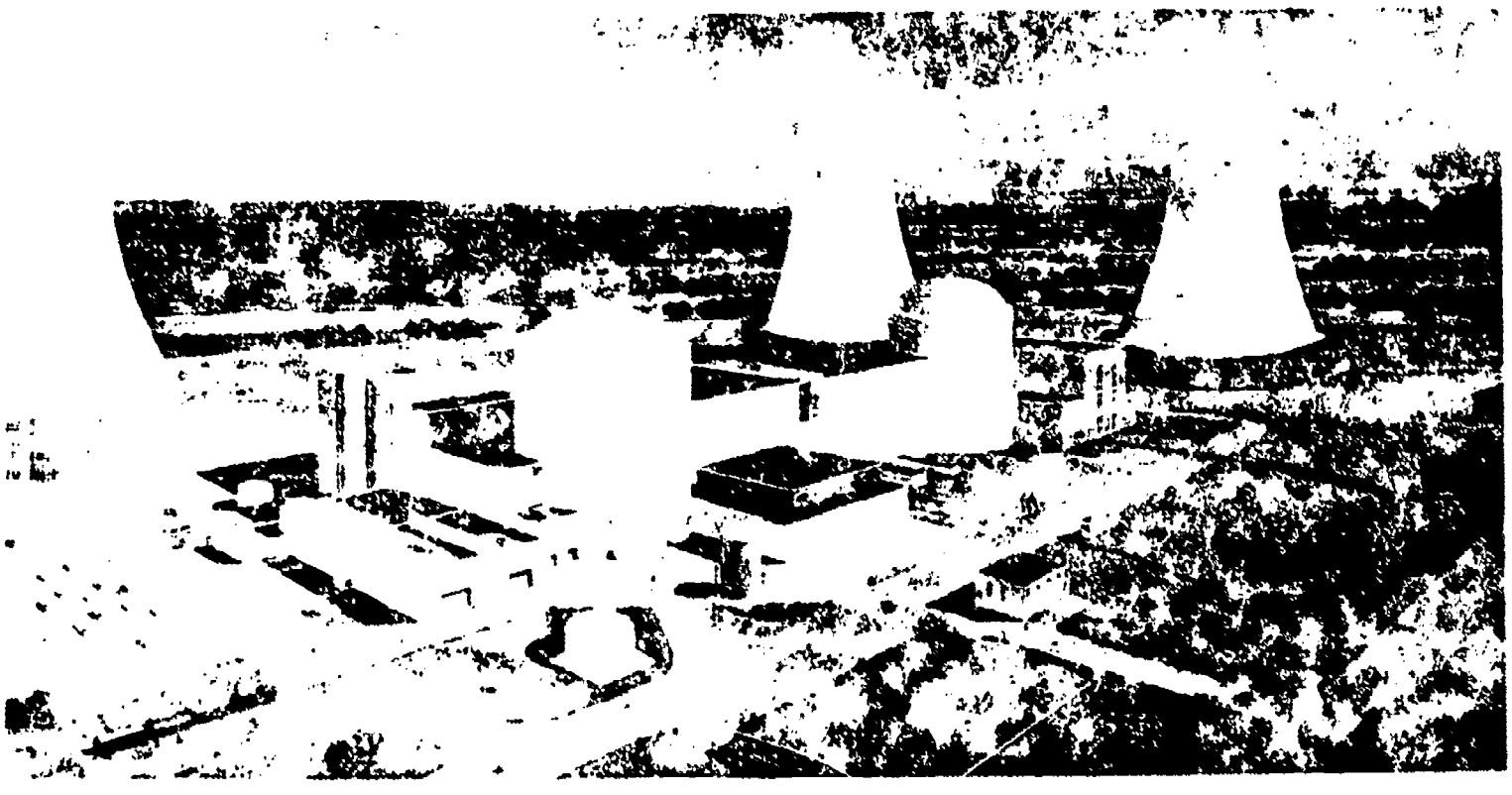
Another environmental problem of increasing concern is that of the pollution of our lakes, rivers and streams. Nuclear power plants require tremendous amounts of water to keep them cool and to produce the steam needed to generate electricity. However, at no time at Three Mile Island does this water come into contact with the nuclear elements of the plant. At certain times and under certain circumstances, small portions of the cooling water may have to be returned to the river; but, even then, they will be as pure and clean as when they were taken. Further, the closed circuit design of the Three Mile Island cooling towers assures that there will be no measurable increase in the water temperature of the Susquehanna River during operation.

Three Mile Island Nuclear Generating Station will be a leader in the fight to conserve this country's natural resources and create a healthful, beautiful environment.



The Future of Three Mile Island

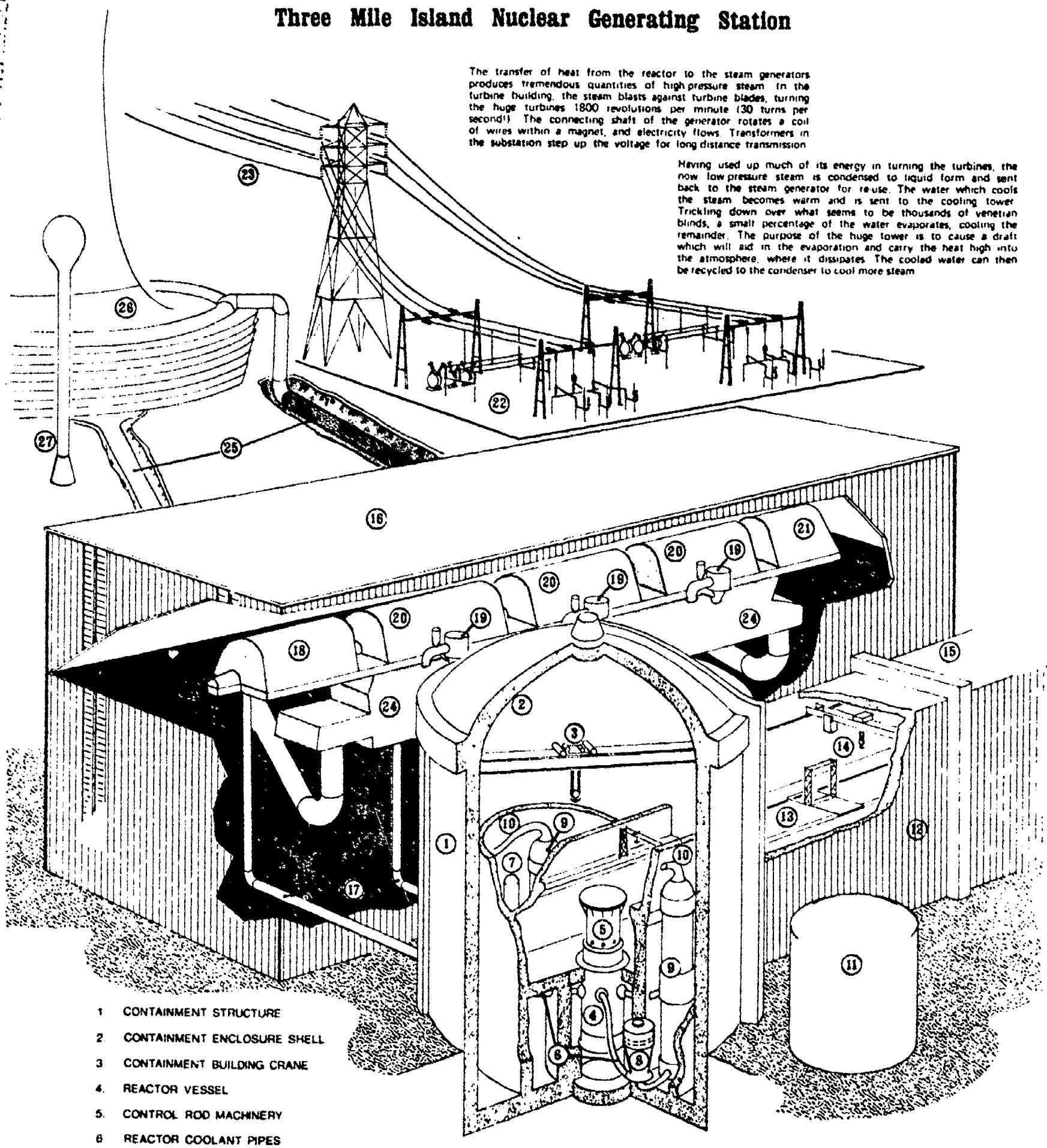
Three Mile Island Nuclear Station is now included in an ever-growing list of atomic power stations being built to satisfy the country's demand for electric power, a demand that doubles approximately every ten years. By 1980, it is expected that nuclear energy will produce one-third of the nation's electricity, at the same time helping to conserve our fossil-fuel resources, be a major factor in abating some of the nation's problems of air pollution, and fight inflation trends. With the completion of the new station, the 50-mile stretch of the Susquehanna from Middletown to the Chesapeake Bay will become one of the world's leading producers of electric power and a "test-book tour" of the chief energy sources used to make that power--water, fossil-fuel, and nuclear fission.



Three Mile Island Nuclear Generating Station

The transfer of heat from the reactor to the steam generators produces tremendous quantities of high pressure steam. In the turbine building, the steam blasts against turbine blades, turning the huge turbines 1800 revolutions per minute (30 turns per second!). The connecting shaft of the generator rotates a coil of wires within a magnet, and electricity flows. Transformers in the substation step up the voltage for long distance transmission.

Having used up much of its energy in turning the turbines, the now low pressure steam is condensed to liquid form and sent back to the steam generator for re-use. The water which cools the steam becomes warm and is sent to the cooling tower. Trickling down over what seems to be thousands of venetian blinds, a small percentage of the water evaporates, cooling the remainder. The purpose of the huge tower is to cause a draft which will aid in the evaporation and carry the heat high into the atmosphere, where it dissipates. The cooled water can then be recycled to the condenser to cool more steam.



1 CONTAINMENT STRUCTURE
2 CONTAINMENT ENCLOSURE SHELL
3 CONTAINMENT BUILDING CRANE
4. REACTOR VESSEL
5. CONTROL ROD MACHINERY
6 REACTOR COOLANT PIPES
7 PRESSURIZER
8 REACTOR COOLANT PUMP
9 STEAM GENERATORS
10 MAIN STEAM LINES
11 BORATED WATER TANK
12 FUEL HANDLING BLDG
13 SPENT FUEL STORAGE POOL
14 FUEL MANIPULATOR CRANE, PLATFORM BRIDGE, & HOIST
15 FUEL SHIPPING AREA
16 TURBINE BUILDING
17 MAIN STEAM PIPING
18 HIGH PRESSURE TURBINE
19 MOISTURE SEPARATOR
20. LOW PRESSURE TURBINES
21 ELECTRICAL GENERATOR
22 ELECTRICAL SUBSTATION
23. HIGH VOLTAGE TRANSMISSION LINES
24 CONDENSER
25 COOLING WATER LOOP
26. COOLING TOWER
27. WATERSPHERE (FOR FILTERED WATER) AND FIRE SERVICE

THREE MILE ISLAND NUCLEAR STATION
FACT SHEET
(As of mid-1972)

UNIT NUMBER ONE		UNIT NUMBER TWO
818,900 kilowatts	NET CAPACITY	904,500 kilowatts
	REACTOR BUILDINGS	
137 feet	Outside Diameter	138 feet
201 feet	Overall Height	202.9 feet
3.5 feet	Wall Thickness	4 feet

REACTOR VESSELS

Outside Diameter: 15' 8"
Overall Height: 41' 3"
Weight: 804,500 pounds
Wall Thickness: 8.4 inches

FUEL

Uranium dioxide, 2 1/2 - 3% enriched
Form: Glazed pellets, 1 inch long, 1/2 inch diameter
Number: 144 pellets in each 12-foot long fuel rod
Fuel Rods: 208 in each assembly
Fuel Assemblies: 177 in each reactor,
each 12 feet long and 15 inches square

CONTROL

Control rods in 69 of the 177 fuel assemblies
16 control rods in each of the 69 assemblies
Boric acid mixed with reactor water (Chemical Shim)

PERSONNEL

Approximately 155 for both units

COST

Total Project - Over $700,000,000

COMMERCIAL OPERATION

November 1973	May 1975

THE CASE FOR THE BREEDER, excerpt from *National Journal CPR*, July 17, 1971.

Promoters of the breeder reactor support their case with three principal arguments.

. They cite projections of an immense increase in demand for nuclear power; they argue that the breeder is economical because it produces its own fuel, and further, that it is an essential next step in nuclear power development since uranium resources are limited.

. They say the breeder would be less harmful to the environment than present reactors.

. They say that the United States stands to lose its lead in nuclear technology to other nations unless it proceeds with the breeder.

Breeder and energy needs: The Federal Power Commission projects that the nation's total energy demands will more than double by the year 2000.

Some of the demand will be met by increased production of fossil fuels-coal, oil and gas. But the greatest increase by far will have to come in production of electricity.

In 1965, fossil fuels supplied 78.4 per cent of the nation's energy requirements; but the FPC projects that their share of the energy market will drop to 50 per cent by the end of the century. U.S. electrical generating capacity must grow six-fold by that time to meet the demand, according to the commission's projections.

Since there are relatively few hydroelectric sites left that can harness falling water, most electricity will have to be produced by thermal plants in which heat produces steam to turn electric turbines.

The fossil fuels now used to produce heat in most thermal plants are either limited in supply or contaminating to the environment. Thus, 65 per cent of the projected increase in generating capability is expected to come from nuclear plants.

Assuming that the nation inevitably will turn to nuclear power as its most important source of electrical energy, the promoters of the liquid metal fast breeder reactor argue that the characteristics of its technology will result in major savings.

"With the breeder reactors," said AEC Commissioner James T. Ramey, *"we can extend our use of uranium reserves from decades to a thousand years or more."*

Current commercial reactors use only 1 to 2 per cent in the energy in uranium. But breeders would effectively use up to 75 per cent of energy contained in the ore.

In addition, the breeders would be able to use plutonium wastes efficiently as fuel-both the wastes they would produce in using uranium and the wastes produced at conventional nuclear plants.

Savings in cost of power generation would stem largely from the reduced need for uranium. A conventional present-day nuclear plant needs 150 tons of uranium a year; a breeder of the same size would use only 1.5 tons. Over the course of the next 50 years, the breeder could reduce by 1.2 millions tons the amount of uranium required to supply the nation's energy needs.

This will have the side effect of reducing the pressures for a steep rise in the price of uranium ore, producing additional savings for the utilities.

A recently completed AEC cost-benefit analysis concluded that introduction of commercial breeders in 1986 would save the United States $21.5 billion in power costs through the year 2020, assuming that the funds invested in the reactors would earn 7 per cent a year if invested otherwise.

Environment: Breeder reactors are expected to reduce the environmental impact of nuclear power plants in two ways.

. They will reduce thermal pollution. The breeders will achieve a thermal efficiency of 39 per cent or better, which compares with 32 per cent for the light water reactors and a national average of 33 per cent for all fossil-fuel plants.

. They also will reduce the escape of radiation into the air and water. The reactor core will essentially be sealed, and the small amounts of radioactive fission products now released by light water reactors will be largely bottled up in the core.

[Most environmentalists concede that these features of the breeder are attractive. Some, however, have attacked the breeder on grounds that major environmental disasters could result from widespread handling of radioactive plutonium. The plutonium will have to be stored before use, and transported across the country to reactor sites. In addition, there will be the problem of disposing of the radioactive wastes produced in increasing quantities by the breeder plants.]

International competition: A final argument that is likely to surface more fully in coming months and years concerns U.S. competition with other advanced industrial countries for the lead in high technology programs.

While the United States does not have a monopoly on the sale of light water reactors, it has far overshadowed all other countries. General Electric Co. and Westinghouse Corp. have sold 27 LWRs abroad to date.

There are now, however, six nations–the Soviet Union, West German, Britain, France, Japan and Italy–which have embarked on ambitious programs to demonstrate the technical and commercial feasibility of breeder reactors.

For the period 1978-81, all except Japan expect to complete construction of liquid metal fast breeder reactor plants of 1000 megawatts [electric] or more. This is twice the size of the demonstration plant planned here.

Commenting on this worldwide effort, GE executive Karl P. Cohen said: *"I think the U.S. demonstration program, though somewhat slower and more cautious, will ultimately pay off in better results. The problem, however, is not in the program but in the political arena."*

"We are faced with a political, intellectual and social climate in this country that is hostile to major new technological efforts like the breeder. So it's hard to say how fast we will be able to proceed."

Cohen is general manager of GE's reactor development division.

California's Rep. Craig Hosmer, the ranking House Republican on the Joint Atomic Energy Committee, said: *"Well, if we don't build them, then we'll end up buying them from other countries and further eroding our position as the lead nation in high technology."*

FAST BREEDER COMES UNDER ATTACK

Excerpt from *Industrial Research*, June, 1972.

In government circles today, the most popular solution to the impending energy crisis is the fast breeder reactor; the Uranium-238 device that not only produces power, but also breeds more fuel than it uses.

Increased funding of the Atomic Energy Commission liquid metal fast breeder reactor (LMFBR) program, including construction of a demonstration plant in Tennessee, was a central theme of the President's 1971 energy message. But now the breeder concept is coming under attack.

Central to the criticism has been an analysis of the AEC's claims for the breeder by Thomas B. Cochran, a physicist for the Washington think tank, Resources for the Future, which questions many of the economic asumptions the commission used to justify its faith in breeders.

Cochran suggests, for example, that the agency used an unrealistic discount rate in economic projections, that it underestimated the extent of uranium reserves in the U.S., that it overestimated the demand for electric power in the last decade of this century when the breeders should become truly economic, and that it skated over the costs of the advanced technology that will be necessary to bring breeders to commercial use.

Other critics have focused on potential hazards of commercial breeder reactors. Their fears were summarized in a recent statement put out by thirty prominent scientists, including Nobel Laureates Linus Pauling, Harold Urey, James Watson, and George Wald.

"The (LMFBR) reactor's cooling system will utilize liquid sodium, which is highly reactive and burns on contact with air or water," reads the statement. *"Breeder reactors are inherently more difficult to control than today's commercial fission reactors, they operate closer to the melting point of their structural materials, and they generate and use much larger quantities of plutonium. Plutonium has a half-life of 24,000 years and is one of the most toxic substances known to man."*

The AEC's critics do not go as far as to remove breeders from contention as energy sources for the future. They do, however, call for the AEC to spend more money on *"such basic problems as reactor safety, waste storage, and plutonium management"*–as well as alternative energy sources such as solar power, fission, and magnetohydrodynamics.

The AEC's reply to its critics is that its economic and safety calculations are correct–that there is an immediate need to develop breeders because the alternative energy sources are either inadequate or too far from commercial development, and that safety precautions are sufficient. To back up its position, the agency notes that it has been transporting and storing plutonium for more than a quarter of a century, as part of the nation's nuclear weapons program, with an essentially perfect safety record. And the agency loses no chance to plug the excellent environmental qualities of breeder reactors-they produce no air pollution and only minimal thermal pollution.

CHAPTER 4

FOSSIL FUELED ELECTRICAL GENERATING STATIONS

A. OBJECTIVES

1. The student will identify the methods of using fossil fuel to produce electricity by steam generation.

2. The student will discussexisting reserves of fossil fuels and their predicted availability.

3. The student will discuss the particular problems related to the use of coal in the production of electricity.

4. The student will describe the process of coal gasification and discuss the potential effects of this process.

B. ACTIVITIES

1. Have your students construct and demonstrate Hero's Engine, made from a toilet tank float and copper tubing. Discuss its operation.

2. Perform destructive distillation of a sample of soft coal.

3. Visit a fossil fueled electrical generating station.

4. If you are located near a coal mine or gas or oil wells, arrange a class visit.

C. AUDIO-VISUAL MATERIALS

1. *"Invasion by Oil,"* 1968, 16mm sound, 27 min. On oil spills. U.S. Army Engineer District, Attention PAO, P.O. Box 4970, Jacksonville, Florida, 32201.

2. *"The Invisible Power of Coal,"* 16mm sound, 28 min., National Coal Association. Available from Modern Talking Picture Service. Must be booked from their exchange nearest you.

3. *"Natural Gas and Clean Air,"* 1970, 16mm sound, 20 min. American Gas Association, Film Service Library, 1515 Wilson Blvd., Arlington, Virginia, 22209.

4. *"Flame of the Future,"* 1966, 16mm sound, 13 min. On natural gas. American Gas Association–see Number 3 above.

5. *"Natural Gas–Energy in the Home,"* 16mm sound, 13 1/2 min. American Gas Association–see Number 3 above.

6. *"Natural Gas–Science Behind your Burner,"* teaching kit including filmstrip. American Gas Association–see Number 3 above.

7. *"Power from Paradise,"* 1964, 16mm sound, 32 min. On construction of a coal-burning plant. Tennessee Valley Authority, Film Services, Information Office, Knoxville, Tennessee, 37902.

D. REFERENCES

1. *"Coal in Today's World,"* a booklet available in classroom quantities from National Coal Association, Education Division, 1130 Seventeenth St., N.W., Washington, D.C. 20036.

2. *"Protecting our Resources,"* a booklet on petroleum available in single copies from American Oil Co., Attention Steve Walker, Public Relations Department, 910 S. Michigan Avenue, Chicago, Illinois, 60605.

3. *"Coal is Cheap, Hated, Abundant, Filthy, Needed,"* Jane Stein, Smithsonian, February 1973, pp. 19-27.

BACKGROUND INFORMATION FOR THE TEACHER

GAS FROM COAL -- FUEL OF THE FUTURE, *Environmental Science and Technology*, December, 1971

Rapidly growing demands for energy coupled with increasingly stringent requirements for a clean environment have created an extraordinary and indeed critical fuels supply situation. Although not generally recognized until recently, coal gasification can play a uniquely important role in providing an abundant supply of clean-burning fuel from resources which are secure within national boundaries

The spotlight was turned on coal gasification in the President's June 4 energy message which said, *"As we carry on our search for cleaner fuels, we think immediately of the cleanest fossil fuel–natural gas. But our reserves of natural gas are quite limited in comparison with our reserves of coal. Fortunately, however, it is technically feasible to convert coal into a clean gas which can be transported through pipelines. The Department of the Interior has been working with natural gas and coal industries on research to advance our coal gasification effort... We are determined to bring greater focus and urgency to this effort."*

The Secretary of the Interior asserted that coal gasification has top priority among all Departmental programs related to coal conversion. In August, the Department of the Interior signed an eight-year agreement with the American Gas Association to develop jointly facilities to turn coal into pipeline gas. Federal expenditure for this program will be doubled to $20 million a year, and industry has agreed to provide $10 million a year.

Changing energy requirements

Natural gas supplies one third of the Nation's total energy requirements, including approximately half the demand of residential, commercial, and industrial consumers. One fourth of the needs of steam electric power plants is also supplied by gas. While oil supplies 43% of U.S. energy needs, currently about one fourth is imported. Therefore, at the present time, natural gas represents the largest energy fuel produced and used in the United States.

The fuel use situation is the reverse of fuel supply. Oil and gas supply three quarters of U.S. energy fuel, whereas coal, which supplies 20% of U.S. energy, represents three quarters of the fossil fuel reserves.

Both the growth of total energy demand and the interrelationship of the different energy fuels are changing (see chart). During the 30-year period ending 1970, energy demand grew at an average yearly rate of 3.4%. A 3.5% average annual increase is projected by the Bureau of Mines for the 1970 to 2000 period. At this projected rate, energy use will grow from 69 quadrillion Btu in 1970, to 133 quadrillion Btu in 1985, and 192 quadrillion Btu in the year 2000.

While the use of nuclear power will increase enormously, in 2000 it will still only supply 23% of the total energy demand. However, the demand for each of the fossil fuels–oil, gas, and coal–is projected to double by the year 2000.

Pipeline gas demand

For many years before air quality standards imposed their special requirements for clean fuels, gas consumption far exceeded the growth rate of other fuels, averaging an annual increase of 6% between 1950 and 1970. But, the level of proved reserves of natural gas in the lower 48 United States dropped in 1970 for the third successive year. The reserve/production ratio is currently 12/1 compared to 21/1 in 1960. The Potential Gas Committee reported in 1969 that, in addition to the proved reserves of 287 trillion ft^3, that there are yet 1227 trillion ft^3 of domestic gas.

The gas demand-supply situation is such that while there may be undiscovered gas supplies which could last beyond the year 2000, the proved reserves are small, the rate of discovery is rapidly falling behind, and there are demands which apparently will not be met in the next few years. Nor can we depend on imports to satisfy demands. The Canadian National Energy Board has forecast that, at most, Canada will be able to supply the United States with not more than 2.3 trillion ft^3 of gas in 1980. If all goes well with the current proposals for importing Liquid Natural Gas (LNG), as much as 0.9 trillion ft^3 may be expected from this source in 1975. The price of this gas is expected to range from 75 to 85 cents/million Btu.

Attesting to the pressing need for pipeline gas, commitment for six U.S. synthetic gas plants to produce gas from naphtha has been announced recently. The total design capacity of these plants will be 860 MMcfd, and it is estimated that the cost of this gas will be in the range of $1.14-1.41/million Btu.

Consideration of all factors has led to the projection of a dramatic gap between gas supply and demand (see chart). This gap will reach as much as 17 trillion ft^3/year by 1985 if synthetic gas is manufactured only on the small scale shown. Such considerations have led to proposals for a massive *"crash"* program for coal gasification.

An additional use for methane as automotive fuel, although controversial, has tremendous potential. Methane is a high-octane fuel (130 O.N.); it can be used in an internal combustion engine with markedly decreased air pollution relative to gasoline; and it can be manufactured from coal which is in abundant supply at a cost which compares favorably to that of gasoline. It will almost certainly be necessary to supply a synthetic fuel from coal for transportation in about 10 years.

Coal gasification

Coal gasification consists of the chemical transportation of solid coal into gas and, in the present discussion, includes those process steps which result in the manufacture of pipeline-quality gas. Pipeline gas is composed essentially of methane, is virtually free of sulfur, and contains no carbon monoxide or free hydrogen. The heating value is about 1000 Btu/ft^3 of gas.

Synthetic pipeline gas approaching the specifications of natural gas from coal can be manufactured by producing a synthesis gas followed by purification and catalytic methanation. A typical process begins with coal preparation in which coal is ground to a powder (see chart). It is then pretreated with air or oxygen to destroy the caking property since heating causes some coals to swell and plug the reactor. Then follows the gasification step in which synthesis gas is formed when steam and oxygen react with coal. This synthesis gas will contain varying amounts of carbon monoxide, hydrogen, and methane as valuable components and carbon dioxide and sulfur compounds as impurities that must be removed in further processing.

After removing tar and dust from the gasifier product, the gas is conducted over a *"shift"* catalyst where the reaction $CO + H_2O \rightarrow CO_2 + H_2$ partially occurs. The objective is to bring the H_2/CO ratio to 3, which is required for the subsequent methanation step: $CO + 3H_2 \rightarrow H_2O + CH_4$. An intensive purification precedes methanation – strict sulfur removal being required to keep the catalyst active. Following methanation, the product gas is virtually sulfur free, essentially void of carbon monoxide, but contains a small amount of hydrogen gas. The heating value is typically about 50 Btu/ft^3 less than natural gas.

Gasification occurs at reasonable rates only at high temperature. (1700° to 2500°F.) Pressure alters the gas composition with higher pressures resulting in higher proportions of methane. While gasification can be carried out at 300-1000 psi, commercial processes are expected to operate near 1000 psi (the pressure used in gas transmission).

Technology

Since the hydrogen content of coal (averaging about 5 wt %) is very low compared to that of methane (25%), coal gasification consists of adding hydrogen to coal. In addition, the sulfur, nitrogen, and oxygen constituents of coal are converted to H_2S, NH_3, and H_2O, respectively. (Illinois #6 coal, for example, has a composition represented by the formula $C_{100}H_{85}S_{2.1}N_{1.5}O_{9.5}$.)

As bituminous coal is heated, it becomes soft and may stick together or cake at about 600°F, then devolatilizes about 1000°F, and finally undergoes the gasification reactions in the presence of steam at 1800°F. Gasification reactions of significance are:

	H, kcal/g-mol @ 25° C
(1) $C + O_2 \rightarrow CO_2$	-94.1
(2) $C + H_2O \rightarrow CO + H_2$	+31.4
(3) $C + 2H_2 \rightarrow CH_4$	-17.9

(negative values indicate that heat is given off, and positive values indicate that heat must be supplied).

The rates of reaction, equilibria, and heat requirements are all of critical importance. Reaction 2 is realtively slow and a temperature of above about 1800°F (lower for lignite) is required for sufficiently rapid gasification.

From a heat balance viewpoint, it is important to supply heat to endow thermic Reaction 2 by having as much possible of exothermic Reaction 3 occur in the gasifier. If the methanation reaction (4) $CO + 3H_2 \quad CH_4 + H_2O$ (-49.) is carried out as a separate step, much as the heat generated is lost.

The two most expensive process steps in conversion of coal to pipeline-quality gas are gasification and purification. The gasification reaction absorbs large quantities of heat. The required heat can be furnished by any of several methods:

- partial combustion of coal with oxygen
- heat released by reacting carbon dioxide with a metal oxide
- by inert heat carriers
- by electrical energy.

Using oxygen is effective but expensive so these processes attempt to minimize the amount of oxygen required. To do this, a maximum quantity of methane must be produced in the gasifier. Not only is the quantity of coal needed to react with steam to make synthesis gas reduced, but the formation of methane in the gasification reactor produces a significant fraction of needed heat (since the heat of formation of methane is large and exothermic). When large amounts of methane are formed in the gasification reactor, the reduced volume of gas has a salutary effect on process costs involving purification, shifting, and methanation. For each volume of methane produced in the gasifier, the quantity of synthesis gas to be treated subsequently is reduced by 75%.

Types of processes

There are a great number of significant coal gasification processes. When air is used instead of oxygen, a so-called producer gas is manufactured which has a low-volumetic heating value, for example, 250 Btu/ft^3. Although not considered suitable for pipeline gas since transportation costs are relatively high for gas on a volume basis (18 cents/1000 miles/1000 ft^3 for methane), producer gas may have a future for steam plant generation of electricity.

About 60 coal gasification plants of the Lurgi or fixed-bed type which require a noncaking and sized coal (3/8 to 1 in.) are operating in Europe. Pipeline gas made by this older technology will result in a gas which is still generally too expensive. However, since the fixed-bed technology is well developed, such a process may be adopted for the short term. El Paso Natural Gas has announced that they will build a $250 million plant to produce 250 million ft^3/day using the Lurgi process (which necessitates adding a new methanation step to meet U.S. gas specifications for increased heat value).

New processes (see chart) being intensively invesitgated for pipeline gas manufacture differ primarily with respect to the method of gas-solid contracting, supply of heat to the steam decomposition reaction, and the extent to which direct hydrogenation of coal to methane is combined with steam decomposition in the high-temperature reaction. Others of current interest are the Bureau of Mines hydrogasification process, the M. W. Kellogg *"molten salt process,"* the FMC, and the Batelle Foundation gasification systems. Underground gasification and nuclear energy are longer range possibilities.

Special features of each process include:

- In the IGY HYGAS process (Hydrogasification), residual char is gasified with steam using electrical energy as the heat source. The gas so formed, rich in hydrogen and low in carbon dioxide, is reacted with pretreated coal in two hydrogenation stages to produce a gas with high methane content. When processing caking coals, the coal is first introduced into a pretreater and oxidized with air at relatively low pressure to render it noncaking. Slurried with oil and pumped under pressure to a fluid bed where the oil is stripped off for recycle, the coal is then contacted with hydrogen-rich gases in two successive stages, consisting of an entrained fluid and a fluid bed. The residual char then enters an electrothermal gasifier. If desired, additional char is produced for power generation. After shifting and purification, a *"cold gas"* methanation system is used, circulating product gas to control heat rise over a number of fixed beds of supported pelleted nickel catalyst.

- A variation of the HYGAS process produces hydrogen-rich gas as a raw synthesis gas ($CO + H_2 + CO_2$) by contacting char with oxygen instead of electrothermal means.

- The CSG process (also called the CO_2 acceptor process) utilizes the reaction between hot lime (calcium oxide) and CO_2 to furnish required gasification heat. Purified oxygen is not needed.

Preheated lignite is fed to a devolatilizer and heated with synthesis gas from the gasifier and hot lime to drive off the volatiles, which are largely converted to methane. Char and spent lime are carried by steam to the gasifier, where they come in contact with the additional hot lime. The reaction of steam with the char forms a synthesis gas containing CO_2 which reacts with the lime converting it to limestone (calcium carbonate) and generating additional heat. The char is totally gasified except for that needed for reburning the limestone. The process has been tested in the laboratory, and a pilot plant (without a methanation system) is under construction to gasify about 36 tons of lignite per day.

. Synthane process carries out pretreatment of caking coals under pressure, integral with the gasifier. That is, a small amount of oxygen is added, all solid and gaseous products are carried forward into the reactor where carbonization occurs in a dense fluid-bed zone, and gasification occurs in a dilute fluid-bed zone. Process simplicity is important to operability. More than half the ultimate methane is made in the gasifier under nonslagging conditions. After shifting and purification, methanation occurs in either of two systems, hot gas recycle or tube-wall reactor, both using Raney nickel catalyst.

. BI-GAS process is a steam-oxygen process designed for complete conversion of coal. Coal and gas are introduced in an upflow (entrained) gasifier, where the coal is devolatilized and the volatiles are largely converted to methane. The char produced is carried overhead by the gas flow through a char separator and returned to the gasifier to react with oxygen and steam at a temperature that slags (melts) the ash. The hot gases produced furnish heat for the first-stage gasification reaction. The synthesis gas containing methane is shifted and methanated to produce a pipeline-quality gas. In contrast to the other processes discussed, the gasification temperature is sufficiently high to melt or slag the coal ash which is drawn off as a liquid.

. The steam-iron process uses hydrogen produced by reacting steam with reduced iorn ore, FeO. The resulting magnetite, Fe_3O_4, is then reduced to ferrous oxide with a producer gas derived from devolatilized char, air, and steam. The hydrogen is used for hydrogasification of coal and for catalytic methanation of carbon monoxide.

. Fixed Bed. The fixed-bed gasifier is the only type now being operated commercially. The BuMines pilot plant has an agitator or stirrer which operates to break up coke masses which form when American caking coals are used. Most bituminous coals, particularly those located in the eastern half of the United States, are too strongly caking to be gasified in a conventional fixed bed. Noncaking coals can be gasified in this type of unit without a stirrer in the bed of coal, and moderately caking coals have been used in some commercial producers with a mechanical stirrer.

Several processes are planned for pilot plant testing by 1975. A full-scale plant could be built by 1978. Thus, large-scale commercialized coal gasification will not occur until 1980 or later.

Cost of gas

There are three basic price levels for pipeline gas–the wellhead price (16.4 cents/thousand ft_3 in 1968), the city gate or wholesale price (35.2 cents), and the consumer price ($1.00). The consumer price varies and includes residential, commercial, and industrial uses. The need for gas has recently initiated higher priced alternatives for gas supply. Liquid natural gas, mentioned earlier, is one alternative. Pipeline gas from coal offers another alternative, and its costs have been analyzed in some detail. Revised estimates in 1971 raised estimated selling price to 64 cents/thousand. Columbia Gas estimates 85 cents/1999 ft_3 with coal at $5.50/ton. The price of gas is sensitive to coal costs–an increase of $1.00/ton being equivalent to 7 cents/million Btu.

An economic examination of the new coal gasification processes is shown in the chart. The fraction of the total price of the methane contributed is shown in each process step, and includes capital, labor, and other charges in accordance with federal and state regulations for utilities.

Methane comes principally from two sources: first, from the coal's volatile matter by heating pretreated coal to devolatilization temperature. The second source of methane is devolatilized char which is reacted with steam to form CO and H_2. These are converted to methane, either through external catalytic methanation or in-situ gasification.

The cost of adding heat to the steam-carbon

reaction represents nearly one third of the total cost of the methane produced. To reduce the cost of methane from coal, a process must optimize devolatilized methane production and keep the cost of added heat to the steam-carbon system to a minimum.

Coal gasification consequences

The enormous scale of the potential coal gasification industry has tremendous environmental, economic, demographic, and political implications. As mentioned earlier, there is a projected gap between gas demand and supply of as much as 17 trillion ft^3 by 1985. Manufacture of 10 trillion ft^3 of pipeline gas from coal would require 120 plants of 250,000,000 ft^3 daily capacity each (12 such plants/trillion ft^3). Estimating plant costs at $200 million each, including the mine, corresponds to a total capital investment of $24 billion. Moreover, each plant would consume about 6 million tons of bituminous coal annually or a total of 720 million tons; this would more than double U.S. coal production (currently about 600 million tons per year). The American Gas Association has reported that there are at least 176 potential coal gasification sites in the U.S.

To supply energy needs in the next 30 years, synthetic fuels from coal or corresponding increases in oil importation will be required. Oil importation is now at the $2.7 billion/year level. By 1980, projections predict $10 billion with higher amounts later.

Environmental factors

From an environmental viewpoint, land, water, and air are all critically involved. As mentioned earlier, 120 fuel gasification plants would more than double present coal consumption. Strip mining is expected to be utilized to a large extent. The greatly increased amount of mining will require restoration of mined areas.

Water management is also an important factor. For each plant, 100,000 gal/min would be circulated, of which 20,000 would be consumed. Special precautions are necessary to prevent discharging water-soluble contaminants such as phenols.

Thermal pollution in coal gasification is significant since the conversion of coal to pipeline gas is only about 65% thermally efficient (120 plants would require disposal of about 5×10^{15} Btu/year). Heat disposal to the air is planned by evaporative cooling, which consumes most of the water mentioned above. Disposal of coal ash from the coal processed is also necessary. Fortunately, coal gasification is carried out in closed vessels which prevents air pollution.

An important fact is that the gas produced is usually free of sulfur, having only a few parts per billion. The sulfur in coal is removed in the gasification process and is transformed to elemental sulfur for storage, shipment, or use in a satellite industry. Therefore, the conversion of coal to gas represents a net environmental benefit in reducing pollution by sulfur oxides and particulate matter.

Additional reading

Statement, Hon. Rogers C. B. Morton, before Committee of Interior and Insular Affairs, U.S. Senate (SR 45), June 15, 1971.

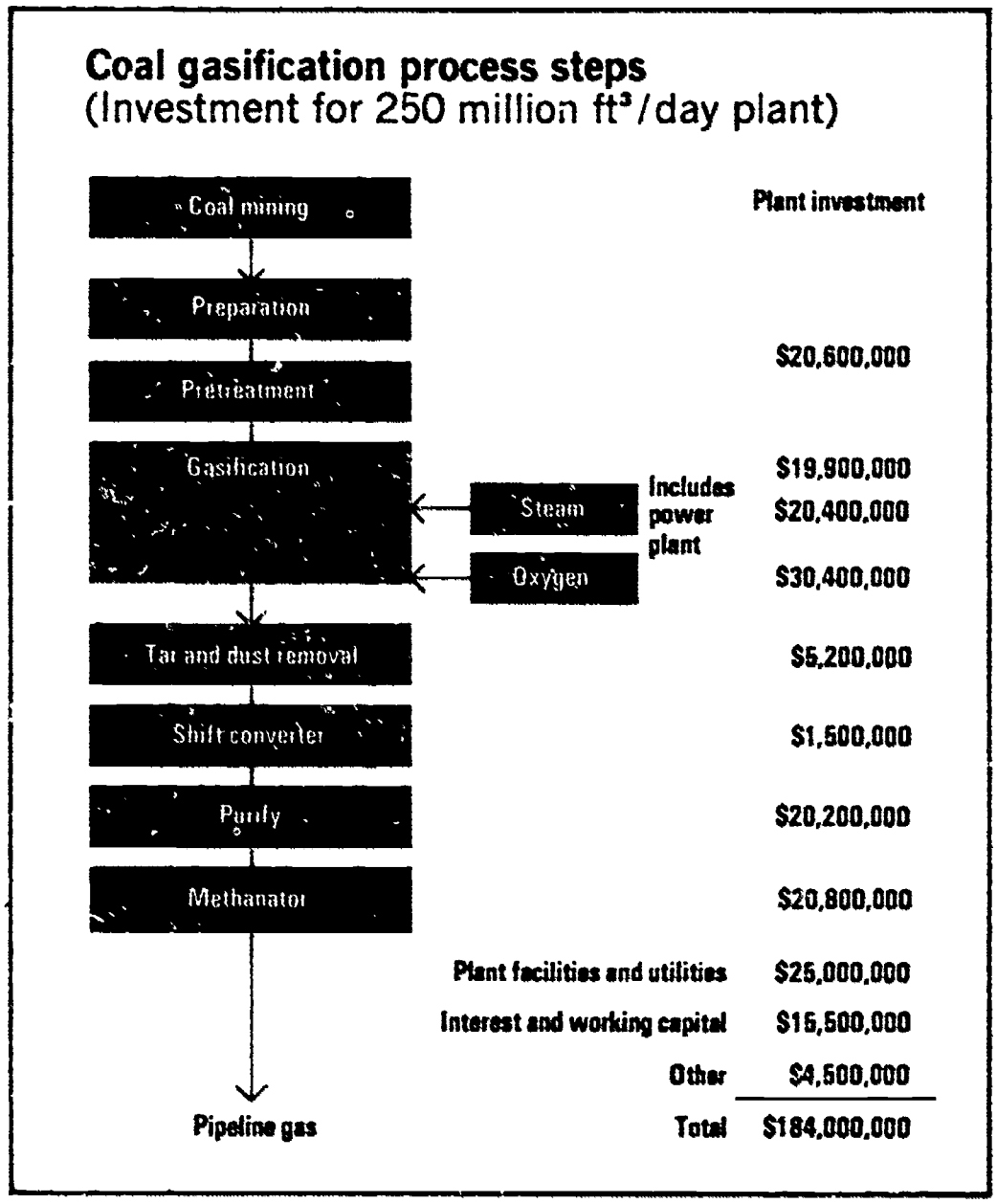
"Fuels Management in an Environmental Age," G. A. Mills, H. Perry, and H. Johnson, ES&T, Vol. 5, 30 (1971).

"An Economic Study of Pipeline Gas Production from Coal," J. P. Henry, Jr., and B. M. Louks, Chem. Tech. 239 (1971)

"Electrothermal HyGas Process, Escalated Costs," C. L. Tsaros and T. K. Dubramanian, O. C. R. Contract 14-01-0001-381, Report No. 22, Interim No. 6, February 1971.

"A Reassessment of the Prospects of Coal Gasification," H. R. Linden, Coal Age, 73, May 1971.

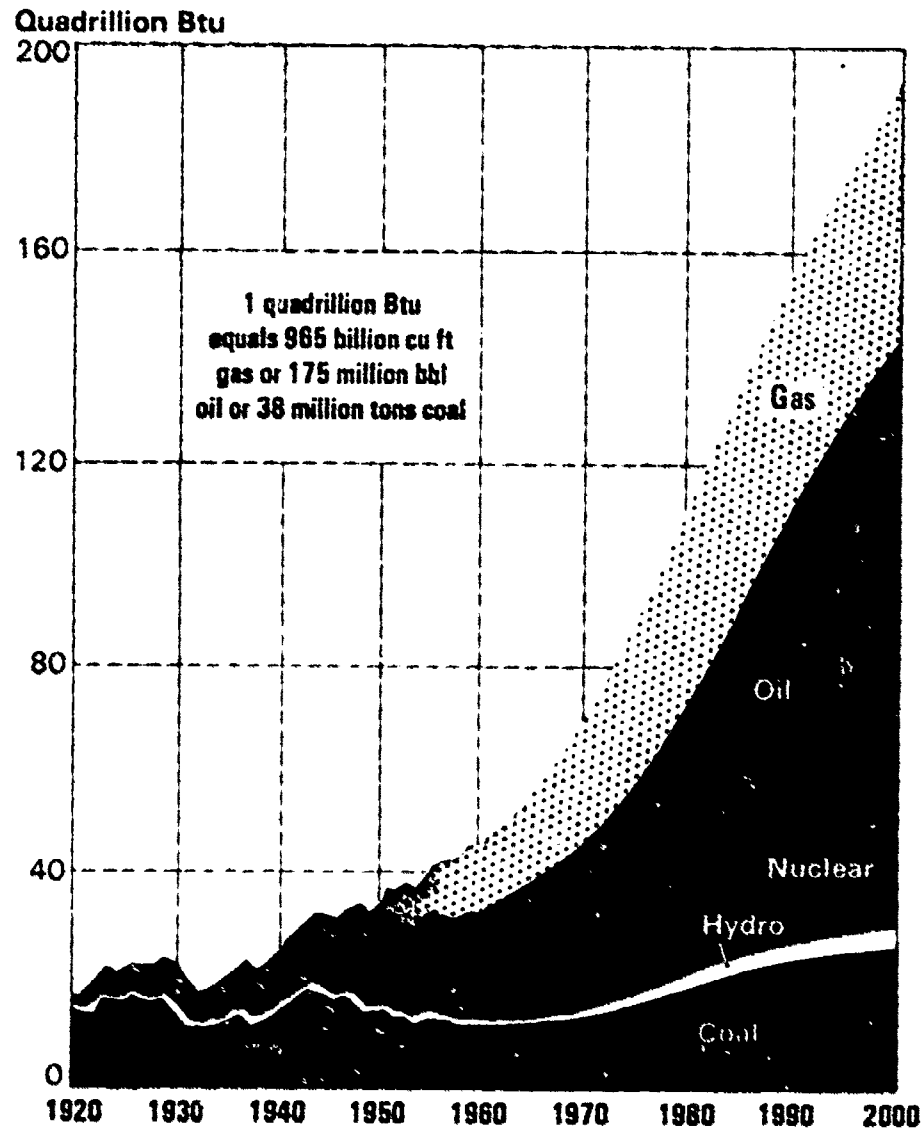
Presentation to the National Coal Association, Partridge, The Columbia Gas Systems, Inc., June 14, 1971.



Coal Gasification Processes

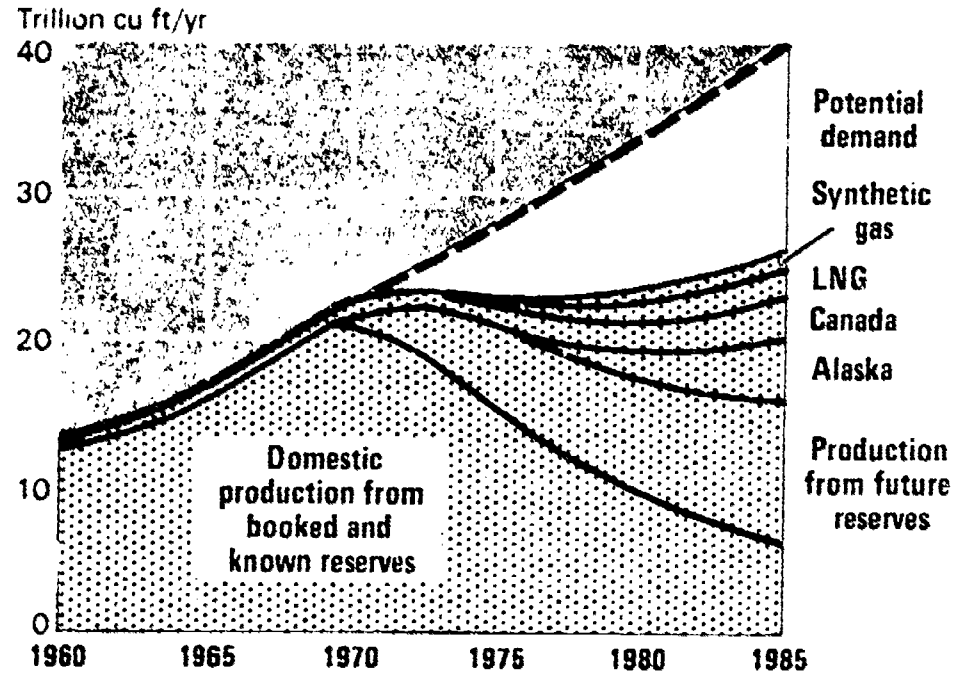
Process	*Laboratory*	*Sponsor*	*Federal Funding FY 1972*
HYGAS (Electrothermal	IGT	OCR-ARA	$3,500,000
HYGAS (Oxygen	IGT	ARA	
CSG (CO_2 Acceptor	Consolidation Coal Co.	OCR	3,420,000
SYNTHANE	BuMines	BuMines	1,500,000
BI-GAS	BCR	OCR-NCA	3,300,000
STEAM-IRON	IGT	Industrial	
FIXED BED	BuMines	BuMines	750,000
FIXED BED	Lurgi	Lurgi	

U.S. demand for energy sources continues increase

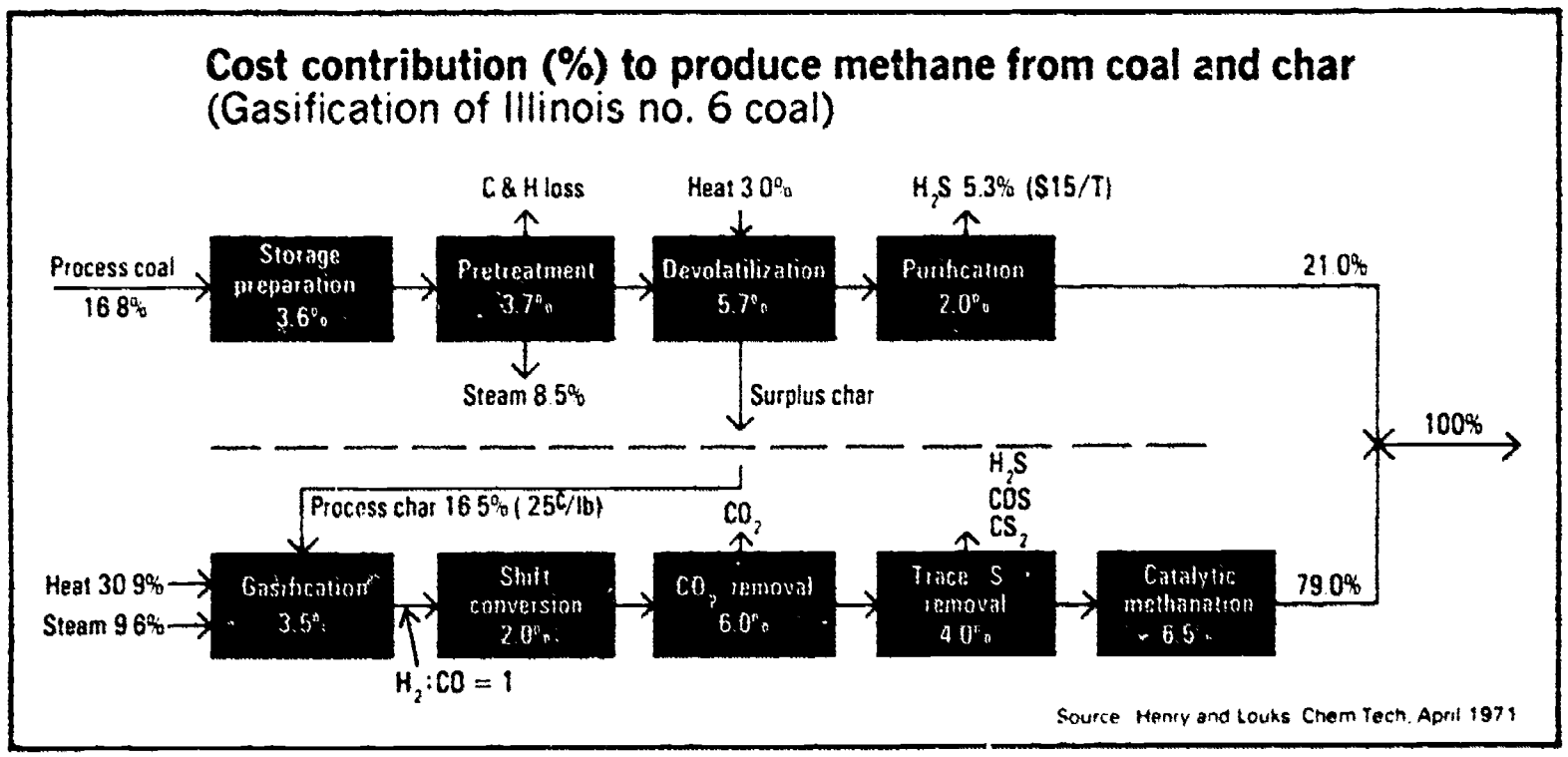


Source U S Bureau of Mines

U. S. gas demand exceeds supply



Source Humble Oil & Refining Co


Cost contribution (%) to produce methane from coal and char
(Gasification of Illinois no. 6 coal)
C & H loss
Heat 3.0%
H_2S 5.3% ($15/T)
Process coal
16.8%
Storage preparation 3.6%
Pretreatment 3.7%
Devolatilization 5.7%
Purification 2.0%
21.0%
Steam 8.5%
Surplus char
100%
Process char 16.5% (25¢/lb)
CO_2
H_2S
COS
CS_2
Heat 30.9%
Steam 9.6%
Gasification 3.5%
Shift conversion 2.0%
CO_2 removal 6.0%
Trace S removal 4.0%
Catalytic methanation 6.5%
79.0%
H_2:CO = 1
Source Henry and Louks Chem Tech, April 1971

CHAPTER 5

BIOLOGICAL EFFECTS: A COMPARISON

A. OBJECTIVES

1. The student will identify and describe the major types of radiation emitted from radioactive materials.

2. The student will identify the basic units of radiation dose.

3. The student will compare in order of dose rate received the major sources of radiation to the general public at this time.

4. The student will recognize the various factors which influence the biological effects of radiation.

5. The student will describe the effects of both acute and chronic exposure to radiation in terms of somatic and genetic effects.

6. The student will recognize the assumptions that are made when radiation protection guidelines for low-level exposures are made.

7. The student will list the gaseous effluents from the combustion of fossil fuels for electric generation, and their effects upon human health and upon the physical environment. (Gaseous effluents include oxides of sulfur and nitrogen, and particulate matter.)

8. The student will describe the concept of benefit versus risk.

B. ACTIVITIES

1. Demonstrate absorption and assimilation of phosphorus-32 from water by fish. (See **Radioactivity: Fundamentals and Experiments**, by Hermias and Joecile, Holt, Rinehart and Winston, 1963, pp. 155-157.)

2. Conduct a student experiment on effects of radiation on the germination of seeds. (See Hermias and Joecile, op. cit., pp. 148-151.) Have beans or corn irradiated at your local hospital, or buy irradiated seeds from a commercial source. Keep the number of seeds for each sample above 100, varying the radiation dosage. Study rates of germination and percentage of germination.

3. Have your local radiologist meet with the students to discuss effects and uses of radiation and radioisotopes.

4. Have your students perform various experiments on the biological effects of radiation. Many are described in Hermias and Joecile (op. cit.) or in **Nuclear Science**, Chase, Rituper, and Sulocoski, Burgess Publishing Company, 1970.

5. Determine the half life of a short-lived radioisotope such as barium-137m. (These may be obtained from commercially produced radioisotope generators available from Union Carbide Corporation, Tuxedo, New York.)

6. Have the students compute their own radiation dosage from p. 39 of the text.

7. By means of class discussion, try to have your students define the term *"quality of life"* and what risks they are willing to take to maintain this quality.

C. AUDIO-VISUAL MATERIALS

1. *"Atomic Medicine,"* 1968, 16mm sound, 27 min., U.S.A.E.C. Film Library, Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee, 37830.

2. *"Radiation and the Population,"* 1962, 16mm sound, 29 min. On genetics. U.S.A.E.C.–see Number 1 above.

3. *"Air is for Breathing,"* 1971, 16mm sound, 29 min. On biological effects of air pollution. Shell Film Library, 450 N. Meridian Street, Indianapolis, Indiana, 46204.

4. *"No Turning Back,"* 1971, 16mm sound, 27½ min. This film points up AEC's long-term commitment to environmental

research and the clear importance of further study in the search for final answers. It helps us to see man's obligation to the fragile biosphere that sustains him and the need to improve the quality of life on earth.

5. *"Endless Chain,"* 1971, 16 mm sound, color, 28 min. A poetic, intimate look at the "endless chain of life" in the desert, the effects of man's intrusion, and the threat to the environment essential to his own existence.

6. *"A Sea We Cannot Sense,"* 16 mm sound, color, 28 min. Discussion of low level radiation effects, both natural and manmade, and an effort to put these in perspective.

D. REFERENCES

1. From the Understanding the Atom series, a complete set of which may be obtained free by teachers by writing to U.S.A.E.C., P.O. Box 62, Oak Ridge, Tennessee, 37830.

   "Your Body and Radiation"
   "Radioisotopes and Life Processes"
   "The Genetic Effects of Radiation"

2. Nuclear Power and the Public, Harry Foreman, editor, University of Minnesota Press, Minneapolis, Minnesota (1970).

3. *"The Effects on Populations of Exposure to Low Levels of Ionizing Radiation,"* Superintendent of Documents, GPO, Price $2.75. Report of the Advisory Committee on the Biological Effects of Ionizing Radiations, Division of Medical Sciences, National Academy of Sciences-National Research Council.

4. *"Ionizing Radiation: Levels and Effects."* A report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the General Assembly with Annexes (A/8725). Volume I: Levels, Sales No. E. 72 IX. 17. Volume II: Effects, Sales No. E. 72 IX. 18. Available from United Nations, Sales Section, New York, N.Y.

BACKGROUND INFORMATION FOR THE TEACHER

A COMPARISON OF PUBLIC HEALTH RISKS: NUCLEAR VS. OIL-FIRED POWER PLANTS

C. Starr, M. A. Greenfield, and D. F. Hausknecht, *Nuclear News, October, 1972.*

Unless there is a major breakthrough in the technology and production of gas (as by coal gasification) there are probably insufficient supplies of gas to meet the near-term requirements without substantial increases in cost and unreliability of supply. Consequently, this analysis will be restricted to the comparative public health aspects of oil-fired and nuclear power plants and their associated activities of a typical urban setting. Operations of these plants under conditions up to the present federal regulatory limits is estimated in this example to cause 60 times more respiratory deaths due to fossil fuel pollution than cancer deaths due to nuclear plant effluents. In normal practice, neither plant would be expected to expose the public to these limits, primarily because the routine effluents must be reduced below regulatory levels to meet a variety of conditions, and would thus be expected to be substanitally less (by a factor of 10 or more) under average circumstances.

In both types of plants, public risks of continuous operation at regulatory limits are in the range of those due to other activities of man which have general societal acceptance. They are in the *"low"* part of this socially acceptable range for the oil-fired plant (60 deaths per year in a population of 10 million) and in the *"negligible"* part of the range for the nuclear plant (one death per year in a population of 10 million).

In both cases the integrated accident risk (averaged over time and all episodic events) is about 10^{-5} of the continuous exposure, for either the nuclear plant or the oil-fired plant. For the analyzed accident and *equal* probability of occurrence, the oil-fired plant has a substantially worse public health impact than the nuclear. For example, the one-in-a-million-years event for the oil-fired plant would lead to approximately 700 respiratory deaths in a population center of 10 million people; while the one-in-a-million-years event for the nuclear plant would result in approximately one death in the same population.

Table I summarizes the estimates of mortality for exposure of large populations to routine and accidental releases from both the nuclear and the oil-fired plant.

Pollutants and their effects

Information on steady-state releases to the atmosphere and to bodies of water is plentiful and well established for both fossil and nuclear fuel plants. Estimation of the frequency and magnitude of transient or accidental releases is less firm. In either case, the correlation of levels of pollutants and public health risks is primarily based on epidemiological studies. These characteristically represent small samples of the population with many variables that are not as controllable as in a laboratory study. Experiments on animals in controlled situations are numerous but extrapolations to humans do not generally rest on a proven model. Hence the correlation of public health risks with pollutant levels is on a much less firm basis than the correlation of pollutant emissions with plant size or type.

The central difficulty in making a comparison of the health effects of power plants that use different fuels arises from the problem of comparing pollutants with totally different effects on humans. For example, the somatic risks due to sulfur dioxide or radioactive iodine depend not just on the relative quantities involved but on the nature and severity of their effects on humans. Considering an oil-fired plant alone, the types of pollutants released may change significantly when different fuel supplies are used. For example, some available South American oil reserves yield an ash that is 60 percent vanadium pentoxide, the health effects of which are not well known. For chronic low-level exposures of the public to any pollutant, the difficulty is compounded by more subtle synergistic effects, which have been less susceptible to quantitative measurements–such as the ubiquitous combination of sulfur oxides and particulates. In addition, the sensitivity of individuals varies widely.

In spite of the lack of precision in our knowledge, some perspective on the relative effects of important pollutants is possible. Figure 1 summarizes available data and uses known lethal levels as a benchmark for radiation, sulfur dioxide,

and nitrogen dioxide. Because of the uncertain data for large population, the transition from medically perceivable effects to disability and lethality are indicated as three approximate ranges in Figure 1. Ranges of medically perceivable effects are about 10 times lower than lethal levels for radiation and sulfur dioxide and about 100 times lower for nitrogen dioxide. In this discussion *"medically perceivable"* is being used to mean *"in vivo"* clinical measurements on man, in contrast to studies on other forms of life. Included on the graph are the natural background levels which have been man's normal environment during most of his evolutionary history. For all three pollutants the natural background levels are about 100 times lower than the ranges of medically perceivable effects.

Included in Figure 1 are regulatory limits governing radiation, sulfur dioxide, and nitrogen oxide. Each of these limits applies to an average level to which large populations might be exposed on a continuing basis. They are, however, not all implemented in the same way. The limit for average radiation dose to large populations is complied with by continuous monitoring of reactor effluents. In the case of fossil fuel pollutants, measurements are usually conducted off-site and the ambient levels are usually the resultant of contributions from power plants and other sources-e.g., fuel combustion for other purposes such as industrial plants and transportation.

In examining the figure and noting that the AEC limit on reactor emission levels is the only regulation that is below background, it is enlightening to calculate the percent above background permitted by the various regulations. The values are 1 percent, 10,000 percent, and 400 percent for radiation, sulfur dioxide, and nitrogen dioxide, respectively. Much greater excursions above background levels are allowed for pollutants that are less well understood as to their medical implications. This is especially true with respect to the possible carcinogenic or genetic effects of sulfur dioxide and nitrogen dioxide when compared to the information on radiation.

In revising its regulations in June 1971, establishing 1 millirem as the maximum acceptable large population exposure, the AEC explicitly stated that no new biological evidence had been presented, but that the new regulations reflected a further implementation of the *"as low as practicable"* point of view. Similarly, the very low ambient concentration level required for nitrogen dioxide might also reflect a practicable limit. The high regulation for sulfur dioxide implies that abatement methods are not presently economically feasible. This suggests that federal regulations are not consistently or solely determined by the available medical data or public health criteria.

Cellular effects of pollutants

Chemical attack on DNA, the genetic material of living cells, can produce mutations–changes in the structure of DNA that are inherited by succeeding cell generations. When the DNA is in a germ cell, the mutation becomes part of our load of mutations; it may result in an increased frequency of occurrence in children of such major afflictions as cystic fibrosis, sickle cell anemia, hemophilia, and phenylketonuria, or occurrence of one of the innumberable minor genetic disabilities that are *"the differential cause of the death or failure to reproduce of between one-fifth and two-thirds of the persons who escape being killed before reproduction, or being prevented from reproducing, by other, purely extrinsic causes."* When the DNA is in the developing fetus, the mutation may result in fetal wastage or in one or another of the congenital birth defects that afflict some six to eight percent of the newborn. When the DNA is in a somatic cell of a child or an adult, the mutation may result in the transformation of the normal cell to a malignant cell and thus induce a potentially lethal cancer.

One of the principal modes of action of ionizing radiations on living cells is through the production of free radicals in the water within the cell. These free radicals–chemical species with an odd number of electrons-are highly reactive and attack DNA at many sites. But radiations are not unique in their ability to initiate free radicals within cells. Ozone, for example, when dissolved in water, decomposes to form free radicals. The normal amount of ozone at sea level, 0.02 ppm, if entirely converted to free radicals in the body, would produce about 4,000 times more free radicals than are produced by the natural background radiation levels of about 0.1 rad per year.[2,3] Ozone contents of 0.02 to 0.2 ppm are not uncommon in the Los Angeles basin, and the *"alert level"* of ozone in smog in Los Angeles is 0.50 ppm. Not only ozone, but also oxygen, is converted in the body into free radicals by normal metabolic processes. Thus the action of radiation is not qualitatively different from that of other environmental agents, and the risk of increasing radiation levels by the operation of nuclear power stations must be weighed against the qualitiatively similar risk of increasing the ozone and other

pollutants in the atmosphere by the operation of fossil-fueled power plants.

At the molecular level mutations can result from the reaction of a single molecule with a molecule of DNA. Therefore, single ionizations can produce mutations or activate laten viruses in living cells. Similarly, carcinogens (benzo(a)pyrene, for example, which is found in cigarette smoke and is produced in the burning of oil and other fossil fuels) can induce cancer when bound to DNA in ratios of one molecule or less of carcinogen to one molecule of DNA.[4] From this viewpoint the notion of a threshhold, a level of radiation or ozone, or benzo(a)pyrene, or other of the innumerable carcinogens, below which there is absolutely no risk to the population, is illusory. Thus there is a potential hazard from the emmissions of nuclear power stations–fission or fusion–or from conventional power stations–oil, coal, or gas. This is also true of every natural and manpmade physical or chemical agent in the environment. The important question is, *"How great is the hazard associated with a given level of each emission?"*

A general statement that can be made about the magnitude of the hazards associated with environmental agents is that the hazards increase with the level of the agent and the duration of exposure of the population. A more specific statement must be based on detailed data about the action of each agent. Even closely related chemical agents, for example, when tested at equal concentrations on isolated mammalian cells, differ by several orders of magnitude in their ability to bind to DNA or cause mutations in the DNA.[5] Interactions among agents further complicate the picture. Radiation, for example, can increase the effeciency of oncogenic viruses in transforming normal mammalian cells to malignant cells. This complexity increases greatly going from isolated cells to laboratory animals, and increases enormously in the human population. Therefore, to the extent possible, estimates of the magnitude of the risks associated with the exposure of human populations to various environmental agents must be based on data accumulated from observation of human populations that have been exposed to these agents.

Respiratory effects

The effluents of fossil-fueled plants are comprised of a wide variety of materials including sulfur dioxide, nitrogen dioxide, hydrocarbons, carbon monoxide, heavy metals, particulate matter, radioactive radon and daughter products. Some of these substances take part in photochemical reactions leading to other species of concern–e.g., ozone.

From this variety of materials there is a spectrum of physiological effects. Deleterious effects on the respiratory system caused by sulfur dioxide and nitrogen dioxide acting in concert with suspended particulate matter are generally assumed to be the primary areas of public health concern. This assumption will be adopted for this study only because more quantitative health effects data are available for these materials. In particular, for chronic exposure of populations to low levels of episodic exposure to high levels of sulfur dioxide and particulate matter, an estimate of the correlation of mortaility risk can be made from available data. Nevertheless, there is an additional unquantified risk from the other components of fossil fuel emissions.

Ranges of concentrations of sulfur dioxide and exposure times for significant health effects and mortality rates in excess of normal expectation are summarized in Figure 2. Particulates are not taken into account in this figure, but they must be present for sulfur dioxide to be effective as indicated.

Detailed analytic studies of several types of populations in Chicago indicate a significant incremental point for the occurrence of increased death rates, increased symptoms in bronchitis and increased occurrence of respiratory infections. This point occurs between sulfur dioxide levels of 0.19 ppm and 0.29 ppm (12-hour average), associated with the other usual urban pollutants. Considering the federal 24-hour standard (0.14 ppm), these data indicate an inadequate margin of safety for the populations studied. Indeed, these investigators, extrapolating mortaility figures, suggest that for some segments of the population (susceptibles) no threshold for health effects or mortaility effects can safely be assumed.

Study of pulmonary function measurements in healthy human subjects indicates a significant effect on airway resistance and mid expiratory flow rates after 15-minute challenges with sulfur dioxide at 0.5 ppm, when administered with distilled water or saline aerosols. Heightening of this physiologic response, persistence of it, and provocation of attacks might well be expected in susceptibles such as asthmatics, severe bronchitis, or individuals with genetic susceptibility to respiratory disease.

Air concentration data reported only from locations remote from major point sources of sulfur dioxide and particulate effluents may significantly underestimate the level of challenge experienced by a general population in the immediate downwind catchment. In a general population up to 10 to 20 percent may be expected to exhibit more lung functional changes or more episodes of respiratory disease symptoms on experiencing intermittent high-level pollution episodes (SO_2 appraoching 0.5 ppm) than their average normal neighbors. In the downwind conurbation of the Los Angeles power generating belt, a population of upwards of 530,000 individuals would thus offer some 53,000 susceptibles whose illness responses to as few as four high sulfur dioxide episodes per year could cost them between $10 million and $20 million.

No standards are published for SO_3 or its hydrated form despite the potential for oxidation of sulfur dioxide to this form in the humidified air of coastal population centers. This substance is of concern because of its magnified (three to fourfold) effect on respiratory mechanics when compared with sulfur dioxide.

Risks from steady-state effluents

For a given basin with a fixed volume of air, the question of relative public health risk attributed to various types of power plants can be posed as follows: How many plants of a given type can be operated without reaching a pollutant concentration level having public health significance? Table II presents quantitative answers to this question.

A simplified approach has been taken to arrive at the numbers shown in the table. This approach was meant to eliminate as many complexities as possible, while maintaining a valid comparison of different types of power plants. For this purpose, meteorological considerations have been precluded by assuming the pollutants are released into a large mixing chamber. Each power plant operates at full capacity for one day, and no natural removal mechanisms such as washout by rain or impaction on obstacles have been allowed to deplete the gaseous effluents from the plants. Although inclusion of these mechanisms might be expected to permit operation of more plants, they are irrelevant for the purposes of this comparison. Many more hazardous meteorological conditions can be postulated than the one-day ventilation rate used here. In the table *"tolerable"* is used to mean the maximum number of 1,000 MWe plants that could operate for one day without exceeding an average concentration in the air basin volume corresponding to legislated limits. The limits used were:

Air Quality Standards and Regulation for Radioactive Effluent

SO_2	(24-hour average, federal)	0.14 ppm
NO_2	(1-hour average, State of California)	0.225 ppm
Radioactivity	(federal)	2×10^{-19} Ci/cm^3

The assumption made here is that these legislated limits are related to prevention of health effects. As mentioned earlier, there is in fact a very large (orders of magnitude) safety factor built into the concentration limit for radioactive releases. In contrast, the margin between health effects and air quality standards is quite narrow, especially for SO_2. This can readily be seen by referring back to Figure 1. As pointed out earlier, there is sufficient evidence to connect a substantial cost with increased illness responses in an area subjected to as few as four high sulfur dioxide episodes per year in a setting such as the Los Angeles basin.

This comparison is based on a different approach than the continuous exposure column of Table I. In the table the public health risks associated with the exposure of large populations to regulated limits is compared. In Table II the degree to which plants contribute towards using up the regulated limit is compared.

Meterological stagnation of several days duration is not an uncommon event in several areas of California. It is an historical fact that the AQS are exceeded regularly in some areas and that these occurrences coincide with meteorological stagnation. Increased mortality data for these occurrences is impossible to glean from the public health data, unless the meteorological conditions are extremely adverse and of long duration resulting in substantial mortality and morbidity, such as the New York, Donorra, or London episodes. Nevertheless, lesser occurrences should not be assumed to have no impact.

Transient releases

If the public health risk of any technological system is to be determined, the frequency and

consequences of accidents must be considered. For a well-established system, such as a fossil-fueled power plant, the frequency and magnitude of public-risk accidents can be estimated from historical records where they are available. In the case of nuclear power plants, their history is short and their number is relatively small. Hence, more than their record is needed to estimate the frequency and magnitude of their releases.

A deductive approach for making this estimate for nuclear plants has been developed and applied to reactors for a number of years. It consists of determining how an accident can occur by assuming failure of one or more elements in the plant and the probability of such failure. Once the plant has been studied by analyzing all the *"credible"* paths leading to accidents, the question of other accidents that might occur but have not been thought of must be faced. It is assumed that the accidents that have been analyzed represent a sample of a complete spectrum of possible accidents and hence can be used to establish the entire spectrum.

This probabilistic approach to quantifying risk has not been the historical approach to power plant safety–either fossil-fueled or nuclear. Three basic approaches to safety analysis can be identified. The most common is the empirical (or inductive) study of actual performance history to estimate the level of risk of various events. The second is the judgmental (or intuitive) review by experienced professionals to determine if adequate design precautions have been taken. The third is the estimation of system risk as derived from the reliability of individual compoents and their interaction–a deductive process. Only the first (empirical) and the third (deductive) provide a quantitative result. In the absence of a substantial operative history, nuclear plants have typically been studied by the second (or judgmental) approach. However, in order to make a meaningful comparison between oil-fired and nuclear plants, this report uses the third (deductive) method based on recent studies.

An illustration of the outcome of this approach is presented in Figure 3 for a 1,000 MWe pressurized water reactor (as studied by Otway and Erdmann). The validity of such an accident sequence analysis depends on reliability of the plant safety devices, their ability to function in sequence as expected, and on the inherent dynamic characteristics of the plant type. Because of the very low probability of large releases, the over-all public health risk calculation is not sensitive to the accuracy of the accident sequence analysis. The study presented in Figure 3 should be representative of a modern PWR plant and has therefore been used in this report. A liquid-metal-cooled fast breeder reactor was analyzed in an analogous manner as part of the present study, and the over-all risks due to accidents was found to be not significantly different than those from the PWR.

The maximum-consequence accidents for both the PWR and the LMFBR are consistent with a frequently cited early study of catastrophic reactor accidents.[6] In the sequel it will be seen that the mortality risks from a nuclear plant are no worse than for a comarable fossil-fueled plant.

The general trend for the amount of radioactive material released to the public (in equivalent curies of iodine-131) is small releases from the more frequent events and large ones from the low-probability events. The small circles represent analyzed accidents on which the smooth curves are based. The two curves represent a distinction in character of the accident sequence which results from a deficiency in the reactor cooling system or in the reactivity control system. Both are considered together in some situations. Others may be explored in a specific plant study. In addition to the accidents forming these curves, a cluster of accidents of higher probability (10^{-2} to 10^{-4} per year) were also included. These were such things as fuel handling mishaps and are shown as a dotted extension in the figure.

For a 1,000-MWe oil-fired plant there is an associated storage capacity of the order of 2 million barrels. Although some of this storage may not be on the plant site, it is never far removed. Conflagration of some fraction or all of these fuel supplies is a possibility and as such must be considered in estimating the over-all risks of oil-fired plants. As in the case of nuclear reactors, the public health risk due to accidents associated with an oil-fired plant is greater from the released pollutants than from the direct effects of an explosive fire. Hence, an estimate of the frequency of occurrence and the amount of oil burned is needed to assess the risk from released pollutants.

No data specifically for power plants has come to light, but the American Petroleum Institute (API) has tabulated data for fire losses occurring at various types of properties over a number of years. During

the past five years (1966 through 1970), API has tabulated data that categorize the magnitudes of the fires into four size groups. After examination of the tabulations for these five years, two classes of properties were selected as being representative of the sizes and types of oil products associated with oil-fired power plants. They were bulk terminals and pipeline stations. these data, after conversion to quantities of oil lost in pounds, and with normalization to the unit of property-year, are presented in Figure 4.

From this graph the probability of releasing quantities of sulfur dioxide, oxides of nitrogen, hydrocarbons, precursors of oxidants, and heavy metals can be estimated. This was carried through only for SO_2 by assuming the values $3 and 331 pounds per barrel of oil containing 0.5 percent by weight of sulfur. The pounds of SO_2 emitted with varying frequency are also given in the figure.

Figure 4 for an oil-fired plant is then the analogue of Figure 3 for the nuclear plant. They are presented together on a common probability scale in Figure 5. For the oil-fired plant the entire release-probability distribution falls within the regime of high-frequency, small-release accidents of nuclear plants. Another way of contrasting the two graphs is that the least probable, maximum release (a 2-million-barrel fire) of an oil-fired plant is more likely to occur than any of the releases from the nuclear plants, which could be considered more severe than a minor mishap.

Assuming the oil-fired plant and nuclear plant are located at the same site, athospheric dispersion of the pollutants from an accident and fumigation of the surrounding population can be handled identically in either case. This comparison was based on a stable meteorological condition (Pasquill F category) with a wind velocity of 2 meters per second blowing constantly into a 30-degree sector.

In order to correlate mortality with prevailing pollutant concentrations, the following correlations were used:

1×10^{-6}	per person per rem is the mortality risk from thyroid irradiation with no available data demonstrating a risk below 1 rem
30×10^{-6}	mortality risk per person per rem for whole-body irradiation down to the background level of 100 mrem
4×10^{-5}	$X(SPt)^{1/2}$ mortality risk (death due to respiratory cause only) per person exposed to S (ppm) of SO_2, P(gm/m^3) of particulate matter for t (years) down to 10^{-4} (ppm-(gm/m^3)-year) which is a routine urban exposure

Although these correlations, which are based on statistical analyses of epidemiological data, are far from proven physical laws, they are in keeping with the state of knowledge at present.

A comparison of the cumulative mortality risks with distance from the two types of plants is shown in Figure 6. These results suggest the accidental releases from the two types of plants are not substantially different in their overall mortality effect during the life of the plants. The relatively greater likelihood of occurrences at an oil-fired plant is offset by the greater lethality but less likely radioactive releases from a nuclear plant.

Another important perspective to be gained from this analytic approach is that the occurrence of a large oil fire is a rare event in our conscious experience, but relatively commonplace when compared with significant reactor releases. In other words, events that occur with frequencies of less than once in a million years approach the meaning of *"never"* in everyday language.

The public reaction (or social trauma) that might result from the very rarest and most extreme accidents is difficult to gauge, but is not likely to be large in either case. In the case of an oil-fired plant, the combination of the most adverse meteorological conditions and largest fire might be expected once in a million years and could cause about 70 respiratory deaths per million population (about one-half of the normal annual rate). Because the incremental mortality (and morbidity) would occur in a short time interval, the impact of such an accident probably would be publicly noticeable.

In the case of an extreme nuclear accident, a probability can be assigned to a maximum impact of about 500 cancer deaths per million population (about one-third of the normal annual cancer rate), estimated to occur less than once in 100 million years. Because most of the fatalities resulting from such radiation exposure would be spread over very many years, the public impact of such a nuclear plant accident is unlikely to have much general visibility. It would be possible to measure the full impact only by maintaining lifetime statistics of the exposed population.

Consequences of accidents are graphed with their corresponding probabilities in Figure 7. For the oil-fired plant, there is not enough known to estimate the worst hypothetical case. It is generally known that respiratory ailments can be increased by the synergistic interaction of various *"insults"* to the system. An extraordinarily rare hypothetical combination of a variety of airborne pollutants, respiratory epidemics (such as influenza), and chronic irritants (including asthmogenic allergens) might substantially increase regional fatalities. It is quite possible that because of the focusing of all these impacts on the respiratory system, the oil-fired plant maximum hypothetical accident could cause as many fatalities as the maximum hypothetical nuclear plant accident–with a probability of occurrence equally low. Also omitted from this estimate is the synergistic effect of other polluting effluents from the oil-fired plant–such as nitrogen oxides, heavy metals (lead, mercury, cadmium, nickel), radioactive elements, carbon monoxide, and carcinogenic compounds. Nitrogen oxides, in particular, may be a serious hazard, but little is known about their quantitative health effects as yet. Insufficient data on respiratory effects are available to evaluate the full impact of all the multiple synergistic combinations that might possibly occur.

Transportation of nuclear fuels

For a thermal power plant to operate on a continuing basis, fuel transportation is a necessary adjunct. For oil- or natural-gas-fueled plants this takes the form of pipelines, while for nuclear plants, trucks, rail cars, or barges are used. Public health risks from pipeline rupture accompainied by fuel burning exist, but are not analyzed in this report. Because of public concern regarding radiation, the shipment of spent nuclear fuel elements has been examined. Additionally, the location of a reprocessing plant for nuclear fuel might be contingent on the degree of risk involved in transportation.

There has never been a recorded major accident that has killed, injured, or overexposed people as a result of the transportation of radioactive fuel materials. The accumulated experience of such shipping is relatively small. However, accident rates can be estimated if the assumption is made that spent fuel shipments will suffer at the same rate as shipments of explosives and other dangerous materials. This assumption is supported by the fact that the standards in the U.S. (10CFR71, 49CFR171-178 and 46CFR146) place primary reliance for safety on packaging rather than mode of transportation of radioactive material. Hence, commercial carriers can be used. A survey of transportation accident data suggests a reasonable expectation to be 2.5 accidents per million vehicle miles for either rail or truck modes of transportation.

Because of the stringent requirements on spent fuel packaging most accidents will not result in a release of radioactive material to the environment. The AEC operational experience from 1949 through 1967 has been used to estimate that in 2.5 percent of the accidents, some fraction of the radioactive material being transported will be released to the environment. In order to estimate the distances to be covered, three potential reprocessing plant locations were considered. They included both an optimally located plant in the state (California) and an inexpediently (with respect to distance) located plant out of the state. The average distance from power plants in the state to the latter location was 2.4 times greater than the former.

Choosing the greatest average transportation distance and assuming every accident which leads to a radioactive release to the environment is a maximum credible accident (all fission gases in the shipping container plenum are released), a conservative projection can be made for the year 2000. The number of serious injuries in the state was found to be less than one in 1,000 years for the projected fuel logistics requirements. This conclusion was based on an average population density and would change in proportion to the actual population density on any chosen route. Two conclusions are derived from this result:

- Transportation of spent nuclear fuel does not measurably add to the public health risks of the power plant.

- Siting of nuclear power plants does not depend on the location of reprocessing plants because the two can be decoupled with little or no change in the total risk.

These conclusions are not meant to imply that the public health risks associated with the siting of facilities for either chemical reprocessing of fuel or waste disposal can be neglected. However, it is expected that future AEC regulations governing releases from any new chemical reprocessing plant or waste disposal facility will be as stringent as those presently applicable to nuclear power plants.

How safe is safe enough?

In comparing the public risk from fossil-fueled and nuclear power stations, it is important to understand what is really meant by risk. The public is confused and misled when leaders and experts make statements with qualitative comparisons such as *"safe"* versus *"unsafe,"* *"credible"* versus *"incredible,"* *"cautious"* versus *"incautious,"* *"reasonable"* versus *"unreasonable"*–in reference to the risk of injury to the individual. These terms imply absolute boundaries of risk that do not really exist.

Therefore we must ask the question, *"How safe is safe enough?"* and provide quantitative guidelines which will make possible a rational approach towards defining acceptable levels of public risk.

Risk in this study has been used to mean the quantitative probability of injury–i.e., the predictable chance of some specified personal damage occurring in a specified time interval. Public risk is the averaging of individual risks over a large population. The injuries involved may vary from minor annoyances and discomfort (not enough to prevent normal activities), to disabilities that cause reduction in normal productivity (morbidity rate) to loss of life (mortality rate). Because of the dramatically visible nature of death, public risk is usually conceived of in terms of fatalities or mortality rate. However, the importance to the public welfare of the less visible morbidity rate (disabilities) may be much greater in terms of humanistic, economic, and social values. For example, the annual number of deaths in the United States due to automobile accidents is often quoted with alarm, but one rarely hears of the disabling injuries which number hundreds of times as many and may have an equal or greater social importance.

The same situation has existed in environmental pollution issues. Most public discussions relate almost exclusively to short-term episodes of extreme pollution–either real or projected. In fact, most professional concern has been focused on these infrequent extreme situations. However, from the viewpoint of social costs or of the public health burden, it is important to consider long-term effects of low pollution levels as well as the short-term effects of the more visible episodic high levels–and, in addition, mobidity as well as mortality.

Averaged over a large population and a long time period (man's lifetime) there exist two continuous ranges of events. The first of these is the range of accident magnitudes or public exposure. The second of these is the end result of such exposures, ranging from discomfort to disability to death. It is interesting that an approximate relationship of frequency varying inversely with magnitude appears to apply to most public exposures to risk, (either man-made or natural)[7] and very probably to the pollution effects from both fossil-fueled and nuclear power plants. A statistical and theoretical basis for these relationships can be suggested, but the inadequacy of epidemiological data makes it difficult to verify its generality.

Because mortality data is most readily available, the foregoing quantitative power plant comparisons have dealt with the public risk of fatalities, recognizing that this is only indicative of the total risk, and that the social cost should include a multiplier that accounts for associated disabilities. Similarly, a usually neglected but important factor from low-level exposures is the time required for physiologic impairment to develop. If the time for the effects of exposure to develop is long, then only the younger members of the population may have their later life affected (as with smoking). These factors of degree of morbidity, age, and duration of exposure, changing social value as a function of age, and other similar public health parameters theoretically should be included in any complete study. Unfortunately, basic physiologic and technical data in the air pollution field are generally so uncertain quantitatively that such a refined analysis is only occasionally justified. *"Order of magnitude"* answers are usually all that can be expected in such areas of public risk.

A study of the public acceptance or mortality risk arising from involuntary exposure to socio-technical systems such as motor vehicle transportation indicates that our society has accepted a range of risk exposures as a normal aspect of our life.[7] Figure 8 shows the relation between the per capita benefits of a system and the acceptable risk as expressed in deaths per exposure year (i.e., time of exposure in units of a year). The highest level of acceptable risks that may be regarded as a reference level is determined by the normal U.S. death rate from disease (about one death per year per 100 people). The lowest level for reference is set by the risk of death from natural events–lightning, floods, earthquakes, insect and snake bites, etc. (1 death per year per million people).

In between these two bounds, the public is

apparently willing to accept *"involuntary"* exposures–i.e., risks imposed by societal systems and not easily modified by the individual–in relation to the benefits derived from the operations of such societal systems. Although an individual often *"voluntarily"* exposes himself to much higher risks, the public nevertheless expects the regulatory institutions of our society to maintain a consistently cautious approach to its hazards. The princiapl point of the relationship in Figure 8 is that society does pragmatically accept in existing systems a level of risk related to the benefits it derives.

In commonly familiar terms, an averaged involuntary risk may be considered *"excessive"* if it exceeds the incidence rate of disease, *"high"* if it approaches it, *"moderate"* if the risk is about 10-100 times less, *"low"* if it approaches the level of natural hazards, and *"negligible"* if it is below this. Events in these last two levels of risk have historically been treated as *"acts of God"* by the public generally–in recognition of their relatively minor impact on ou. societal welfare as compared to the effort required to avoid the risk.

Thus, any risk created by a new socio-technical system is acceptable *"safe enough"* if the risk level is below the curve of Figure 8. More accurately, when the increment of additional risk added by the new system is associated with an incremental benefit equal to or greater than that indicated by the curve, the system is *"safe enough."* If, as is usually the case, a new system has a range of uncertainty in its risks, a design target may be set below the curve by an equivalent amount–possibly as much as a factor of 10 or 100.

The position of electric power plants in this benefit-risk relationship is shown in Figure 8. The risk calculation based on regulatory limits has been described earlier–with oil-fired plants setting the upper value and nuclear the lower value. As previously noted, actual risks may be very much less because such plants will operate at less than regulatory limits. The benefits of electricity includes an estimate of both the incremental contribution to industrial output and to other social needs. It is evident that both types of power plants are well within the acceptable risk range.

To summarize, death, disability, and discomfort have always been a normal part of life. Society has historically adjusted its acceptance of these so that changes in societal systems are associated with adequate benefits and also do not substantially or drastically alter the public's involuntary exposure to risk. None of this means that efforts to reduce the risk of death, disability, and discomfort should not be made. However, in the application of our resources to reducing public risks, the economic principle of marginal utility should be used–i.e., the resources should be applied where they will do the most good. There is little point in spending effort on improving the safety of a system that is already in the category of *"negligible risk."* The effort would be better applied to the higher risk systems that will substantially influence our public health statistics.

The evident fact that the risk perspective of an individual may differ from that of a social sector creates a problem in a democratic political system. Rational decision-making on a societal level may thus require an intensive public education and public discussion of the issues and trade-offs. This is particularly difficult in emotion–laden areas, and perhaps especially so when death, disability, and discomfort of human beings are involved.

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TABLE I

Public Risk Comparison

Plant Type	Expected Annual Averages (Deaths per 10 million population per 1,000-MWe plant per year)	
	Continuous Operation at Regulated Exposure Limits	Total Risk from Accidents
Nuclear reactor (cancer deaths)	1	Negligible (0.00006)
Oil-fired plant (respiratory deaths)	60	Negligible (0.0002)

TABLE II

Tolerable Numbers of Power Plants as Implied by Current Practices in Los Angeles County*

Plant Type	Critical Pollutant	Tolerable Number of 1,000-Mwe Plants (Exclusive of Pollutants from Other Sources)
Oil	SO_2	10
Natural gas	NO_2	23
Nuclear reactor (LWR)	Radioactive gases	160,000

*Based on the following assumptions:

1. Unspecified mixture of radioactive isotopes released from nuclear plant (Most restrictive assumption based on 1 mrem).
2. Compliance with 0.5 percent by weight sulfur content for oil.
3. Air volume of Los Angeles County was assumed to be 3,165 km.³ which implies a mean inversion height of 300 m.
4. Ventilation of this volume requires one day.
5. Effluent volume rate for 1,000-MWe reactor is taken as 0.5 × 10⁶ cfm which is an estimated upper limit.

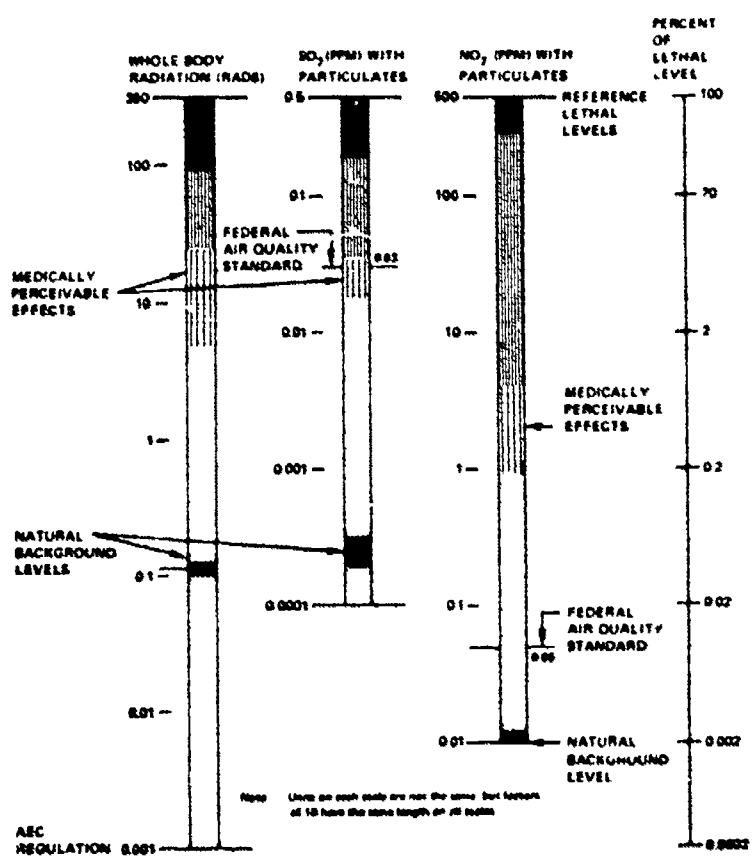


Fig. 1. Observed effects on physiological function of humans

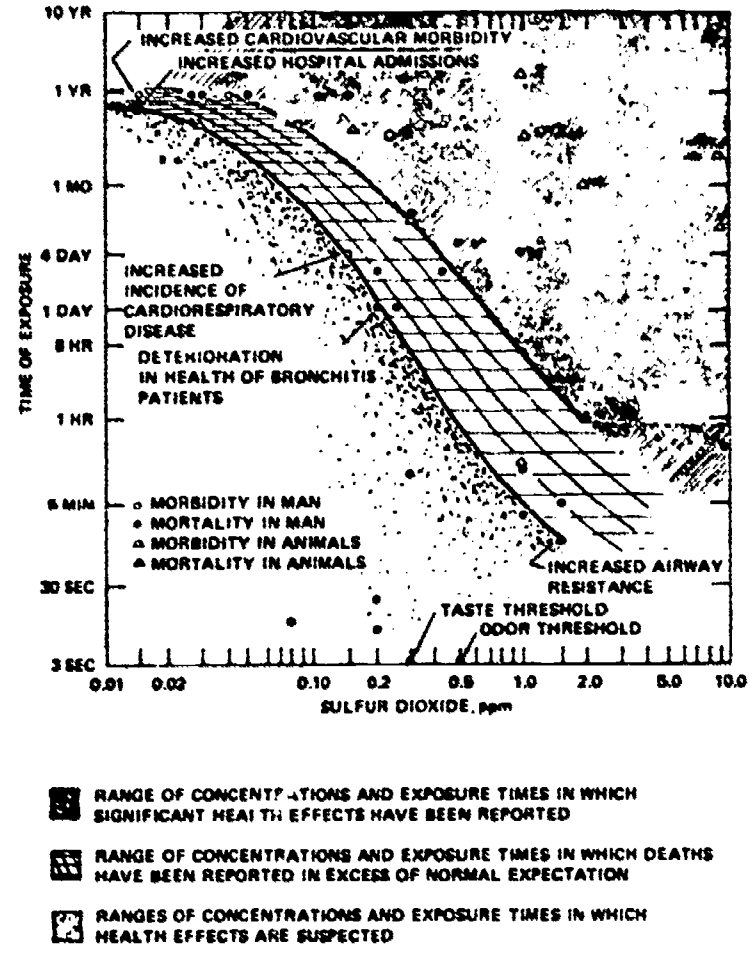


Fig. 2. Effects of sulfur dioxide pollution on health ("Air Quality Criteria for Sulfur Dioxides," a talk by Bernard E. Conley, chief, Air Quality Criteria, National Center for Air Pollution Control)

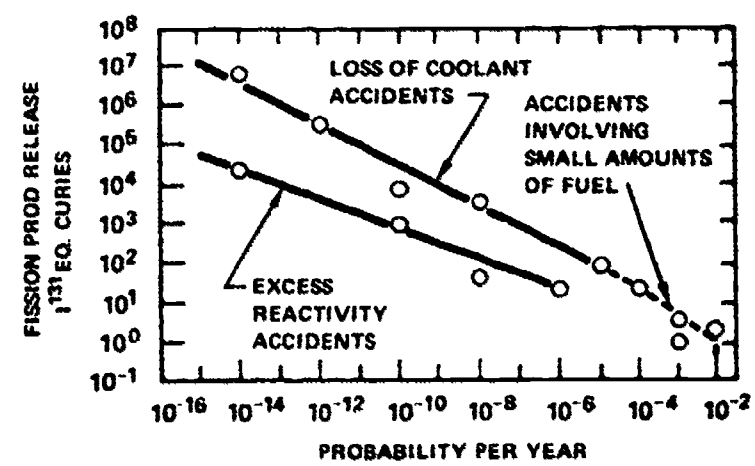


Fig. 3. Fission product release versus accident probability for a 1,000-MWe PWR. Taken from "Reactor Siting and Design from a Risk Viewpoint," H. J. Otway and R. C. Erdmann, Nuclear Engineering and Design, Vol. 13, pp. 365-376 (1970).

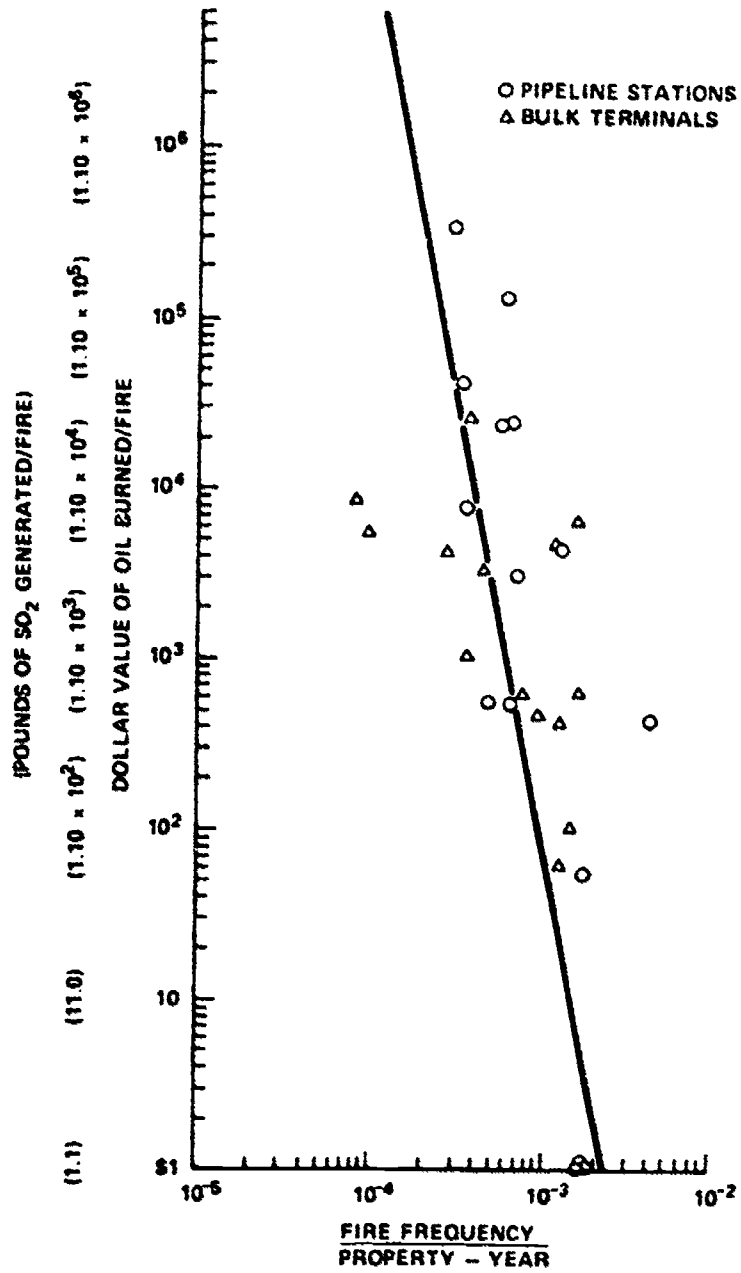


Fig. 4. Size of oil fire vs frequency of occurrence

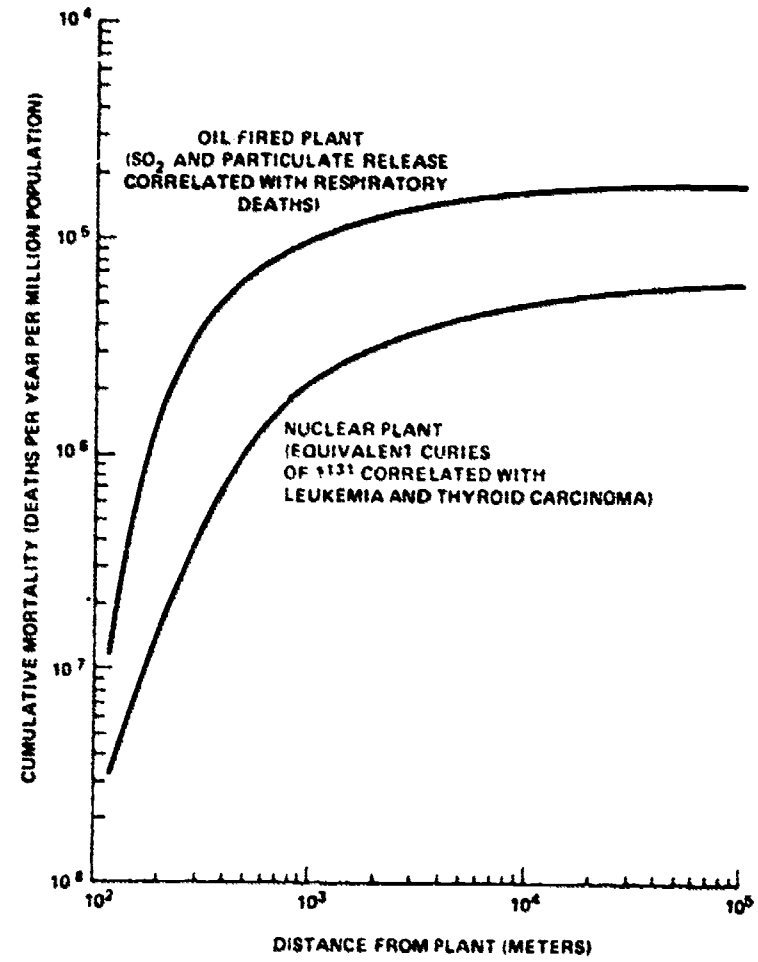


Fig. 6. Cumulative accident mortality with distance

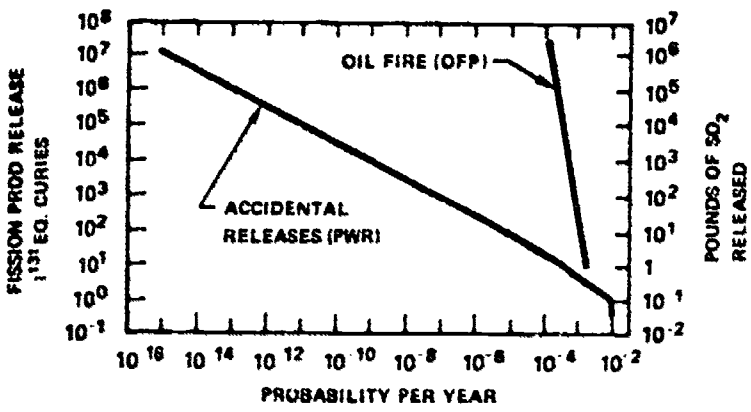
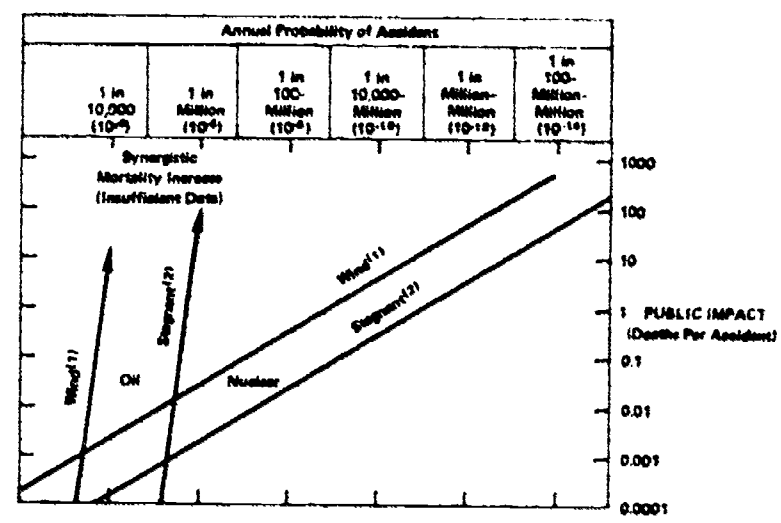


Fig. 5. Comparison of release magnitudes on a common probability scale



(1) The prevailing wind blows into a 30° sector at 2 meters per second under stable meteorological conditions (Pasquill F condition).
(2) The stagnant meteorological condition was assumed to prevail for 4 days with an inversion height of 300 meters.

Fig. 7. Comparison of public risk from individual accidents

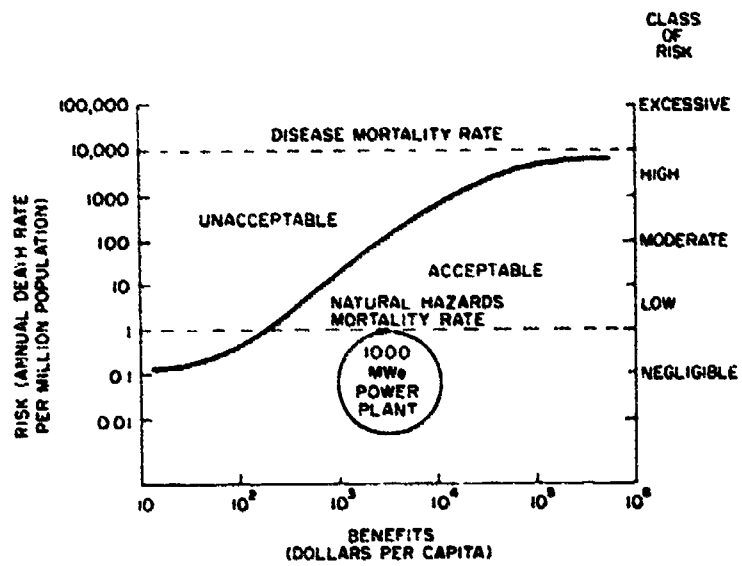


Fig. 8. Benefit-risk pattern for involuntary exposure

BLACK LUNG DISEASE: PNEUMOCONIASIS

by: John J. McDermott

Pneumoconiasis or *Black Lung Disease* is well established as an occupational disease of coal miners, resulting from the coal-dust-laden environment in which they work. The mining of coal produces dust in various sized particles. Those particles larger than 10 microns are responsible for environmental hazards arising from impaired visibility or mine explosions. Particles smaller than 20 microns are referred to as respirable dust. While particles of this size do not impair visibility they are inhaled, affecting the respiratory system and eventually causing pneumoconiasis or black lung disease. This condition eventually develops into progressive massive fibrosis, a state wherein a chemical reaction occurs between the lung fibers and the dust.

Coal miner's pneumoconiasis may be defined as the accumulation of coal dust in the lungs and the reaction of the lung tissue to the presence of this dust. Fifteen years is usually required for the disease to progress to the point hat it can be detected by X-ray techniques, although some individuals show evidence of the disease in a shorter time. Once the disease has progressed to the stage of a progressive fibrosis, death may result from plumonary insufficiency or from a secondary infection such as tuberculosis.

Coal miner's pneumoconiasis is an international problem because of both human suffering and financial cost. The U S. Department of Health, Education and Welfare has budgeted for fiscal 1972 the amount of 384 million dollars for payment to pneumoconiasis victims.

The Federal Coal Mine Health and Safety Act of 1969 has imposed dust standards for coal mines, requiring mines which exceed specified dust concentration limits to supply the miners with dust respirators. The miners are required to undergo X-ray examination at specified intervals, to detect the presence of the disease at an early stage.

SOCIAL BENEFIT VERSUS TECHNOLOGICAL RISK

Wh is our society willing to pay for safety?
by: Chauncey Starr, *Science*, Sept. 19, 1969.

The evaluation of technical approaches to solving societal problems customarily involves consideration of the relationship between potential technical performance and the required investment of societal resources. Although such performance-versus-cost relationships are clearly useful for choosing between alternative solutions, they do not by themselves determine how much technology a society can justifiably purchase. This latter determination requires, additionally, knowledge of the relationship between social benefit and justified social cost. The two relationships may then be used jointly to determine the optimum investment of societal resources in a technological approach to a social need.

Technological analyses for disclosing the relationship between expected performance and monetary costs are a traditional part of all engineering planning and design. The inclusion in such studies of *all* societal costs (indirect as well as direct) is less customary, and obviously makes the analysis more difficult and less definitive. Analyses of social value as a function of technical performance are not only uncommon but are rarely quantitative. Yet we know that implicit in every nonarbitrary national decision on the use of technology is a trade-off of societal benefits and societal costs.

In this article I offer an approach for establishing a quantitative measure of benefit relative to cost for an important element in our spectrum of social values–specifically, for accidental deaths arising from technological developments in public use. The analysis is based on two assumptions. The first is that historical national accident records are adequate for revealing consistent patterns of fatalities in the public use of technology. (That this may not always be so is evidenced by the paucity of data relating to the effects of environmental pollution.) The second assumption is that such historically revealed social preferences and costs are sufficiently enduring to permit their use for predictive purposes.

In the absence of economic or sociological theory which might give better results, this empirical approach provides some interesting insights into accepted social values relative to personal risk. Because this methodology is based on historical data, it does not serve to distinguish what is *"best"* for society from what is *"traditionally acceptable."*

Maximum Benefit at Minimum Cost

The broad societal benefits of advances in technology exceed the associated costs sufficiently to make technological growth inexorable. Shef's socieconomic study (1) has indicated that technological growth has been generally exponential in this century, doubling every 20 years in nations having advanced technology. Such technological growth has apparently stimulated a parallel growth in socioeconomic benefits and a slower associated growth in social costs.

The conventional socioeconomic benefits–health, education, income–are presumably indicative of an improvement in the *"quality of life."* The cost of this socioeconomic progress shows up in all the negative indicators of our society–urban and environmental problems, technological unemployment, poor physical and mental health, and so on. If we understood quantitatively the causal relationships between specific technological developments and societal values, both positive and negative, we might deliberately guide and regulate technological developments so as to achieve maximum social benefit at minimum social cost. Unfortunately, we have not as yet developed such a predictive system analysis. As a result, our society historically has arrived at acceptable balances of technological benefit and social cost empirically–by trial, error, and subsequent corrective steps.

In advanced societies today, this hisotrical empirical approach creates an incresingly critical situation, for two basic reasons. The first is the well-known difficulty in changing a technical subsystem of our society once it has been woven into the economic, political, and cultural structures. For example, many of our environmental-pollution problems have known engineering solutions, but the problems of economic readjustment, political jurisdiction, and social behavior loom very large. It will take many decades to put into effect the technical solutions we know today. To give a specific illustration, the pollution of our water resources could be completely avoided by means of engineering systems now available, but public interest in making the economic and political adjustments needed for applying these techniques is very limited. It has been facetiously suggested that, as a means of motivating the public, every community and industry should be required to place its water intake downstream from its outfall.

In order to minimize these difficulties, it would be desirable to try out new developments in the smallest social groups that would permit adequate assessment. This is a common practice in market-testing a new product or in field-testing a new drug. In both these, cases, however, the experiment is completely under the control of a single company or agency, and the test information can be fed back to the controlling group in a time that is short relative to the anticipated commercial lifetime of the product. This makes it possible to achieve essentially optimum use of the product in an acceptably short time. Unfortunately, this is rarely the case with new technologies. Engineering developments involving new technology are likely to appear in many places simultaneously and to become deeply integrated into the systems of our society before their impact is evident or measurable.

This brings us to the second reason for the increasing severity of the problem of obtaining maximum benefits at minimum costs. It has often been stated that the time required from the conception of a technical idea to its first application in society has been drastically shortened by modern engineering organization and management. In fact, the history of technology does not support this conclusion. The bulk of the evidence indicates that the time from conception to first application (or demonstration) has been roughly unchanged by modern management, and depends chiefly on the complexity of the development.

However, what has been reduced substantially in the past century is the time from first use to widespread integration into our social system. The techniques for *societal diffusion* of a new technology and its subsequent exploitation are now highly developed.

Our ability to organize resources of money, men, and materials to focus on new technological programs has reduced the diffusion-exploitation time by roughly an order of magnitude in the past century.

Thus, we now face a general situation in which widespread use of a new technological development may occur before its social impact can be properly assessed, and before any empirical adjustment of the benefit-versus-cost relation is obviously indicated.

It has been clear for some time that predictive technological assessments are a pressing societal need. However, even if such assessments become available, obtaining maximum social benefit at minimum cost also requires the establishment of a relative value system for the basic parameters in our objective of improved *"quality of life."* The empirical approach implicitly involved an intuitive societal balancing of such values. A predictive analytical approach will require an explicit scale of relative social values.

For example, if technological assessment of a new development predicts an increased per capita annual income of x percent but also predicts an associated accident probability of y fatalities annually per million population, then how are these to be compared in their effect on the *"quality of life"*? Because the penalties or risks to the public arising from a new development can be reduced by applying constraints, there will usually be a functional relationship (or trade-off) between utility and risk, the x and y of our example.

There are many historical illustrations of such trade-off relationships that were empirically determined. For example, automobile and airplane safety have been continuously weighed by society against economic costs and operating performance. In these and other cases, the real trade-off process is actually one of dynamic adjustment, with the behavior of many portions of our social systems out of phase, due to the many separate *"time constants"* involved. Readily available historical data on accidents and health, for a variety of public activities, provide an enticing stepping-stone to quantitative evaluation of this particular type of social cost. The social benefits arising from some of these activities can be roughly determined. On the assumption that in such historical situations a socially acceptable and essentially optimum trade-off of values has been from disease, their inclusion is not significant.

Several major features of the benefit-risk relations are apparent, the most obvious being the difference by several orders of magnitude in society's willingness to accept *"voluntary"* and *"involuntary"* risk. As one would expect, we are loathe to let others do unto us what we happily do to ourselves.

The rate of death from disease appears to play, psychologically, a yardstick role in determining the acceptability of risk on a voluntary basis. The risk of death in most sporting activities is surprisingly close to the risk of death from disease--almost as though, in sports, the individual's subconscious computer adjusted his courage and made him take risks associated with a fatality level equaling but not

exceeding the statistical mortality due to involuntary exposure to disease. Perhaps this defines the demarcation between boldness and foolhardiness.

In Figure 2 the statistic for the Vietnam war is shown because it raises an interesting point. It is only slightly above the average for risk of death from disease. Assuming that some long-range societal benefit was anticipated from this war, we find that the related risk, as seen by society as a whole, is not substantially different from the average nonmilitary risk from disease. However, for individuals in the military-service age group (age 20 to 30), the risk of death in Vietnam is about ten times the normal mortality rate (death from accidents or disease). Hence the population as a whole and those directly exposed see this matter from different perspectives. The disease risk pertinent to the average age of the involved group probably would provide the basis for a more meaningful comparison than the risk pertinent to the national average age does. Use of the figure for the single group would complicate these simple comparisons, but that figure might be more significant as a yardstick.

The risks associated with general aviation, commercial aviation, and travel by motor vehicle deserve special comment. The latter originated as a *"voluntary"* sport, but in the past half-century the motor vehicle has become an essential utility. General aviation is still a highly voluntary activity. Commercial aviation is partly voluntary and partly essential and, additionally, is subject to government administration as a transportation utility.

Travel by motor vehicle has now reached a benefit-risk balance, as shown in Figure 3. It is interesting to note that the present risk level is only slightly below the basic level of risk from disease. In view of the high percentage of the population involved, this probably represents a true societal judgment on the acceptability of risk in relation to benefit. It also appears from Figure 3 that future reductions in the risk level will be slow in coming, even if the historical trend of improvement can be maintained (4).

Commercial aviation has barely approached a risk level comparable to that set by disease. The trend is similar to that for motor vehicles, as shown in Figure 4. However, the percentage of the population participating is now only 1/20 that for motor vehicles. Increased public participation in commercial aviation will undoubtedly increase the pressure to reduce the risk, because, for the general population, the benefits are much less than those associated with motor vehicles. Commercial avaiation has not yet reached the point of optimum benefit-risk trade-off (5).

For general aviation the trends are similar, as shown in Figure 5. Here the risk levels are so high (20 times the risk from disease) that this activity must properly be considered to be the category of adventuresome sport. However, the rate of risk is decreasing so rapidly that eventually the risk for general aviation may be little higher than that for commercial aviation. Since the percentage of the population involved is very small, it appears that the present average risk levels are acceptable to only a limited group (6).

The similarity of the trends in Figures 3-5 may be the basis for another hypothesis, as follows: the acceptable risk is inversely related to the number of people participating in an activity.

The product of the risk and the percentage of the population involved in each of the activities of Figures 3-5 is plotted in Figure 6. This graph represents the historical trend of total fatalities per hour of exposure of the population involved (7) The leveling off of motor-vehicle risk at about 100 fatalities per hour of exposure of the participating population may be significant. Because most of the U.S. population is involved, this rate of fatalities may have sufficient public visibility to set a level of social acceptability. It is interesting, and disconcerting, to note that the trend of fatalities in aviation, both commercial and general, is uniformly upward.

The hour-of-exposure unit was chosen because it was deemed more closely related to the individual's intuitive process in choosing an activity than a year of exposure would be, and gave substantially similar results. Another possible alternative, the risk per activity, involved a comparison of too many dissimilar units of measure; thus, in comparing the risk for various modes of transportation, one could use risk per hour, per mile, or per trip. As this study was directed toward exploring a methodology for determining social acceptance of risk, rather than the safest mode of transportation for a particular trip, the simplest common unit–that of risk per exposure hour–was chosen.

The social benefit derived from each activity was converted into a dollar equivalent, as a measure of

integrated value to the individual. This is perhaps the most uncertain aspect of the correlations because it reduced the *"quality-of-life"* benefits of an activity to an overly simplistic measure. Nevertheless, the correlations seemed useful, and no better measure was available. In the case of the *"voluntary"* activities, the amount of money spent on the activity by the average involved individual was assumed proportional to its benefit to him. In the case of the *"involuntary"* activities, the contribution of the activity to the individual's annual income (or the equivalent) was assumed proportional to its benefit. This assumption of roughly constant relationship between benefits and monies, for each class of activities, is clearly an approximation. However, because we are dealing in orders of magnitude, the distortions likely to be introduced by this approximation are relatively small.

In the case of transportation modes, the benefits were equated with the sum of the monetary cost to the passenger and the value of the time saved by that particular mode relative to a slower, competitive mode. Thus, airplanes were compared with automobiles, and automobiles were compared with public transportation or walking Benefits of public transportation were equated with their cost. In all cases, the benefits were assessed on an annual dollar basis because this seemed to be most relevant to the individual's intuitive process. For example, most luxury sports require an investment and upkeep only partially dependent upon usage. The associated risks, of course, exist only during the hours of exposure.

Probably the use of electricity provides the best example of the analysis of an *"involuntary"* activity. In this case the fatalities include those arising from electrocution, electrically caused fires, the operation of power plants, and the mining of the required fossil fuel. The benefits were estimated from a United Nations study of the relationship between energy consumption and national income; the energy fraction associated with electric power was used. The contributions of the home use of electric power to our *"quality of life"* – more subtle than the contributions of electricity in industry–are omitted. The availability of refrigeration has certainly improved our national health and the quality of dining. The electric light has certainly provided great flexibility in patterns of living, and television is a positive element. Perhaps, however, the gross-income measure used in the study is sufficient for present purposes.

Information on acceptance of *"voluntary"* risk by individuals as a function of income benefits is not easily available, although we know that such a relationship must exist. Of particular interest, therefore, is the special case of miners exposed to high occupational risks. In Figure 1, the accident rate and the severity rate of mining injuries are plotted against the hourly wage (2, 3). The acceptance of the activity to the individual risk is an exponential function of the wage, and can be roughly approximated by a third-power relationship in this range. If this relationship has validity, it may mean that several *"quality of life"* parameters (perhaps health, living essentials, and recreation) are each partly influenced by any increase in available personal resources, and that thus the increased acceptance of risk is exponentially motivated. The extent to which this relationship is *"voluntary"* for the miners is not obvious, but the subject is interesting nevertheless.

Risk Comparisons

The results of the societal activities studied, both *"voluntary"* and *"involuntary,"* are assembled in Figure 2. (For details of the risk-benefit analysis, see the appendix). Also shown in Figure 2 is the third-power relationship between risk and benefit characteristic of Figure 1. For comparison, the average risk of death for accident and from disease is shown. Because the average number of fatalities from accidents is only about one-tenth the number achieved, we could say that any generalizations developed might then be used for predictive purposes. This approach could give a rough answer to the seemingly simple question *"How safe is safe enough?"*

The pertinence of this question to all of us, and particularly to governmental regulatory agencies, is obvious. Hopefully, a functional answer might provide a basis for establishing performance *"design objectives"* for the safety of the public.

Voluntary and Involuntary Activities

Societal activities fall into two general categories–those in which the individual participates on a *"voluntary"* basis and those in which the participation is *"involuntary,"* imposed by the society in which the individual lives. The process of empirical optimization of benefits and costs is fundamentally similar in the two cases–namely, a reversible exp[illegible]ion of available options–but the time required [illegible] npirical adjustments (the time

constants of the system) and the criteria for optimization are quite different in the two situations.

In the case of *"voluntary"* activities, the individual uses his own value system to evaluate his experiences. Although his eventual trade-off may not be consciously or analytically determined, or based upon objective knowledge, it nevertheless is likely to represent, for that individual, a crude optimization appropriate to his value system. For example, an urban dweller may move to the suburbs because of a lower crime rate and better schools, at the cost of more time spent traveling on highways and a higher probability of accidents. If, subsequently, the traffic density increases, he may decide that the penalties are too great and move back to the city. Such an individual optimization process can be comparatively rapid (because the feedback of experience to the individual is rapid), so the statistical pattern for a large social group may be an important *"realtime"* indicator of societal trade-offs and values.

"Involuntary" activities differ in that the criteria and options are determined not by the individuals affected but by a controlling body. Such control may be in the hands of a government agency, a political entity, a leadership group, an assembly of authorities or *"opinion-makers,"* or a combination of such bodies. Because of the complexity of large societies, only the control group is likely to be fully aware of all the criteria and options involved in their decision process. Further, the time required for feedback of the experience that results from the controlling decisions is likely to be very long. The feedback of cumulative individual experiences into societal communication channels (usually political or economic) is a slow process, as is the process of altering the planning of a control group. We have many examples of such *"involuntary"* activities, war being perhaps the most extreme case of the operational separation of the decision-making group from those most affected. Thus, the real-time pattern of societal trade-offs on *"involuntary"* activities must be considered in terms of the particular dynamics of approach to an acceptable balance of social values and costs. The historical trends in such activities may therefore be more significant indicators of social acceptability than the existent trade-offs are.

In examining the historical benefit-risk relationships for *"involuntary"* activities, it is important to recognize the perturbing role of public psychological acceptance of risk arising from the influence of authorities or dogma. Because in this situation the decision-making is separated from the affected individual, society has generally clothed many of its controlling groups in an almost impenetrable mantle of authority and of imputed wisdom. The public generally assumes that the decision-making process is based on a rational analysis of social benefit and social risk. While it often is, we have all seen after-the-fact examples of irrationality. It is important to omit such *"witchdoctor"* situations in selecting examples of optimized *"involuntary"* activities, because in fact these situations typify only the initial stages of exploration of options.

Quantitative Correlations

With this description of the problem, and the associated caveats, we are in a position to discuss the quantitative correlations. For the sake of simplicity in this initial study, I have taken as a measure of the physical risk to the individual the fatalities (deaths) associated with each activity. Although it might be useful to include all injuries (which are 100 to 1,000 times as numerous as deaths), the difficulty in obtaining data and the unequal significance of varying disabilities would introduce inconvenient complexity for this study. So the risk measure used here is the statistical probability of fatalities per hour of exposure of the individual to the activity considered.

Public Awareness

Finally, I attempted to relate these risk data to a crude measure of public awareness of the associated social benefits (see Fig. 7). The *"benefit awareness"* was arbitrarily defined as the product of the relative level of advertising, the square of the percentage of population involved in the activity, and the relative usefulness (or importance) of the activity to the individual (8). Perhaps these assumptions are too crude, but Figure 7 does support the reasonable position that advertising the benefits of an activity increases public acceptance of a greater level of risk. This, of course could subtly produce a fictitious benefit-risk ration–as may be the case for smoking.

Atomic Power Plant Safety

I recognize the uncertainty inherent in the quantitative approach discussed here, but the trends and magnitudes may nevertheless be of sufficient validity to warrant their use in determining national *"design objectives"* for technological activities. How would this be done?

Let us consider as an example the introduction of nuclear power plants as a principal source of electric power. This is an especially good example because the technology has been primarily nurtured, guided, and regulated by the government, with industry undertaking the engineering development and the diffusion into public use. The government specifically maintains responsibility for public safety. Further, the engineering of nuclear plants permits continuous reduction of the probability of accidents, at a substantial increase in cost. Thus, the trade-off of utility and potential risk can be made quantitative.

Moreover, in the case of the nuclear power plant the historical empirical approach to achieving an optimum benefit-risk trade-off is not pragmatically feasible. All such plants are now so safe that it may be 30 years or longer before meaningful risk experience will be accumulated. By that time, many plants of varied design will be in existance, and the empirical accident data may not be applicable to those being built. So a very real need exists now to establish *"design objectives"* on a predictive-performance basis.

Let us first arbitarily assume that nuclear power plants should be as safe as coal-burning plants, so as not to increase public risk. Figure 2 indicates that the total risk to society for electric power is about 2×10^{-9} fatality per person per hour for exposure. Fossil fuel plants contribute about 1/5 of this risk, or about 4 deaths per million population per year. In a modern society, a million people may require a million kilowatts of power, and this is about the size of most new power stations. So, we now have a target risk limit of 4 deaths per year per million-kilowatt power station (9).

Technical studies of the consequences of hypothetical extreme (and unlikely) nuclear power plant catastrophic which would disperse radioactivity into populated areas, have indicated that about 10 lethal cancers per million population might result (10). On this basis, we calculate that such a power plant might statistically have one such accident every 3 years and still meet the risk limit set. However, such a catastrophe would completely destroy a major portion of the nuclear section of the plant and either require complete dismantling or years of costly reconstruction. Because power companies expect plants to last about 30 years, the economic consequences of a catastrophe every few years would be completely unacceptable. In fact, the operating companies would not accept one such failure on a statistical basis, during the normal lifetime of the plant.

It is likely that, in order to meet the economic performance requirements of the power companies, a catastrophe rate of less than 1 in about 100 plant-years would be needed. This would be a public risk of 10 deaths per 100 plant-years, or 0.1 death per year per million population. So the economic investment criteria of the nuclear plant user–the power company–would probably set a risk level 1/200 the present socially accepted risk associated with electric power, or 1/40 the present risk associated with coal-burning plants.

An obvious design question is this: Can a nuclear power plant be engineered with a predicted performance of less than 1 catastrophic failure in 100 plant-years of operation? I believe the answer is yes, but that is a subject for a different occasion. The principal point is that the issue of public safety can be focused on a tangible, quantitative, engineering design objective.

This example reveals a public safety consideration which may apply to many other activities: The economic requirement for the protection of major capital investiments may often be a more demanding safety constraint than social acceptability.

Conclusion

The application of this approach to other areas of public responsibility is self-evident. It provides a useful methodology for answering the question *"How safe is safe enough?"* Further, although this study is only exploratory, it reveals several interesting points. (i) the indications are that the public is willing to accept *"voluntary"* risks roughly 1,000 times greater than *"involuntary"* risks. (ii) The statistical risk of death from disease appears to be a psychological yardstick for establishing the level of acceptability of other risks. (iii) The acceptability of risk appears to be crudely proportional to the third power of the benefits (real or imagined). (iv) The social acceptance of risk is directly influenced by public awareness of the benefits of an activity, as determined by advertising, usefulness, and the number of people participating. (v) In a sample application of these criteria to atomic power plant safety, it appears that an engineering design objective determined by economic criteria would result in a design-target risk level very much lower than the present socially accepted risk for electric power plants.

Perhaps of greatest interest is the fact that this methodology for revealing existing social preferences and values may be a means of providing the insight on social benefit relative to cost that is so necessary for judicious national decisions on new technological developments.

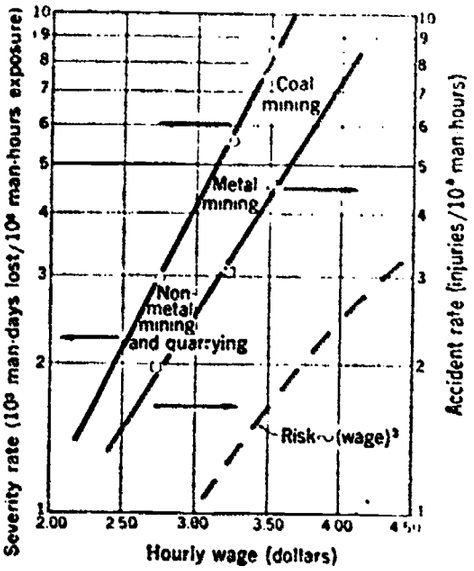


Fig. 1. Mining accident rates plotted relative to incentive.

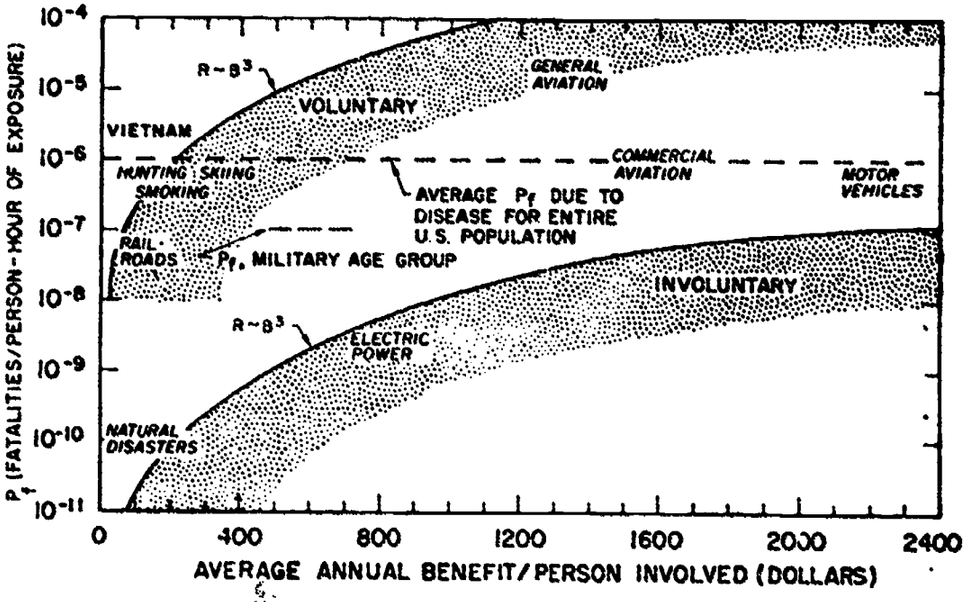
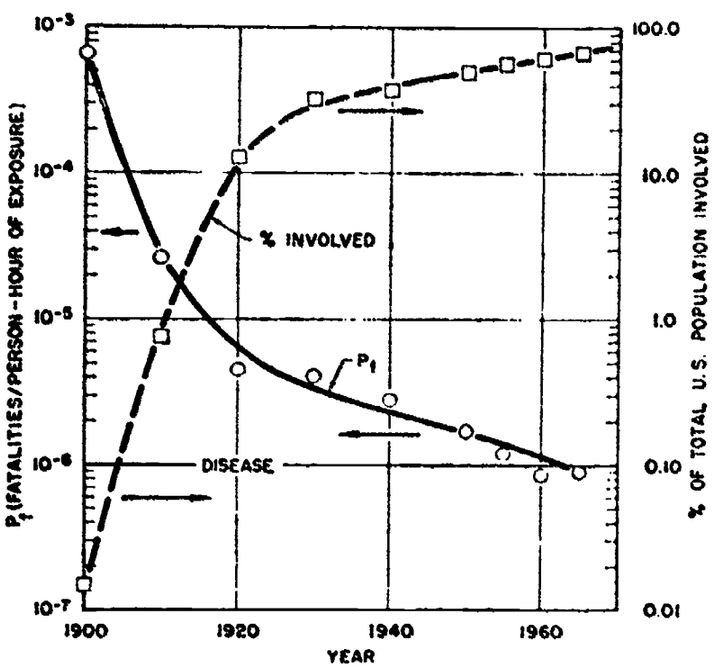


Fig. 2. Risk (R) plotted relative to benefit (B) for various kinds of voluntary and involuntary exposure.



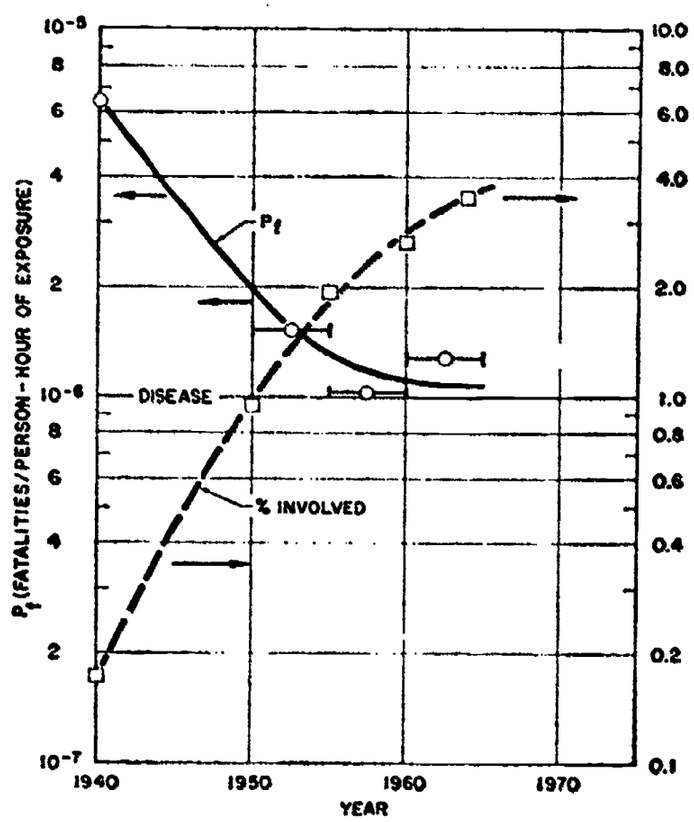
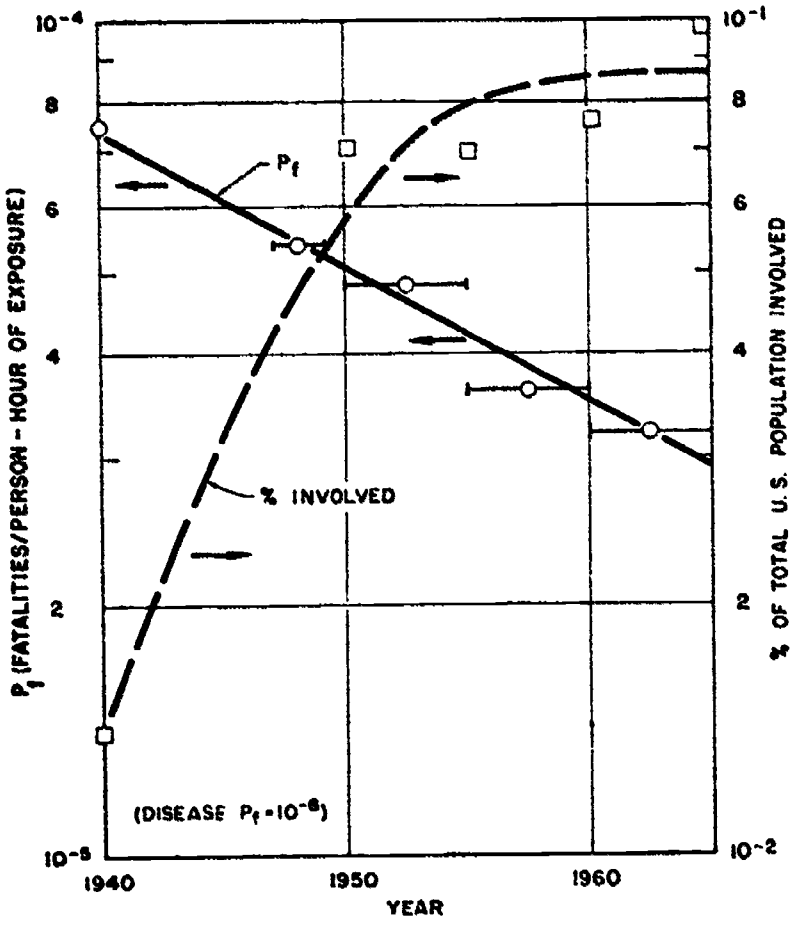


Fig. 3 (above). Risk and participation trends for motor vehicles.

Fig. 4 (right). Risk and participation trends for certified air carriers.



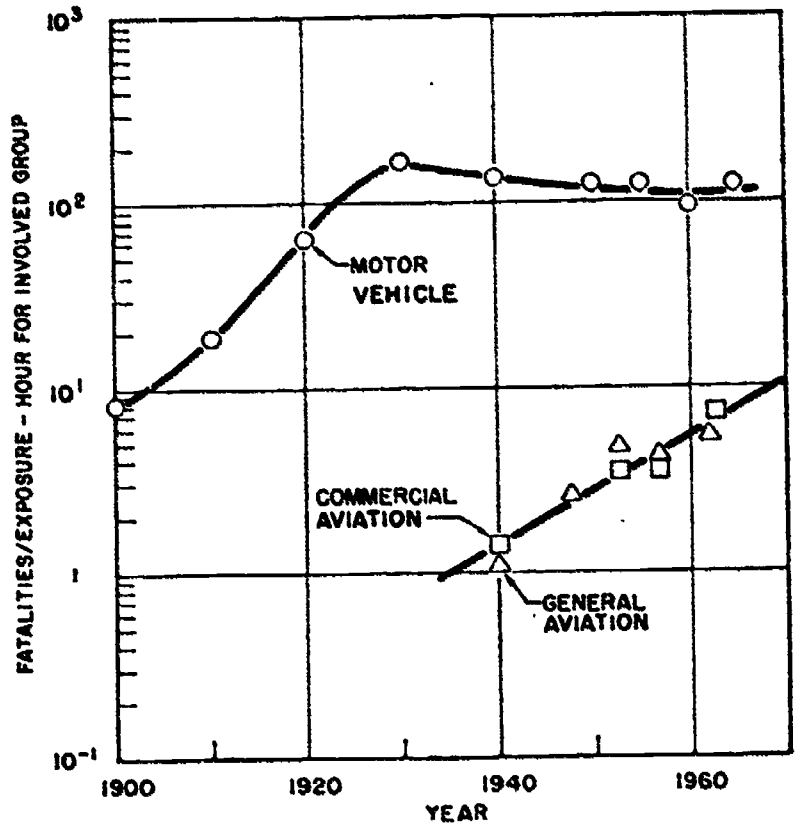


Fig. 5 (left). Risk and participation trends for general aviation.
Fig. 6 (above). Group risk plotted relative to year.

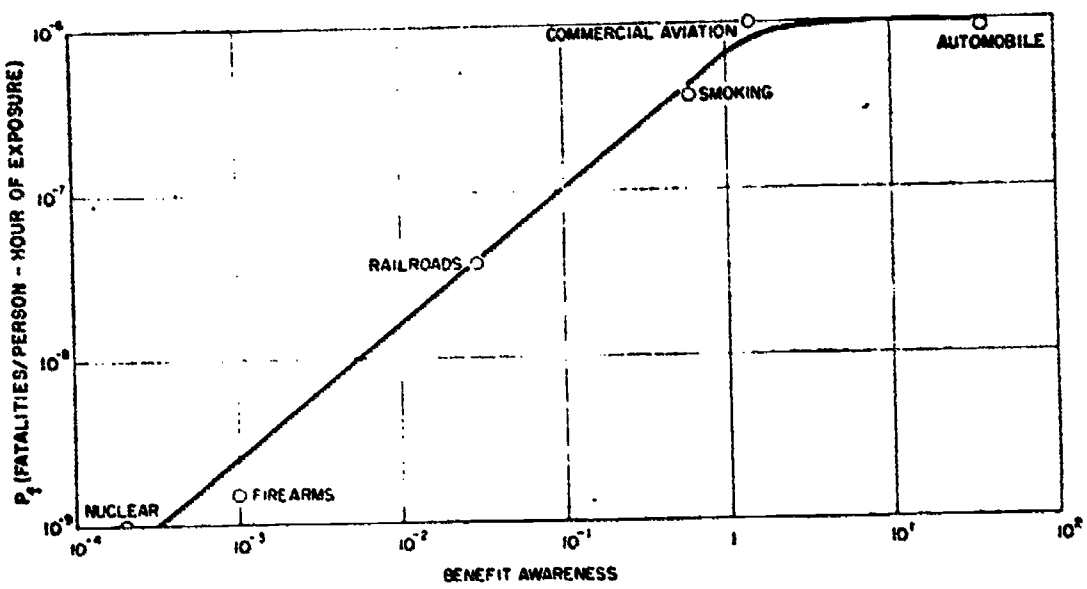


Fig. 7. Accepted risk plotted relative to benefit awareness (see text).

Details of Risk-Benefit Analysis

Motor-vehicle travel. The calculation of motor-vehicle fatalities per exposure hour per year is based on the number of registered cars, an assumed 1 1/2 persons per car, and an assumed 400 hours per year of average car use (data from 3 and 11). The figure for annual benefit for motor-vehicle travel is based on the sum of costs for gasoline, maintenance, insurance, and car payments and on the value of the time savings per person. It is assumed that use of an automobile allows a person to save 1 hour per working day and that a person's time is worth $5 per hour.

Travel by air route carrier. The estimate of passenger fatalities per passenger-hour of exposure for certified air route carriers is based on the annual number of passenger fatalities listed in the **FAA Statisitcal Handbook of Aviation** (see 12) and the number of passenger-hours per year. The latter number is estimated from the average number of seats per plane, the seat load factor, the number of revenue miles flown per year, and the average plane speed (data from 3). The benefit for travel by certified air route carrier is based on the average annual air fare per passenger-mile and on the value of the time saved as a result of air travel. The cost per passenger is estimated from the average rate per passenger-mile (data from 3), the revenue miles flown per year (data from 12), the annual number of passenger boardings for 1967 (132×10^6, according to the United Air Lines News Bureau), and the assumption of 12 boardings per passenger.

General aviation. The number of fatalities per passenger-hour for general aviation is a function of the number of annual fatalities, the number of plane hours flown per year, and the average number of passengers per plane (estimated from the ratio of fatalities to fatal crashes) (data from 12). It is assumed that in 1967 the cash outlay for initial expenditures and maintenance costs for general aviation was $\$1.5 \times 10^9$. The benefit is expressed in terms of annual cash outlay per person, and the estimate is based on the number of passenger-hours per year and the assumption that the average person flies 20 hours, or 4,000 miles, annually. The value of the time saved is based on the assumption that a person's time is worth $10 per hour and that he saves 60 hours per year through traveling the 4,000 miles by air instead of by automobile at 50 miles per hour.

Railroad travel. The estimate of railroad passenger fatalities per exposure hour per year is based on annual passenger fatalities and passenger-miles and an assumed average train speed of 50 miles per hour (data from 11). The passenger benefit for railroads is based on figures for revenue and passenger-miles for commuters and noncommuters given in *The Yearbook of Railroad Facts* (Association of American Railroads, 1968). It is assumed that the average commuter travels 20 miles per workday by rail and that the average noncommuter travels 1,000 miles per year by rail.

Skiing. The estimate for skiing fatalities per exposure hour is based on information obtained from the National Ski Patrol for the 1967-68 southern California ski season: 1 fatality, 17 days of skiing, 16,500 skiers per day, and 5 hours of skiing per skier per day. The estimate of benefit for skiing is based on the average number of days of skiing per year per person and the average cost of a typical ski trip (data from *"The Skier Market in Northeast North America,"* U.S. Dep. Commerce Publ. (1965)). In addition, it is assumed that a skier spends an average of $25 per year on equipment.

Hunting. The estimate of the risk in hunting is based on an assumed value of 10 hours' exposure per hunting day, the annual number of hunting fatalities, the number of hunters, and the average number of hunting days per year [data from 11 and from *"National Survey of Fishing and Hunting."* U.S. Fish Wildlife Serv. Publ. (1965)]. The average annual expenditure per hunter was $82.54 in 1965 (data from 3).

Smoking. The estimate of the risk from smoking is based on the ratio for the mortality of smokers relative to nonsmokers, the rates of fatalities from heart disease and cancer for the general population, and the assumption that the risk is continuous [data from the *Summary of the Report of the Surgeon General's Advisory Committee on Smoking and Health* (Government Printing Office, Washington, D.C., 1964)]. The annual intangible benefit to the cigarette smoker is calculated from the American Cancer Society's estimate that 30 percent of the population smokes cigarettes, from the number of cigarettes smoked per year (see 3), and from the assumed retail cost of $0.015 per cigarette.

Vietnam. The estimate of the risk associated with the Vietnam war is based on the assumption that 500,000 men are exposed there annually to the risk of death and that the fatality rate is 10,000 men per year. The benefit for Vietnam is calculated on the assumption that the entire U.S. population benefits intangibly from the annual Vietnam expenditure of $30 x 10^9.

Electric power. The estimate of the risk associated with the use of electric power is based on the number of deaths from electric current: the number of deaths from fires caused by electricity; the number of deaths that occur in coal mining, weighted by the percentage of total coal production used to produce electricity; and the number of deaths attributable to air pollution from fossil fuel stations [data from 3 and 11 and from *Nuclear Safety 5,325 (1964)*]. It is assumed that the entire U.S. population is exposed for 8,760 hours per year to the risk associated with electric power. The estimate for the benefit is based on the assumption that there is a direct correlation between per capita gross national product and commercial energy consumption for the nations of the world [data from Briggs, *Technology and Economic Development* (Knopf, New York, 1963)]. It is further assumed that 35 percent of the energy consumed in the U.S. is used to produce electricity.

Natural disasters. The risk associated with natural disasters was computed for U.S. floods (2.5 x 10^{-10} fatality per person-hour of exposure), tornadoes in the Mid-west (2.46 x 10^{-10} fatality), major U.S. storms (0.8 x 10^{-10} fatality), and California earthquakes (1.9 x 10^{-10} fatality) (data from 11). The value for flood risk is based on the assumption that everyone in the U.S. is exposed to the danger 24 hours per day. No benefit figure was assigned in the case of natural disasters.

Disease and accidents. The average risk in the U.S. due to disease and accidents is computed from data given in *Vital Statistics of the U.S.* (Government Printing Office, Washington, D.C., 1967).

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The procedure outlined in the appendix was used in calculating the risk associated with motor-vehicle travel. In order to calculate exposure hours for various years, it was assumed that the average annual driving time per car increased linearly from 50 hours in 1900 to 400 hours in 1960 and thereafter. The percentage of people involved is based on the U.S. population, the number of registered cars, and the assumed value of 1.5 people per car.

The procedure outlined in the appendix was used in calculating the risk associated with, and the number of people who fly in, certified air route carriers for 1967. For a given year, the number of people who fly is estimated from the total number of passenger boardings and the assumption that the average passenger makes six round trips per year (data from 3).

The method of calculating risk for general aviation is outlined in the appendix. For a given year, the percentage of people involved is defined by the number of active aircraft (see 3); the number of people per plane, as defined by the ratio of fatalities to fatal crashes; and the population of the U.S.

Group risk per exposure hour for the involved group is defined as the number of fatalities per person-hour of exposure multiplied by the number of people who participate in the activity. The group population and the risk for motor vehicles, certified air route carriers, and general aviation can be obtained from Figs. 3-5.

In calculating *"benefit awareness"* it is assumed that the public's awareness of an activity is a function of A, the amount of money spent on advertising; P, the number of people who take part in the activity; and U, the utility value of the activity to the person involved. A is based on the amount of money spent by a particular industry in advertising its product, normalized with respect to the food and food products industry, which is the leading advertiser in the U.S.

In comparing nuclear and fossil fuel power stations, the risks associated with the plant effluents and mining of the fuel should be included in each case. The fatalities associated with coal mining are about 1/4 the total attributable to fossil fuel plants. As the tonnage of uranium ore required for an equivalent nuclear plant is less than the coal tonnage by more than an order of magnitude, the nuclear plant problem primarily involves hazard from effluent.

This number is my estimate for maximum fatalities from an extreme catastrophe resulting from malfunction of a typical power reactor. For a methodology for making this calculation, see F. R. Farmer, *"Siting criteria-a new approach."* paper presented at the International Atomic Energy Agency Symposioum in Vienna, April 1967. Application of Farmer's method to a fast breeder power plant in a modern building gives a prediction of fatalities less than this assumed limit by one or two orders of magnitude.

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Air Pollution from Combustion Sources

Robert H. Essenhigh, Professor of Fuel Science

Introduction

The majority of the man-made pollutants present in the air today originate from combustion sources. Table 1 illustrates this with a breakdown of data for 1966 and 1968 published recently by the National Air Pollution Control Administration. Five types of pollutants from five categories of sources are identified, and, of the five source types, the first four and a substantial fraction of the fifth originate in combustion chambers. The quantities listed account for more than 90 percent of the problem in the United States. The total weight of all emissions is, perhaps, the most startling figure of all. At 200 million tons or more, this is greater than one-third of the annual coal tonnage used as primary energy source, yet it is made up of components measured in the parts per million range. On the breakdown, certain category types of pollutants stand out – notably, carbon monoxide from transportation alone provides roughly 30 percent of the total, mostly representing inefficiency of automobile engines; next is SO_x from stationary combustion sources – mostly power stations – at 10 to cent; hydrocarbons, i.e., unburned or pa burned fuel from transportation, and carbon monoxide from miscellaneous sources tie for third place at about 8 percent each. These four account for over 50 percent of the total. The type totals amplify this in another way. Carbon monoxide from all sources provides about half the overall total; the remaining types each provide only about 8 to 16 percent.

These figures underline the serious need for abatement; unfortunately, however, the necessary technology has not always been able to keep abreast of desirable legislative requirements. The purpose of this article is to point out some of the problems and difficulties of reducing pollution from combustion sources.

Health Hazards

Quantity alone, however, is not necessarily the sole criterion of significance in assessing the impact of pollutants. Their physiological effect is what is at issue, and this is generally a function of exposure and concentration. The longer the exposure time the lower the concentration that can be permitted if ill effects are to be avoided. This is illustrated in Figures 1 and 2 for sulfur dioxide and carbon monoxide, respectively.

Figure 1 shows the exposure time required to produce stated physiological effects at a given concentration. Points of interest in this graph are the taste and odor thresholds (0.3 and 0.5 p.-p.m.). These would seem to be good danger signals. Evidently, half-a-day to a day's exposure at these levels should cause discomfort, and a week to a month's exposure could be expected to produce adverse effects even in a healthy man. For comparison, average concentrations in cities in the United States have been reported to range from near zero up to 0.16 p.p.m., but significantly higher values are ocassionally reported. In London in December 1952, sulfur dioxide concentrations averaged 0.57 p.p.m. over a four-day period, during which time 4000 *"excess"* deaths occurred.

Figure 2 provides somewhat similar information for the effects of carbon monoxide. Hemoglobin has a greater affinity for CO than it has for oxygen (by a factor of 200), and the toxic effects follow from the reduced oxygen circulated by the hemoglobin. The percentage of hemoglobin saturation by CO (which fortunately is reversible) is a good indicator of the toxicity level. While Figure 2 also shows the saturation level achieved in a given time at a given CO percentage, it gives no information on the longer term exposures. If this should last for a day or more, physical sickness becomes evident at 25 to 50 p.p.m., and for longer terms (a week or more) human performance is probably impaired at anything above 10 p.p.m. This is possibly achieved by one-pack-a-day cigarette smokers.

Comparable graphs for NO_x do not seem to have been constructed. Of the six most commonly encountered nitrogen oxides, NO_2 is evidently the most important since all the others tend to form it given time (from minutes to hours), although NO is the principal product is flames. At sufficient concentrations, NO_2 is toxic and can cause severe damage, leading to death. The odor threshold is just over 1 p.p.m., and irritation starts in excess of 10 p.p.m. By contrast, an otherwise clear sky would just show slight discoloration at something under 1 p.p.m. The toxic levels, lying between 10 and 100 p.p.m., are not generally reached. However, at the lower levels, NO_2 participates in the photochemical reactions leading to oxidant smog. This smog

formation also involves hydrocarbons; hence the concern in reducing both NO_2 and hydrocarbons.

Solid particulates usually have more of a smothering effect than a directly toxic effect, as most are biologically inert, particularly fly-ash and carbon, although they evidently play some part in coating the lungs and reducing the oxygen transfer surface which can be important in bronchial patients. This is usually accepted as having been a factor aggravating the SO_2 effect during the London smog of 1952 when many of the *"excess"* deaths were among those with bronchial difficulties.

Processes of Pollutant Generation from Combustion

The gross processes generating the pollutants by combustion are quite simple, although their detailed mechanisms may be exceedingly complex.

The inorganic particulates are inert materials that enter the flame as minerals and emerge as fly-ash after partial alteration.

Organic particulates are carbon or carbonaceous solids formed by cracking the fuel (coal, oil, or gas) in the flame. Their emissions represents poor combustion control; at the higher concentrations, they are apparent in the combustor exhaust as *"smoke."* It is then common to find CO also present; and if a sample of the exhaust is cooled, condensible hydrocarbons may be found. Control of these pollutants obviously depends on good combustion.

By contrast, NO_x and SO_x are almost indicative of too good combustion. SO_2 results, of course, from sulfur in the fuel, and a substantial fraction usually oxidizes further to SO_3. The SO_3 conversion increases with excess air, so this can be controlled to a considerable extent by firing any furnace or combustor as near to stoichiometric conditions as possible.

Low to zero excess air also reduces the NO_x problem. The nitrogen oxides are formed primarily by reaction of oxygen with atmospheric nitrogen, although nitrogen in the fuel can also participate. In the initial flame reaction, NO predominates, being formed by what is known as the Zeldovich mechanism. The NO formation rate is approximately proportional to the square root of the oxygen concentration, so it is reduced by low excess air. The conversion of NO to NO_2 then depends on relatively slow reaction in the atmosphere, at near ambient temperature, in a large excess of oxygen after escape of the effluent from the stack.

Flame Control of Pollutants

Although the potential for flame control of pollutants is obvious, the details of any procedure are less so. The reduction of excess air – to control SO_3 formation and reduce NO_x – is only permissible when the combustion system is under such good control that there are no significant unburned combustibles in the effluent gas (CO, hydrocarbons, organic particulates) either before or after the excess air reduction. Table 1 shows that, as a generality, this is hardly the case.

The problem centers on the speed of mixing in the combustion chamber related both to the time required for reaction and to the average residence time of the reactants in the chamber. The mixing aspects may include mixing of the fuel and oxidant in the chamber, which are frequently supplied separately for safety or other reasons. The dominant mixing behavior in most cases, however, is between the fresh, incoming reactants and the part-burned combustion gases already in the combustor. This requires a *"backmix"* flow, in contrast, for example, with the bunsen burner, where the gas and air mix in the burner tube and then carry straight on through the flame and out into the surroundings without any feedback to the burner tube.

In most practical situations, however, the mixing is produced by a combination of turbulence and backmix. In general, there are locally identifiable streams, some moving in the same direction and some in the opposite direction to the main flow. These *"forward"* and *"backmix"* streams move gross quantities of reactants and products around in the mixing region of the combustor, and turbulence promotes cross-mix between the streams. Turbulence is frequently pictured as motion of small volume elements of fluid, or eddies formed by shear flow, with a finite but decaying eddy size. The eddies ultimately dissipate to purely molecular motion, finally representing absolute mixing, but during the eddy lifetime there are local inhomogeneities in concentration, and it is these that are likely to be important in pollutant formation.

If the backmix streams are large and few in number, the turbulence eddies must be correspondingly large with correspondingly long lifetimes so that they can survive for the necessary penetration distance into the backmix streams. In the limit of marginal backmix, with stirring dominated by turbulence, the mixing distance must be of the order of the combustor dimensions, and the eddy lifetimes must be comparable with the residence

times in the chamber. However, since the lifetimes have distributions, there is, then, a finite probability that a significant proportion of eddies can escape from the chamber before final decay. If the eddy is almost pure fuel, it can emerge almost intact, or as a range of cracked fuel products, carbon monoxide, hydrocarbon intermediates, and carbon, depending on its temperature history. If the eddy is fuel and oxygen, the volume element might react explosively, and this may possibly be a source of combustion noise. Such localized *"hot spots"* can also contribute to NO formation because of the locally higher temperature.

Even if there is sufficient time for the eddies to decay, final burn-up may still not be complete. Intermediates formed (particularly carbon) may be so much less reactive that the reaction time is increased and exceeds the chamber residence time. This is further aggravated if the products are then quite rapidly cooled. In a small coal-fired boiler (of about 100,000 lb. steam/hr.), cooling of gases through the tube banks can approach 10^4 deg./sec., which is a rate found from post-flame studies that would effectively quench the CO conversion to CO_2. In reciprocating engines, the reaction time is substantially shorter, and the rate of cooling even faster. In consequence, the high level of CO and hydrocarbon emissions from transportation power units is almost inevitable (aggravated in many instances by bad maintenance).

This argument suggests that the objective should be to increase backmix while reducing the turbulence. The ssible limit of this is mixing without turbulence – a process known as *"blending."* At the present time, however, the tendency seems to be to go in the opposite direction.

Abatement

In principle, something can be done about potential contaminants by treatment before and after the flame. Five ways can be suggested, although not all are suitable for each of the five principal pollutant types.

• (1) **Pretreatment** – Cleaning of the fuel would be aimed at removing mineral matter and sulfur. Removing mineral matter to cut down fly-ash applies only to coal. Cleaning coal is a well-developed technique, but for use in power stations it is usually omitted because of cost, particularly in mine mouth operations where the mined coal goes straight to the crushers. In this case, the inorganics are then removed from the stack gases as flyash.

If pretreatment of coal to remove sulfur is eve practiced (as it is on occasion for oil), simultaneous removal of mineral matter might be practicable. Desulfurization by hydrogenation is also potentially possible, with sulfur conversion to H_2S, and has the advantage over post-combustion cleaning in that the weights or volumes of gas to be handled are substantially smaller, with proportionately higher component concentrations. A possible reactor scheme to achieve this was published recently, but only the first steps have so far been taken to implement the proposal.

(2) **Flame Control** – This is altogether more promising, in spite of the problems outlined above (See. *"Flame Control of Pollutants"*), by the recycling of flue gas and staged air addition. These do not overcome the turbulence problems already mentioned, but are aimed rather at reducing overall temperature levels, and particularly temperature peaks, either by direct dilution (flue gas recycling) or by delaying the total air addition by staging. This staging is aimed particularly at the NO_x formation, although the staged air addition will reduce the local oxygen concentrations through the flame, which will also help to reduce the SO_3 formation.

Flue gas recycling in sufficient quantities can also cut down smoke formation by a mechanism that has not yet been elucidated. Experiments some years ago showed that smoke from combustion of No. 2 oil could be eliminated by firing at 50 percent excess air, or at zero excess air but with 50 percent flue gas recirculation (and in a little more than direct proportion between these limits). Even more surprising was the discovery that when the flue gas recirculation was increased still further, the yellow flame turned blue. This behavior is now the basis for a number of attempts to commercialize a blue-flame oil burner for the domestic market with prospects for reduced noise and emissions.

(3) **Exhaust Effluent Treatment** – This has traditionally been practiced to cut down fly-ash and particulate emissions, particularly in power stations generally using cyclomes and electrostatic precipitators. Additional treatment to include removal of sulfur and nitrogen oxides has been attempted more recently, particularly for SO_x, but success has not been widespread. Strauss describes several liquid absorption methods for SO_2, with three applied to power stations, but he also states that no really satisfactory solution of general applicablity has

been found. The alternative to liquid absorption is solid absorption with calcium oxide or calcimed dolomite as possible choices. Activated carbon is a further possibility.

Treatment of automobile exhause with its high level of CO and hydrocarbons has centered on catalysts to burn up both, but again these are still in the development stage.

(4) Dilution – If the exhaust effluent from a stack cannot be cleaned by existing techniques, the final resort is dilution. This is achieved by building stacks so high that when the plume reaches the ground the contaminants have been reduced, under most conditions, to below the statutory limit. The atmosphere has, of course, been the traditional sink for most effluents in any case, but the very high stack is the logical outcome of arguments that the atmosphere is still simi-infinite so far as current levels of contaminant generation are concerned. If, for example, it is true that the SO_2 average concentration as it exists naturally in the atmosphere would only double in 15 years at the present rates of SO_2 generation (and disregarding washout), then it would seem reasonable only to make sure that it was well dispersed by a high stack.

Such an operation would be satisfactory for most of the time although lower sulfur fuels would have to be available for use under special atmospheric conditions such as inversions, or those allowing fumigation. It has been estimated that this would occur only about 2 percent of the time in England, but in some parts of the United States it could be a good deal more. The maritime climate of England would account for the relatively low figure of 2 percent but the continental climate of the United States could easily be responsible for a single pollution alert lasting a week or more.

(5) Thermal Efficiency – This is one final possibility for pollution abatement that deserves some attention. The rate of production of contaminants will be roughly proportional to the total fuel consumption, so reduction of this total by using the fuel more efficiently must reduce the rate of generation of pollutants. A breakdown of the energy market into four groups of users gives the following: (1) electricity generation and transmission – 15 percent; (2) residential and commercial – 20 percent; (3) transportation – 25 percent: and (4) industrial – 40 percent. There is not now too much scope for improvement in thermal efficiency in the electricity generation area without radical modification of existing methods, so this will leave the largest SO_x and NO_x sources as they are, with abatement based on other factors. There should, however, be room for improvement in the other three areas, and particularly in industry, which uses the largest fraction of energy and where there is considerable scope for addition of heat recovery equipment.

There has not usually been too much incentive to do this in the past because of the difficulty of justifying such equipment on the basis of recovery of costs. The fraction of manufacturing costs that is due to energy or fuel is only 3.5 percent for all manufacturing, although it is rather higher in heavy industry (ferrous and nonferrous metals, refractories, chemicals, etc.), where it ranges from 10 to 25 percent. The cost recovery situation might be improved, however, if manufacturers were to pay for the air they use directly or indirectly (traditionally regarded as free) by a tax on their fuel and electricity consumption.

Judging by Table 1, efficiency improvements would have only a small impact on the pollutant emissions since industry evidently generates only about 15 percent of the total – a surprisingly low figure – but it would provide a lead and would also contribute to alleviation of the power shortage.

Conclusions

Air pollution from combustion sources is a problem, and in some areas of the country a serious one, but it has still not yet reached the uniformly catastrophic proportions that some of the self-appointed priests and policemen moralizing over the sins of industry would have us believe. However, such catastrophic proportions could well be achieved within a generation if effective uniform action is not taken very shortly. Unfortunately, what can be done is still somewhat limited as much of the needed technology is still undeveloped.

Of the five pollutant types listed in Table 1, particulates are the easiest to live with without further action, although here the removal techniques are also the most advanced; indeed, in a number of instances they depend only on payment for installation costs. The easiest to eliminate on the basis of current knowledge ought to be the combustibles (CO, hydrocarbons, and sometimes organic particulates) emanating from all sources except

transportation, although extensive supplementary development research may still be necessary in some cases, particularly in incineration. Knowledge of the basis for controlling NO_x is gaining ground, although again extensive development research will probably be needed in a number of cases to apply the results. The biggest problems still seem to be: CO emissions, particularly from transporation, and SO_x emissions, particularly from power stations. Elimination of CO by catalytic after-burning outside the engine is a stopgap answer at best. The problem really stems from the nature of the reciprocating engine, which cannot really be regarded as an example of elegant engineering design. Can a better unit be produced to displace it? And will society pay the cost in view of the immense capital investment already involved in reciprocating engines? Finally, SO_x emissions still seem to be currently the most intractable. A number of promising possibilities exist, but there is still no commercial process that is simple, cheap, effective, and reliable. It is, perhaps, fortunate that the tall stack solution is available as a stopgap, as long as local ordinances are not unimaginatively rigid and as long as sufficient low-sulfur, stand-by fuel is available for periods when meterorological conditions are adverse.

Prodded by environmentalists, the research is slowly moving toward solutions, aided by much verbal encouragement from bystanders and occasional financial assistance from appropriate funding agencies. The problem exists, of course, very largely because of too little rather than too much science, although some of the more excitable members of the community advise a return to the primitive to eliminate both science and pollution. Such suggestions, however, miss the point. Man, like all living things, generates wastes. This he must live with. It is not the waste of itself that constitutes pollution but the generation of so much waste that adversely affects the environment. This is not unique to man. Even animals can so adversely affect their environment that they suffer for it; for example, by overbreeding when food is plentiful, they overgraze when it is not and many die. Man can do this, too, but he has also learned how to avoid it. Measures to control wastes are not new. One of the most significant steps in waste control ever taken was the production of cheap steel pipe, in quantity, that enabled the separation of drinking water from sewage, and it probably did as much for the general health and reduction of mortality as all medical research to date.

There is no reason to suppose that the current problem of air pollution cannot be solved, given the will and the means. Curiously, one of the big difficulties at present – in addition to the invariable shortage of research funds – is availability of trained manpower to undertake the necessary research. Preaching and legislation are useless without the technology. If those who are so vocal in criticizing the shortcomings of science, industry, and the universities in solving *"relevant"* problems were to take a hand in developing the necessary technical solutions, even if it means getting their hands dirty, we should get there a good deal faster.

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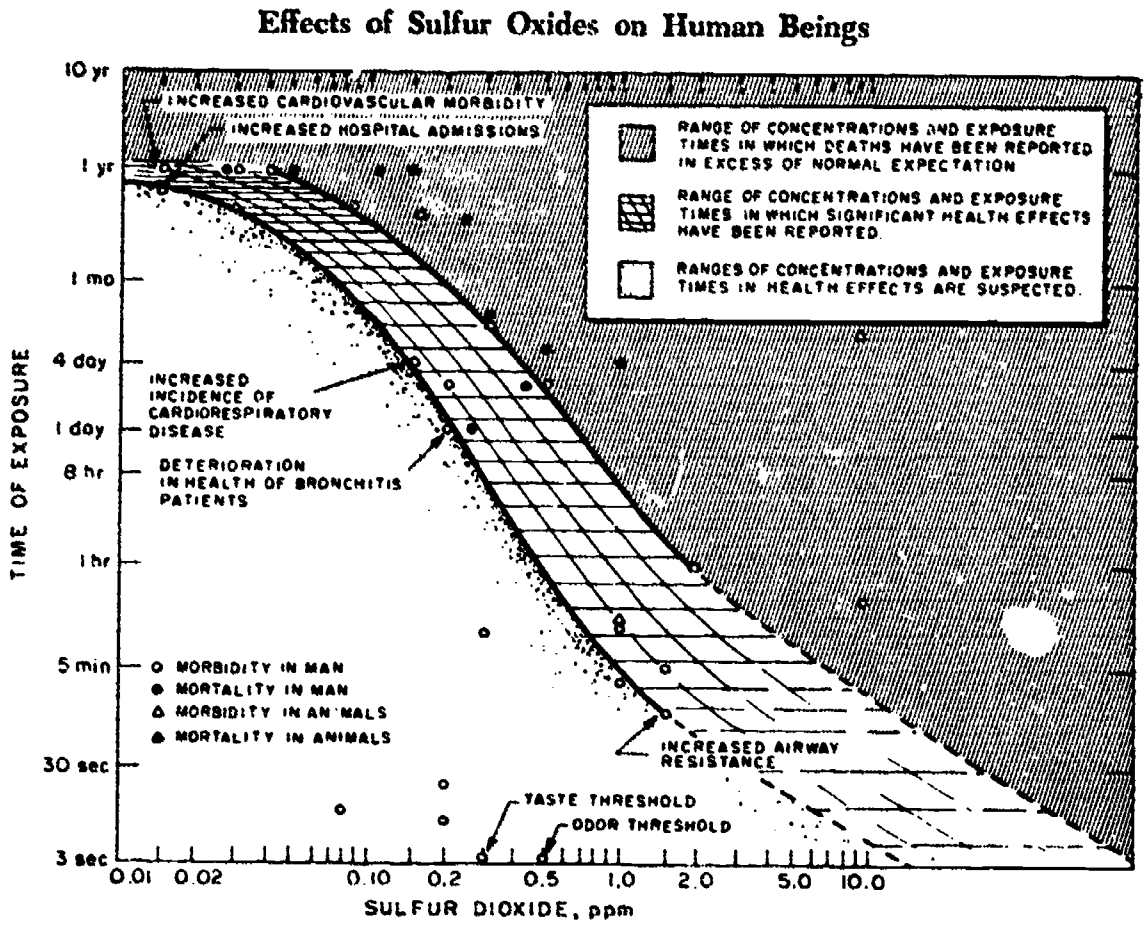

Fig. 1. *Variation of health response with SO_2 concentration and exposure time. (From U.S. Department of Health, Education, and Welfare Publication No. 1619.)*

Table 1

Emission Rates of Dominant Pollutant Types and Sources for 1966 and 1968

Millions of Short Tons per Year

These data account for more than 90 percent of all emissions in the United States

Pollutant Source	Pollutant Type: CO	Hydrocarbons	NO_x	SO_x	Particulates	Total by Source	Year
Transportation	63.8	16.6	8.1	0.8	1.2	90.5	1968
	64.5	17.6	7.6	0.4	1.2	91.3	1966
Stationary Combustion Sources	1.9	0.7	10.0	24.4	8.9	45.9	1968
	1.9	0.7	6.7	22.9	9.2	41.4	1966
Industrial Processes	9.7	4.6	0.2	7.3	7.5	29.3	1968
	10.7	3.5	0.2	7.2	7.6	29.2	1966
Refuse Incineration	7.8	1.6	0.6	0.1	1.1	11.2	1968
	7.6	1.5	0.5	0.1	1.0	10.7	1966
Miscellaneous*	16.9	8.5	1.7	0.6	9.6	37.3	1968
	16.9	8.2	1.7	0.6	9.6	37.2	1966
Total by Type	101.1	32.0	20.6	33.2	28.3	214.2	1968
	101.6	31.5	16.7	31.2	28.6	209.8	1966

*Includes such sources as forest fires, structural fires, coal refuse, agriculture, organic solvent evaporation, and gasoline marketing

Data Source: National Air Pollution Control Administration

Remarks by
Dr. James R. Schlesinger, Chairman, U.S. Atomic Energy Commission
Before the 100th Annual Meeting
American Public Health Association
Atlantic City, New Jersey
November 14, 1972

POWER PRODUCTION, HEALTH AND THE ENVIRONMENT

It is both a pleasure and a signal honor to be invited to deliver this keynote address at this session of the Centennial Meeting of the American Public Health Association. For one hundred years this Association has dedicated itself to and has made a major contribution toward public enlightenment and improved policies pertaining to the nation's health. It has performed that role on a continuing basis in the face of dramatic changes in the cultural and political milieu and in the state of the technological art and scientific knowledge.

To cite one example of the rapid adjustment to change, significant for our purposes today, as early as the 1946 meeting of this Association a paper was presented on *"The Benefits and Hazards of Nuclear Energy"* (perhaps significantly entitled at the last moment *"Safe and Beneficial Utilization of Nuclear Energy"*). As the latest edition of The Nation's Health has commented: *"There was no doubt that the Association was firmly in the Atomic Age."* It was an early harbinger of one element in the theme for today's session: Toward a National Health Policy for the Environment.

The invitation to speak may be more than a signal honor; it is also something of a challenge. When Dr. Kimmey wrote to me originally, he stated that *"This Association has not always been in complete accord with the policies of the Atomic Energy Commission in the past."* Dr. Kimmey also indicated that more recently there have been *"positive changes"* that some of you have found encouraging. While this is somewhat complimentary, from an Agency standpoint it does not sound altogether complimentary. So this may be something of a challenge.

In a wholly serious vein I do hope that my comments today will help illuminate the trade-offs with respect to environmental or health matters that the nation must examine, and the uncertainties and perplexing questions that must be addressed. We, as a nation, must address these questions in an intellectually disciplined manner with a careful assessment and balancing of risks.

Consequently, if I may indulge in some stirring of nostalgia: Come now let us reason together! That phrase from Isaiah, many of you will recall, enjoyed a certain currency and vogue just before the direct involvement of this nation in the Vietnamese War, and just before deep currents of irrationality stirred this society and the veneration of anti-reason became the fashion in the later sixties. Nevertheless, it can now serve even more appropriately as a guiding star.

I take it that there is no need with this audience to discuss the role of the AEC-sponsored developments in the medical uses of isotopes for the diagnosis and treatment of disease. You are also far more expert than am I in the medical use of radiation for the treatment of cancer. Therefore, if I may, I shall direct my remarks to the energy problem and later to the possible health implications in this area, particularly to the effects of ionizing radiation.

Nuclear energy is only one of several alternative heat sources—and it should be viewed in this manner. Unfortunately, many members of the public find it nar[illegible] view it so unemotionally. The dramatic origins and prospects for nuclear energy led, during two decades of technological enthusiasm to undue expectation regarding near term results. Those were the days of the romance of the atom. It would power our automobiles and aircraft as well as our vessels. It would provide low cost energy and make the deserts bloom. Costs and harmful side effects tended to be discounted. By contrast, in the anti-technology wave that has become fashionable in the last decade, the romance faded. Undue expectations yielded to undue alarm. The mysterious atom was easy to dramatize. Fears could readily be engendered and exploited. I hope that this era too is now passing. We need a balanced view: neither the romance of the atom nor anti-technological romanticism.

As a source of energy nuclear power has different and unique characteristics, some advantageous, some disadvantageous. By contrast to the more familiar fuels, the chief advantage (aside from relative cost and scarcity) is the absence of the enormous quantities of combustion products otherwise released into the atmosphere. The chief disadvantage is the generation of fission products, which though of limited volume are highly hazardous, and which must be carefully transported, processed, and kept under surveillance or removed from the environment of man. Fuel rods must be shipped in special containers, weighting up to 100 tons, which are designed to withstand crashes, fire, a 30-foot fall, and penetration if dropped on a spike from 3 feet above. A one million kilowatt nuclear plant produces after processing about three cubic meters of solidified high-level waste a year for storage. Reactors must be designed to shield personnel from radiation during normal operations and to avoid the release of fission products through the various containment barriers, should an accident occur.

The present generation of reactors typically operates at relatively low temperatures and consequently low thermal efficiency. Since no waste heat is disposed of directly to the atmosphere, all waste heat is dissipated through cooling water which results in approximately fifty percent more waste heat than from a comparable fossil fuel plant. Until the time that such heat can be beneficially utilized, it consequently presents a larger problem of dissipation. In principle, this is a manageable problem in that cooling towers or cooling ponds can be employed virtually to eliminate the impact on natural bodies of water, should the impact be significantly deleterious–as is increasingly the case for smaller lakes and rivers.

From the proponents of nuclear power one will hear chiefly the advantages–the avoidance of tens of millions of tons of combustion products going into the atmosphere, the avoidance of major sources of sulphur oxides, nitrogen oxides, and particulate matter which contribute so dramatically to the smog problem. This is indeed a significant advantage, and I will return to it presently, but it is not the whole story.

From the opponents of nuclear power one hears only of the disadvantages, frequently in grossly exagerated form. One is informed–quite correctly–that a power reactor in the course of a year will produce as much fission products as a hundred and fifty atomic bombs. The conclusion is obvious–or is it? This is a form of implicit argumentation employing logic I do not understand. Despite its grandiloquent flavor, it is a form of obfuscation, a grand non sequitur. One may note with equal logic that the average automobile in the course of a year produces as much combustion products as five tons of TNT. If one wishes to dwell on overkill, the population of U.S. automobiles produces sufficient carbon monoxide each year to kill three billion people or, to carry the argument to its limit, there is enough water not only in the Atlantic Ocean out there, but even in Lake Erie to drown every man, woman and child in the world. Surely this form of reasoning, if that is what it is, only pollutes the public discourse.

Quite clearly the critical question is whether we can manage the fission products from nuclear reactors in such a manner as to avoid a significant risk to the public health and safety. If that cannot be done–and I believe it can be–it would be a determining mark against nuclear power even if there were no nuclear weapons to serve as a yardstick of fussion products. Similarly, the question about combustion products is not its equivalence in TNT, but how much can reasonably be dissipated in the atmosphere and how successful we might be in reducing the especially noxious combustion products. These turn out to be questions of measurement and of technology improvement rather than a question of misleading analogies.

Let me now attempt to relate nuclear generating facilities and the alternatives to the broader national energy picture–which will permit us to assess the overall health implications of energy usage.

The energy mix utilized by this nation, and to a lesser extent the entire world, is increasingly constrained by three powerful forces:

First, the growing demand for energy, limited as it may appear in logarithmic terms, results in staggering increases in the quantities of fuels utilized. In a finite world the environmental impact must be assessed on an arithmetic rather than a logarithmic basis.

Second, associated with this increasing demand, there exists a selective dwindling of resources by type of fuel and by region.

Third, increasingly rigorous environmental

standards, particularly in this country, sharply limit the ability to utilize certain classes of fuels some of which are abundant.

Within this set of constraints this nation must develop energy policies.

In the United States energy demand grows at about four percent per annum, approximately the rate of increase of the Gross National Product. Some three-fourths of the total is supplied by oil and gas. But total production from domestic sources of oil and gas has levelled out, so that further increases in supply must come from external sources. Under one set of assumptions, the United States might be importing some thirty-five percent of its energy resources by 1985–if it is willing to accept the inherent vulnerabilities and if the balance of payments will permit. We should also recognize the larger implications for the coastal zone with respect to oil spills, superports and refineries. In addition, as a result of supply stringencies, the price of liquid fuels has been moving upward rapidly.

By contrast coal continues to be our most abundant hydrocarbon resource. At current rates of consumption coal reserves represent several hundred years' supply at a minimum The use of coal, however, has increasingly been restricted by more stringent air quality standards, particularly those bearing on particulates and sulphur oxides. In addition, as you are aware, there are controversies over strip mining, the hazards of underground mining, and the like, which could have a major impact on the coal supply. This nation must, I believe, provide the necessary investments in research and development to make our most abundant hydrocarbon resource continually and widely usable. Otherwise, we are likely to face pressures to relax air quality standards, and I am sure the members of this Association would be reluctant to see that occur.

There is a wide gap between what is realistically available and what is environmentally most desirable. From an environmental standpoint there is no question, at least in my mind, that natural gas is the most attractive in terms of cleanliness, flexibility, and production costs. If only the United States were sitting on a vast pool of natural gas, our problems would be readily solvable. Nature, unfortunately, has not been that generous. Natural gas represents thirty-three percent of current domestic usage but only a few percent of domestic fossil fuel reserves. Increasingly we should devote the limited available supply to its highest and best use in the home, and diminish its relative use as boiler fuel for industrial purposes.

From an environmental standpoint, solar energy is indeed attractive. But at this point in time it provides only a partial alternative. Technology is already in hand to permit widespread use of solar energy for the heating and cooling of homes on an economically attractive basis. Because of low energy densities, however, and the consequent costs, it will be at least a generation before solar power could be employed for the generation of electricity.

Until about 1990 at the earliest, whatever energy the United States utilizes will have to come primarily from the existing technologies exploiting either fossil fuels or nuclear power.

The demand for electric power has increased at a rate more rapid than the demand for energy in general. The historical rate has exceeded seven percent, which implies a doubling of demand every decade. Over a period of time there exist possibilities for improved efficiency in production and transmission as well as for conservation. But the public must support these changes and at best they can only be introduced gradually because of the slow pace of technical development and the slow change in customs. Whatever the impact on the long-run rate of growth–and over time small adjustments of growth rates turn out to be significant–it is evident that this nation will acquire extensive new generating capacity, at least three hundred million kilowatts of capacity in the next decade.

Because of the relative fuel availabilities and the impact of air quality standards to which I have referred, as well as the comparative economics for power generation. I myself can see no alternative to a substantial fraction being nuclear. The atom may have lost its glamour, but nuclear power has now become a reality, sizable in its implications.

From what I said earlier about the attractiveness of natural gas, this reality may strike you as falling somewhat short of the ideal. How satisfactory are the implications? In a number of respects, quite so. As a first though small consideration, nuclear plants are aesthetically satisfying, or if you prefer less unaestetic than the readily available alternatives. Second, because of the high power density per pound of fuel, nuclear power curtails the need for the extensive mining operations which would otherwise

be required–with all that this implies for the environment and for health and safety. Third, the fact that nuclear power plants are now designed to contribute essentially no air pollution is a matter of considerable significance in light of national aspirations regarding overall air quality.

Let me dwell on this for a minute before turning to the implications for the radiation environment and its impact on health. One of our difficulties in evaluating environmental and health effects of energy production is the comparative abundance of experimental data on radiation as opposed to the comparative paucity of experimental data on the commonplace air pollutants. Radiation effects have been extensively studied since 1945. Major programs have been sponsored by the Commission, and the results are publicly available.

By contrast, we are only at the beginning of the experimental investigation of the health effects of the commonplace pollutants. Estimates that are made are based upon rather broad observation of consequences rather than on the basis of hard laboratory evidence. Because the evidence is limited and the conclusions imprecise, however, does not suggest that the health effects are small.

Under the attack of sulphur oxides in the atmosphere, one can observe the pitting and deterioration of the Lincoln Memorial. I am informed that the Parthenon actually fizzes like soda pop on the worst days in the new atmosphere of Athens, and that deterioration is accelerating. I would doubt that inhaling the ambient atmosphere in such circumstances can be beneficial to the human lung. On the San Bernandino Mountains near Los Angeles the conifers are dying under the impact of smog. The orange trees in the Los Angeles Basin produce less fruit and suffer a significant shortening of life. I would speculate that the effects on human beings are not likely to be particularly healthful.

Thus, while we have not as yet verified the results through laboratory experimentation, we are in a position to provide ranges of the probable impacts. In the aggregate the combination of sulphur oxides, nitrogen oxides, particulates, and carbon monoxide appear to have heavy, though as yet unmeasured, health effects. The toll of air pollution is undoubtedly substantial.

All forms of contamination of the environment are undesirable. No pollutant in large quantities can be regarded as beneficial. In producing whatever level of electric power the nation chooses, the health and environment effects must be examined systematically in order to minimize the unfavorable consequences. The true alternatives and the total consequences must be meticulously reviewed.

As I have indicated much more is known about the effects of radiation. Because of the difficulties of measurement, however, the effects of low level radiation must be assessed partially by interpolation. High levels of radiation induce a certain incidence of cancer over time. If we assume a linear relationship, as I believe we must, this would imply at very low levels of radiation would still be associated with some small increase in the incidence of cancer discernible against a large population background. The Implication is that the level of nuclear power facilities projected two decades from now is likely to be the source of some additional thousands of cancer cases.

For purposes of comparison, one recent study indicated that respiratory deaths from alternative power facilities would exceed cancer deaths from a nuclear plant by a factor of sixty.

Nonetheless, one clear implication is the need for stringent controls on radiation.

The Commission has adopted regulations that go under the rubric of *"as low as practicable."* Specifically this implies a limit of five millirem at the plant boundary. It also implies less than one millirem on average for the American population in around the year 2000. A dose of one millirem is to be compared with the natural background level of about 125 millirem per year.

By comparison to the radiation standard, the Federal air quality standards are set above, not below, natural background and are much loser to the level of medically perceivable effects.

The allowable dose levels for those employed in nuclear facilities are higher than for the general public. Over the years the AEC has attempted to ascertain the health impact of these higher dose levels on the health of employees in nuclear facilities. As yet, it has not been possible to discern any effect. The employees in such facilities as Hanford or Rocky Flats have tended to outlive and be in better health than their statistical counterparts in the general population. This can hardly be attributed to the

effects of radiation--so that the answer must lie in better pay, better health care and the like. This does underscore, however, the difficulty of getting a precise estimate of the impact of low levels of radiation on health.

Whether an increase for the general population of somewhat less than one percent above natural background is too high a price to pay for power generation is something that I leave to you to judge--hopefully in the light of the true alternatives. Radiation exposure should be strictly controlled, and this is a matter that extends far beyond plants associated with nuclear power production. The effects of ionizing radiation are hardly beneficial, irrespective of the source and irrespective of the position in the electromagnetic spectrum. In connection with ionizing radiation other sources are dramatically more significant than nuclear power plants. We should deal with all sources with equal firmness.

Most obvious are the medical uses of radiation in which the average American now receives 70 millirem a year or a dose beginning to approach that from the natural background. At this point in time the average American receives about one seven-thousandth of that dose from nuclear facilities. The medical uses of radiation and their health effects are, of course, matters that fall appropriately within the purview of this Association. To cite some other examples, a roundtrip jet aircraft flight to the West Coast results in about five millirem of additional radiation exposure. That is about the level that one would receive at a plant boundary or about five hundred times as much as the average American receives from power plants. Also, a nearsighted child who watches color television steadily, close to a badly constructed set, would receive a substantial dose. These are matters of some concern and should be the subject of continuing exploration.

In dealing with stringent control of ionizing radiation the Atomic Energy Commission has its assigned role to play and accumulated expertise to provide. Others must do their part. The subject should be examined across the board--and it may be an appropriate time to review the established international and national standards. I trust that many of you will participate in that review.

In concluding let me say that I have attempted to lay before you some of the facts, trade-offs, and perplexities as I understand them. There is a wide range of human activities for which the health implications must be subjected to through investigation. Prominent among these is the production of power and the usage of energy in general. We should address the inevitable problems forthrightly and objectively. We should keep in mind that there is no area of human activity not subject to risk. The search for purely riskless solutions will either immobilize us or lead us astray. In analyzing the true alternatives one must weigh comparative risks and risks against benefits, seeking to keep the totality of risk within reasonable boundaries.

The profoundest of all infidelities, as Herbert Spencer once said, is the fear that the truth will be bad. Irrespective of the ultimate direction in which it takes us, an objective and dispassionate vision of the future environment must be pursued.

Thank you for your invitation and for your attention.

CHAPTER 6

WASTES IN THE PRODUCTION OF ELECTRIC POWER

A. OBJECTIVES

1. The student will compare the current methods of managing waste heat produced in the generation of electricity.

2. The student will compare the magnitude of thermal pollution from both nuclear and fossil electrical power stations and state the reasons for the differences.

3. The student will describe the three basic principles of radioactive waste management.

4. The student will compare and evaluate the waste management methods for gaseous, liquid, and solid radioactive wastes, including the current and projected volumes and activities of these wastes.

5. The student will describe the wastes resulting from the burning of fossil fuels.

B. ACTIVITIES

1. To illustrate the process of elimination of radioisotopes by natural radioactive decay, experimentally determine the half life of a short-lived radioisotope such as indium-113m (104 minutes), barium-137m (2.6 minutes), or yttrium-90 (64 hours). These radioisotopes are available from minigenerators distributed by Union Carbide Company, Tuxedo, New York. To determine half life, have the students make a series of one-minute counts of a sample at intervals for a period of time covering several half lives. Be certain to determine background and subtract it from each count. On graph paper, plot a graph of activity versus time. Graphically determine the half life.

2. Use a wet-dry blub thermometer or sling psychrometer to illustrate evaporative cooling.

3. Devise an air filter using a vacuum cleaner and filter paper. Compare air samples for various areas of your city. Use a portion of a clean vacuum cleaner bag as your filter.

4. In order to determine air currents which will tend to disperse pollutants over your local area, release a number of helium-filled balloons with return postcards attached. The postcards should be self-addressed and contain a checklist of the information which you wish to receive, such as location, date, time, and name of finder. This will increase student understanding that others are affected by what anyone at any place does.

5. Determine water currents in lakes, rivers, or bays using plastic containers with postcards inside.

C. AUDIO-VISUAL MATERIALS

1. *"High Activity Waste,"* 16mm sound, 17 min. U.S.A.E.C. Film Library, Technical Information Center, P.O. Box 62, Oak Ridge, Tennessee, 37830.

2. *"Transportation of Radioactive Materials, Part II: Accidents,"* 16mm sound, 34 1/2 min., U.S.A.E.C.–see Number 1 above.

D. REFERENCES

1. From the Understanding the Atom series, a complete set of which may be obtained free by teachers by writing to U.S.A.E.C., P.O. Box 62, Oak Ridge, Tennessee, 37830.

   "Radioactive Wastes"

2. Nuclear Power and the Public, Harry Foreman, editor, University of Minnesota Press, Minneapolis, Minnesota (1970).

3. *"Plans for the Management of AEC-Generated Radioactive Wastes,"* WASH-1202(73). Division of Waste Management and Transportation, July 1973. For Sale by Superintendent of Documents, GPO, Price 80 cents.

BACKGROUND INFORMATION FOR THE TEACHER

FUELS MANAGEMENT IN AN ENVIRONMENTAL AGE

Environmental Science & Technology, January, 1971

Until the late 1960's, the selection of a fuel for any use was a matter of choosing one with the lowest overall costs, with little regard for its effects on the environment. The rising concern about the environment, however, has changed the traditional concept of what is desirable.

In selecting a fuel, the effects of production, processing, and utilization of each fuel on the land, water, and air must now be considered. This presents a complex situation, since all the principal energy sources–coal, oil, gas, nuclear, and hydro–have differing environmental effects. Moreover, the severity of the pollution trade-offs must be evaluated and decisions must be made as to which fuel is likely to have the least harmful environmental impact.

Two fuels management problems are particularly urgent. The first, automobile fuels, is undergoing rapid change, and little can be done in the short term to replace gasoline as a fuel. The second, generation of electricity, does have much substitutability from competing energy sources. Both pose unique management problems that must be solved if the nation is to benefit from low-cost energy that is produced and used in a manner that does not further degrade our environment.

Energy demand and resources

Energy demand is growing exponentially, and the established trends are expected to continue through 1980. Demand for oil and gas is expected to show the greatest increase in absolute terms; however, in relative terms, the increase in nuclear energy is the greatest. Projecting to the year 2000, many technological, economic, environmental, and political factors will influence the demand and supply for various energy sources. These factors have been studied by the Bureau of Mines, with the conclusion that demand for each of the most-used fuels–petroleum, natural gas, and coal–will at least double between 1968 and 2000. Uranium, however, will increase by a factor of about 15.

The cumulative requirements for these energy resources are enormous. However, the nation's resource base is adequate to supply the demand through 2000. But, if these demands are to be met, the nation's coal and oil shale resources will have to play an important role, whether they are used to generate electricity or are converted into gases or liquids and used in these more convenient, pollutant-free forms.

The nation's fossil fuel resources are not unlimited, and a maximum of producibility is expected to be reached early in the next century. Thus, after 2000, the nation's energy demand could set the stage for the emergence of unproved systems, such as nuclear fusion, and the widespread use of solar and geothermal energy.

Imported liquid fuels (crude and residual oils and products) now provide 23% of all liquid petroleum consumed in the U.S. Management of fuel resources to solve environmental problems depends upon policy decisions made with respect to future oil import programs, as well as public land leasing, tax treatment, and prorationing policies which, in turn, are intertwined with other factors of national interest such as military security and balance of payments.

The consumption of fuels must also be considered according to the use–household and commercial, industrial, transportation, or electricity generation. By comparing the expected fuel consumption in the year 2000 with use patterns for 1968 (see table), it can be seen that total gross energy imputs are expected to increase from 62 to 163 quadrillion Btu. Electricity generation will dominate in the future, increasing both absolutely, from 14.0 to 72.3 quadrillion Btu, and as a percent of total gross energy input, from 23 to 44%. Nuclear generation is expected to dominate the generation of electricity, increasing from 0.1 to 38 quadrillion Btu; but coal used for this purpose will increase more than threefold, from 7 to 24 quadrillion Btu.

Consumption patterns of different fuels up to about 1968 are a good indication of the amounts and types of fuels that would be used if environmental problems could be largely ignored. Environmental considerations, however, have begun to alter these supply patterns sharply. For example, sulfur dioxide emission standards in 1969 caused a shift from coal to residual fuel oil at east coast electricity generating plants. By early 1970, the initial

penetration of residual oil into the Chicago market had been approved.

The production, processing, and utilization of fuels cause the most environmental problems for the nation. Let us then look at the most significant of these pollution problems, and the impact on land, water, and air.

Land Use

About 3.6 million tons of solid wastes are generated each year in the U.S. agricultural wastes constitute nearly two-thirds of the total, and mineral wastes account for most of the rest. Mineral wastes, not including the large amounts of overburden removed in surface mining but including those wastes generated by mining, processing, and utilization of all minerals and fossil fuels, amount to about 30% of the total wastes. But fuels account for only 125 million tons, or about 3% of all solid wastes generated.

The last complete survey of mining operations in the U.S. indicated that, in 1965, about 3.2 million acres of land had been distrubed by surface mining. Of this total, about 41% resulted from activities associated with coal production.

As yet, only a few tenths of 1% of the total land area of the U.S. has been disturbed by surface mining. Effects of such mining upon the environment, however, vary widely and depend upon such factors as the type of mining, characteristics of overburden, steepness of the terrain, amount of precipitation, and temperature. Where land reclamation is not practiced, water pollution from acid mine drainage and silt damage occur. It is possible, however, to prevent much of this damage through proper land reclamation, adequate drainage, and planting to achieve soil stabilization. In the principal coal mining areas, the average costs of completely reclaiming coal lands range from $169 to $362 per acre, an average cost of 4 to 8 cents per ton.

Underground coal mining can cause subsidence unless the mining systems are designed to prevent deterioration and failure of abandoned mine pillars. Underground fires may weaken or destroy coal pillars that support the surface, causing subsidence with consequent damage to surface structures. An additional threat is the possible collapse of buildings and openings of surface fissures and potholes.

Fuel processing also contributes large quantities of wastes during the washing of coal to improve its quality. Over 62% of all coal mined is washed, producing 90 million tons of waste annually. If not returned to the mine, the water accumulates in piles near the plant and mine. At times, these piles ignite and burn for long periods, thus creating air pollution. Rainwater leaches salts and acid from the piles to contaminate nearby streams.

Utilization of coal also produces solid waste in the form of ash and slag. About 30 million tons of these materials are collected each year; an estimated 8 million tons are discharged into the atmosphere.

Uranium mined by either open pit or underground methods creates similar land effects. Mining in quantity is a relatively new industry, the volumes and tonnages involved are only 1% of those for coal, and the adverse effects are much smaller. Estimates of the solid wastes from the mining of ore and the subsequent extraction of the desired uranium product are 38 million tons annually.

Solid wastes resulting from nuclear generation of electricity involve only small tonnages of materials, but have a very great potential for environmental damage for long periods because of their radioactivity. As nuclear plants become more numerous, the magnitude of this problem will grow.

Transportation of oil and gas, which is largely by underground pipelines, does not normally produce land problems. However, the special case of transporting oil from Alaska by pipeline raises numerous and, as yet, unresolved land-use problems.

Water problems

Two distinct water problems are of growing concern in fuels management – water quality and water temperature. Questions of quality relate to individual energy sources: thermal problems, however, are common to use of all fuel commodities.

Poor water quality, whether it be through chemical pollution or sedimentation, is a major damage resulting from both surface and underground mining. Available data make no distribution between the two, but it has been estimated that approximately 48% of mine water pollution, primarily sediment, results from surface mining. In the U.S., some 5,800 miles of streams and 29,000 surface acres of impoundments and reservoirs are seriously affected

MOST ENERGY SOURCES HAVE SIGNIFICANT ENVIRONMENTAL IMPACTS

	Impacts on Land Resource			Impacts on Water Resource			Impacts on Air Resource		
Energy Sources	Production	Processing	Utilization	Production	Processing	Utilization	Production	Processing	Utilization
Coal	Disturbed Land	Solid Wastes	Ash, slag Disposal	Acid Mine Drainage		Increased Water Temperatures			Sulfur oxides Nitrogen oxides Particulate Matter
Uranium	Disturbed Land		Disposal of radioactive material		Disposal of radioactive material	Increased Water Temperatures			
Oil				Oil spills, transfer, brines		Increased Water Temperature			Carbon monoxide Nitrogen oxides Hydrocarbons
Natural Gas						Increased Water Temperatures			
Hydro									

by such operations. Acid drainage from underground mines is more difficult to control than that from surface mines, but preventing water from entering the mine and the rapid removeal of water which does get into the mine are effectivy methods for reducing pollution. The effects of acid mine drainage can be reduced by decreasing the amount of acid produced at the source, or by neutralization of the mine water befory it is discharged to the streams. The latter technique, though highly effective, is more costly. Erosion and sedimentation from surface mining are serious problems in many areas, but they can be prevented by controlling the surface runoff that follows rainstorms.

In processing uranium ores, some of the poetenitally hazardous radioactive elements or isotopes, particulary Ra-226 and Th-230, are partly dissolved during the leaching operation used to recover uranium oxide. While most processing plants are located in very isolated areas, steps are taken to avoid pollution of water supplies by radioactive constituents of liquid effluents.

Disposal of the effluent is accomplished principally by impoundment and evaporation, controlled seepage into the ground, and injection through deep wells into saline or nonpotable aquifers. Where ore processing plants are adjacent to rivers or streams, the effluents may be released directly to the streams at controlled rates if, after dilution, the concentration is within predetermined limits. During periods of low stream flow, effluents are impounded or may be chemically treated before release.

Onshore oil production, except for accidental occurrences, does not present any difficult pollution problem. Nevertheless, nearly three barrels of brine must be disposed of for every barrel of oil produced. Accidental pollution may occur from blowouts of wells, dumping of oil-based drilling muds, or losses of oil in production, storage, or transportation. At sea, the blowout at Santa Barbara, the oil slicks and the fires and oil spills in the Gulf of Mexico in recent months have demonstrated that these dangers are more than academic in offshore operations. Methods must be found for their prevention and control. Spills and discharges from tankers are also important. However, the greatest, if less dramatic, problem is the contamination of inland waterways and harbors resulting from transfer of oil between or from vessels.

Thermal pollution

By far the most important water problem resulting from fuel use is thermal pollution. Over 80% of all thermal pollution arises from the generation of electricity. The amount of heat rejected to cooling water represents 45% of the heating value of the fuel used in the most efficient fossil fuel plants, and 55% in nuclear plants. If projected use of electricity is accurate and if nuclear energy, as expected, supplies nearly 50% of the electricity demand, more than 10 times as much heat will be rejected to turbine cooling water in 2000 as is being rejected now. Even with greatly increased use of brines or seawater for cooling, the demands for fresh cooling water will be larger than its supply.

This suggests that the solution is not in treating the heat as a *"waste"* product. Rather, the heat must be viewed as a resource that can be used. Evolution of such concepts must not be constrained by current uses, for huge amounts of heat may be used in systems not considered practical or feasible at this time. For example, the heating and cooling of whole cities whose environment is controlled by a protective membrane is one possibility.

Air pollution

Nearly 80% of all air pollution in the U.S. is caused by fuel combustion. About 95% of all sulfur oxides, 85% of all nitrogen oxides, and over half of the carbon monoxide, hydrocarbons, and particulate matter are produced by fuel use. Management of fuels, therefore, is critical for the minimization of the nation's air pollution problems.

The most competitive market for fuels is the generation of electricity. Not only do the fossil fuels compete with each other, but they also compete with hydropower and, more recently, with nuclear energy. Obviously, from an air pollution standpoint, hydropower is the perfect method of electricity generation. During the generation of electricity from fossil fuels, production of oxides of nitrogen or carbon monoxide is not greatly different for any of the fossil fuels used. The production of electricity using natural gas produces no sulfur oxide emissions, but the use of coal and residual oil in electric generating plants is the source of 74% of all the oxides of sulfur emitted into the air.

About seven times as much coal as oil is used in electricity generating plants. For this reason, and because of its relatively high sulfur content, coal accounts for nearly two-thirds of the sulfur oxides emitted to the atmosphere. In addition, nearly one-third of the particulate matter emitted into the atmosphere is from burning coal for generation of electricity.

About one-half of the coal consumed by industry is used to make coke. Part of the sulfur appears in thy coke oven gas and, if this is used as a fuel, it eventually appears as sulfur remains in the coke and is released as hydrogen sulfide in the blast furnace gas. When the gas is used as a fuel or flared, the sulfur appears as sulfur dioxide.

Local air pollution problems in the vicinity of plants that make coke are severe. Alternatives to the use of coke for the production of pig iron are available, and these processes might reduce the amount of air pollutants released to the air. Uncontrolled surface and underground coal fires emit smoke, fumes, and noxious gases.

About 17% of all the oil consumed in this country is used by industry. Much of it is residual oil, which in most cases is high in sulfur. Moreover, residual oil is difficult to burn efficiently and is usually burned in large equipment at high temperatures. Because of these two factors, industrial use of oil tends to contribute larger amounts of carbon monoxide, hydrocarbons, and oxides of nitrogen than the household and commercial sector, which consume about 25% of the fuel oil.

The largest use of oil is for gasoline to power the nation's 100 million vehicles. About 42% of each barrel of oil is used in this manner. If we include diesel and jet fuels, about 54% of each barrel of oil is used for transportation.

The use of fuels in transportation causes approximately one-half of all the air pollution in the U.S. There are alternatives to the use of gasoline for automobiles and trucks, such as natural gas and liquefied petroleum gases. But it is doubtful that the massive changeover that would be requied by two of the country's largest industries would occur if other solutions could be found to reduce air pollution generated by the transportation sector. Moreover, if a switch to electric cars were made, the total pollution load might actually be increased, although controls would be needed on a relatively few electric power plants, rather than on millions of autos and trucks.

Management problems

Ideally, the management of fuels to satisfy environmental requirements should be guided by a system model that relates energy needs to damage, emissions, and fuel availability. Included in the model would be an assessment of the relative damage among dissimilar pollutants, for example, esthetics of land vs. air pollution, as well as comparisons between a small, constant hazard (nitrogen oxide) vs. a large, infrequent hazard (nuclear). Detailed knowledge of what happens to specific pollutants both geographically and over time would also be included in the model. In addition, economics, supply availability, and the broader question of national security would all need to be examined.

No such model now exists. However, many factors can be approximated so that a number of problems associated with fuel use can be examined. Two such problem areas are the automobile and the generation of electricty.

Autos and air pollution

Much that is written and said about automotive pollution indicates that very little is really being done to change the pollution characteristics of internal-combustion engines. It is alleged that, in fact, little can be done. Such negative views are unwarranted, since both engines and fuels offer opportunity for modification to reduce markedly the pollution from internal-combustion engines in all applications. Nevertheless, in the long run, other supplementary methods of transporting people may be needed. All of the alternatives proposed to eliminate automobile-caused air pollution have great implications for fuels and materials management.

Some reduction in pollution from the automobile has resulted from federal standards already enacted through 1971. These standards will result in a continuous improvement in air quality through the 1970's as the controlled vehicles comprise an increasingly larger portion of the car population. Unless further progress is made to clean up exhaust emissions, however, an upturn in emission output is expected near the end of the 1970's as the increasing number of vehicles in use begins to overcome the effects of the standards. Technology is available for continued progress, but lead times of two years or more are required to manufacture and distribute modified fuels and (or) engines. Thus, continued progress will depend upon the decisions made between 1970 and 1975.

The impact of change in fuels and engine design will be far reaching and long lasting. Trends now developing and those established within the next few years will be, in practice, largely irreversible within

the next decade. In terms of today's dollar, costs will be higher for each mile driven, and some of the broad options that are now available for fuels manufacture and for designing high-performance engine and fuel system will be lost.

The types and effectiveness of control methods depend upon the composition of the automobile population in the 1970's. Early in this decade, pre-1968 cars will represent 50% of the automobile population. Even in the last half of the decade, pre-1968 cars will still be a significant part of the population. These vehicles are important, since they generally do not have exhaust-emission controls.

There are options available to reduce pollution from the various automobile populations. Relatively simple engine and fuel-system modifications have been or will be made in 1968-74 model vehicles to meet emission standards. But the major impact of these changes will not be seen until the mid-1970's. Extensive engine redesign and exhaust treatment is expected for the 1975-79 cars. This possibility is widely discussed in the popular press, but the maximum effectiveness of such technology as catalytic conversion of exhaust gases will not be until 1980 or later--a decade away. Gasoline-composition modification is applicable to all cars on the road today, and its effect would be immediate. Field tests of this control method have met with disappointing public response and, in the absence of compulsory legislation, engine returning will probably not result in a significant reduction of polluted air.

Changes in the composition of gasoline which limit volatility during the summer months and eliminate C_4 and C_5 olefins would reduce smog by 25% or more, according to recent research by the Bureau of Mines. This is the most rapid solution toward improving air quality, because such modifications can be accomplished quickly and are applicable to all cars now in use, without requiring any changes in the cars themselves. However, the olefins to be replaced have high octane ratings and their removal would make it more difficult to maintain the octane levels of fuels without using lead. Thus, this control method must be carefully coordinated with lead removal if undue losses in engine performance are to be avoided. It has been estimated that the modifications to gasoline can be achieved without significant changes in the product mix from refineries and at a cost to the consumer of less than 1 cent per gallon of gasoline. No estimates are yet available on the cost of accomplishing the same thing with lowlead and unleaded fuels, but the cost should not be significantly higher provided all fuel composition changes are carefully coordinated.

The lead-in-gasoline issue evokes a strange mixture of emotion, politics, and fact. Lead does contribute to the contamination of our environment--nearly 170,000 tons are released annually. It also forms deposits that foul engines and emission-control systems, unless controlled by additivies, leading to increased emissions. Of particular importance, it presents difficult problems in developing exhaust-treatment catalysts. For effective use of these advanced control systems, the lead content of gasoline should be near zero.

Any move to modify fuels must be guided by the types of vehicles already in use. Many of these vehicles may have marginal acceptable performance using a low-octane, unleaded gasoline. High-octane unleaded fuels that contain large amounts of aromatics blended into the gasoline could increase the smog-forming potential of the exhaust gases up to as much as 25%, depending on the octane level to be achieved. The cost of manufacturing unleaded gasolines with acceptable octane levels would be reflected in gasoline price increases of 1 to 4 cents per gallon.

The lead issue demonstrates the difficult fuels management problem that has arisen as the result of environmental awareness. For example, if engine compression ratios are lowered to accommodate lower octane unleaded gasoline, the efficiency of the engine may drop and gasoline consumption increase. This would significantly reduce our already declining petroleum reserves. The manufacture of high-octane unleaded gasoline could set up severe competition for the stocks normally used as raw materials for the petrochemical industry. Significantly greater amounts of new oil may be required, and the needed fractions would be stripped from this oil. In this case, large volumes of oil products without aromatics would need to find a market.

A sweeping change-over to unleaded gasoline would be a massive technical and economic undertaking, the results of which have not yet been adequately delineated. For these reasons, the gradual transition to unleaded gasoline must be encouraged, the timing to depend on the distribution of the existing car population and on the types of vehicle yet to be manufactured.

Materials management will also become vastly more complex in the 1970's New metal alloys are being developed for use in thermal reactors. A new horizon is opening in the catalytic field--both in refining of modified gasoline and in materials for catalytic conversion systems. And, as lead may be removed, a significant jump in the use of additives to maintain engine cleanliness is expected. All of these will have significant impacts on the current use of raw materials.

Natural gas (methane) and propane have had wide publicity as substitutes for gasoline. Although these fuels have chemical characteristics that permit cleaner exhausts, the crisis over natural gas supplies, problems of distribution, and the added complexities of the fuel system probably preclude general use by the motoring public. Use of these fuels in urban-operated fleets, however, is feasible and will probably increase in the future. Moreover, synthetic gas from coal or oil shale could be an added source for the needed fuel.

All of the alternatives proposed as substitutes for the internal-combustion engine must meet three key tests. Will there be a significant change in pollution? If so, at what cost? Is near-comparable performance obtained? Ultimately, it may be cheaper to meet air-quality standards by a totally different approach that involves engine systems yet to be developed. Present analyses of all competing systems indicate that, into the 1980's the best combination of costs, utility, and potential for reduced pollution output is the current gasoline-powered automobile.

The need for further reductions in total pollution output, however, may force a move to limit the size of both the vehicle and the engine. The increasingly severe problem of urban traffic congestion will result in increasing efforts to develop mass transportation systems. These pressures may cause a significant reduction in the demand for gasoline. This, when combined with adoption of proven technology that will enable a 95% reduction in all automobile pollutants, indicates that air pollution caused by automobiles can and will be solved. However, the accomplishment of this task will present a challenge of fuels and materials management unexcelled in a peace-time economy.

Sulfur and electricity

The immediate and pressing question concerning fossil fuels for generation of electricity relates to their sulfur content. Of the coals shipped to electric utility plants in the U.S. in 1964, 21% had a sulfur content above 3%, 60% had between 1.1 and 3.0% S, and only 19% had less than 1% S. Regulations being established for sulfur in fuels are based on sulfur dioxide believed allowable in the air. Each community translates its requirements into a certain maximum sulfur content of the fuel. For a number of communities, a 1% sulfur maximum has been established. Obviously, much of the coal being mined and that in the ground cannot meet this requirement. Moreover, some regulations already scheduled call for a fuel having an effective sulfur content not exceeding 0.3%. Such coal is not available, and only exceptional supplies of petroleum residuum meet this requirement.

The options for solving the sulfur problem are:

- Fuel substitution.
- Fuel preparation (coal).
- Stack gas removal of sulfur oxide.
- Coal and oil shale conversion low-sulfur fuels.
- New combustion methods.

Substitution of naturally occurring low-sulfur fuel (gas for coal) is not practical in the immediate future since adequate supplies are not available in the U.S. Two promising options for the next several years are removal of sulfur before combustion and removal from the process gases after combustion. Conversion of coal to other low-sulfur fuels and new combustion processes are long-range options.

Fuel preparation

Improvement in coal preparation involves the removal of iron pyrite from coal. Often, the pyrite content accounts for a half of the sulfur in the coal. However, even with improved pyrite removal, it is evident that the degree of sulfur removal necessary to meet anticipated regulations cannot be achieved by this means alone.

Lignitic coal, mostly located in the West, represents a vast national resource, and it typically has a sulfur content of about 0.6%. (The effective sulfur content is a little higher than this, since lignite contains about 7,000 Btu/lb, compared with about 12,500 Btu/lb for bituminous coal.) Moreover, lignite is an inexpensive fuel, priced at only about $1.50 per ton, which is equivalent to about 10 cents per million Btu. Lignitic coals should be helpful in certain areas, but obviously do not solve situations where

regulations call for 0.3% S. Moreover, lignite deposits are generally far removed from population centers, and shipping costs can be excessive. One possibility is the generation of electricity in huge plants in the West, coupled with a system of long-range, low-cost electrical transmission through a cable cooled to very low temperature.

Stack gas removal

The once-through process for removing sulfur oxides from combustion gases, typified by wet carbonate scrubbing (Combustion Engineering), and being installed in three plants, ranges from 125 to 450 MW. It offers the advantage of relatively low capital investment in plant equipment (perhaps $6 to $13 per kW) and low operating cost ($1.50 per ton of coal). However, it does pose problems in disposal of calcium sulfate (or magnesium sulfate) product–indeed, there is the uneasy fear that an air pollution problem may transform into a land or water pollution problem. It seems likely that with pressure for meeting new regulations, systems such as wet limestone scrubbing will be adopted to some extent in the short-term future.

Regenerative processes for stack gas sulfur removal are expensive to install and to operate. Investments might run from $17 per kW to more than $30 per kW, and operating costs would be in the $3 to $5 per ton of coal range. Such systems involve a solid or liquid which chemically reacts with and removes sulfur oxides. The sorbent is regenerated, in a separate step, usually with the production of sulfur. Included in the *"regenerative absorbent"* group are potassium bisulfite (Welman-Lord), magnesia (Chemico), caustic plus electrolytic regeneration (Stone and Webster/Ionic), molten carbonate (North American Rockwell), potassium formate (Consolidation Coal), copper on silica (Houdry), alkalized alumina (Bureau of Mines), and others. Recently, it was announced that a regenerative-type plant, based on magnesia sorbent and costing $5 million, would be installed in the Boston area.

The conversion-type process is typified by the Monsanto Cat-Ox process. Although well defined, it is relatively costly to install and produces sulfuric acid that may not be desired. Bureau of Mines estimates an investment cost of more than $30 per kW for such a process, and an operating cost of about $4 per ton of coal.

New combustion methods, such as fluidized-bed combustion, offer opportunity for some improvement, if not prevention, of air pollution. However, conversion of a high-sulfur to a low-sulfur fuel appears to present the fundamentally best opportunity for a long-term solution.

Synthetic fuels

From a supply standpoint, natural gas–essentially methane–is now in the most critical stage of all fossil fuels. For the second consecutive year, recoverable reserves have declined–that is, more gas was used than discovered. Yet the use of gas is the most rapidly growing of all the fossil fuels (about 7% annually) compared with a growth rate for energy as a whole of about 3%.

Looking ahead to 1985, projected rates of development will not fulfill the projected need for natural gas, even including importation of gas by pipeline from Canada and Alaska, or by cryogenic tanker from overseas. Anticipating this situation, and in the search for new markets for coal, a vigorous research and development program has been in progress for a number of years to provide processes for conversion of coal to gas. Several processes are currently in advanced stages of development.

Pilot plants are under construction for the Hy-Gas (Institute of Gas Technology) and the CO_2 acceptor processes (Consolidation Coal Co.) under the sponsorship of the Office of Coal Research of the Department of Interior. Scale-up of the Bureau of Mines steam-oxygen, fluidized-bed coal gasification process has also been initiated.

In the Bureau of Mines process, coal is reacted with steam and oxygen in a fluidized bed at about 600 to 1,000 psi, to produce a mixture of CH_4, H_2, CO, H_2S, and CO_2. After the CO_2 and H_2S are removed, the CO and H_2 are reacted to form additional methane. For a 250-million ft^3/day plant, the capital requirement has been estimated to be $160 to $180 million, the manufacturing cost 43 cents/ft^3 and selling price 54 cents/1,000 ft^3 using utility company-type financing. It now appears that if the price of gas increases enough, or if adequate technologic-economic improvement in coal gasification can be made, synthetic gas from coal may soon become a commercial reality.

The price of synthetic pipeline gas noted above is too high to be used by electrical utilities. However, there is a very interesting related possibility–the production of low-Btu gas from coal using air instead of oxygen, followed by sulfur and ash removal, and

generation of electricity by gas turbines. In this case, a high-temperature sulfur removal process is needed, in cooling the gas and heating it up again.

Underground gasification of coal and gasification of oil shale offer additional possibilities for gas supply if new technical advances can be achieved. It should be emphasized that all processes contemplated for manufacture of synthetic gases or liquids from coal result in a low-sulfur product.

It is possible to convert coal to liquid fuels, including high-quality gasoline. Moreover, the cost of doing so is approaching the cost of refining gasoline from petroleum. Therefore, probably within the next 15 years, it will be both necessary and economically feasible to make gasoline synthetically.

Another very important possibility which has not yet received emphasis is the conversion of coal to a low-sulfur, low-cost utility fuel. In such a process, coal is contacted with hydrogen and solvent with or without an added catalyst, thus transforming the coal into a new fuel product low in sulfur and ash. It is not important to upgrade the product by removing asphaltenes as in the case of gasoline production. By operation at relatively low pressure and relatively mild temperature, a minimum of hydrogen is used, so that a low-cost fuel can be manufactured.

Petroleum desulfurization

With new regulations and increased demand, it has become necessary to desulfurize petroleum to achieve a more adequate supply. Fortunately, the petroleum industry has developed effective hydrodesulfurization processes. Of a total of about 14 million barrels of oil produced per day, about 4 million are being desulfurized in the U.S. At present, most desulfurized oils consist of lighter petroleum fractions. Significantly, processes for desulfurizing residua are now coming on stream in different parts of the world. The cost of desulfurization ranges from about 20 to 80 cents a barrel. As an example, for a high-sulfur (2.6%) residuum costing 32 cents per million Btu ($2.00 a barrel), it would cost 4 cents per million Btu for each 0.5% by which the sulfur content were reduced. Desulfurization to 0.5% would thus add 16 cents, bringing the cost to 48 cents per million Btu, a 50% increase over the undesulfurized oil. Costs rise sharply, however, below about 0.5% sulfur.

The natural sulfur content of oil varies greatly. For example, residuum from Algeria is low in sulfur, about 0.5%, whereas that from Venezuela is relatively high, about 3%. No large supply of domestic low-sulfur residuum is available. The importation of a high proportion of utility fuel from abroad poses a problem from the viewpoint of national security since the east coast now imports nearly 94% of its requirements. Part of the current shortage in available residuum is due to the increased initial costs and increased tanker rates.

During the past few years, the substitution of low-sulfur petroleum residuum from abroad for high-sulfur domestic coal has been widely adopted on the east coast, where there is no oil import quota on fuel oil. Moreover, governmental approval recently provided for one plant to use imported residuum in the Chicago area. In this instance, the oil, containing 1% sulfur, will replace coal, at a reported cost of 46 cents per million Btu at that location as compared to about 30 cents for coal. This illustrates forcefully that pollution control is expensive.

New technology

Finally, we should not overlook new energy conversion devices which can become important if certain technological breakthroughs are achieved. Specific cases are fuel cells and magnetohydrodynamics. The former would permit the widespread use of gas for the transmission of energy, followed by generation of electricity, in the home or community.

Management of fuels also should take into account one human habit sometimes not recognized in the fuels system–that is, the production of so-called urban and agricultural refuse. Much of this is about half paper. In the U.S., 7 lb. of urban refuse is collected per person per day, and nearly 10 times that amount of agricultural wastes is produced. In the past, urban refuse has been used as landfill or incinerated, causing significant air pollution. Now it is possible to recover energy by controlled incineration, by pyrolysis to make gas and oil, or by hydrogenation to produce a low-sulfur oil. Recent experiments by the Bureau of Mines have shown that heating a ton of garbage to 380°C for 20 minutes in the presence of carbon monoxide and water under high pressure produced over two barrels of low-sulfur oil per dry ton of garbage. Perhaps some such novel means will be necessary for conversion of cellulose, grown by solar energy and discarded by man, into a fuel that can be utilized with less pollution.

THERMAL DISCHARGES: ECOLOGICAL EFFECTS

Environmental Science and Technology, March, 1972.

During the past several years, public interest in environmental quality as it relates to central-station power generation has intensified. The continued dominant role of thermal power plants to meet expanding electrical demands has focused attention on the effects of power plant-heated effluents on aquatic life.

Thus, one of the most important questions being asked today is, *"What are the environmental effects resulting from waste heat additions to rivers, lakes, estuaries, and oceans?"* Possible thermal effects are of concern to sports and commercial fishermen who want game and commercial species of fish available for their enjoyment and livelihood; conservationists who want the ecosystem preserved in its *"natural"* state; government regulatory agencies that set water temperature criteria and standards; and various users of water for cooling purposes who must discharge heated water within certain criteria and standards.

Water Use

Estimated projections indicate that future electric power requirements in the U.S. are expected to double approximately every 10 years. Even though hydroelectric power generation is expected to increase, steam-electric power (including both fossil- and nuclear-fueled plants) is expected to supply over 90% of the requirements in 2020. By the year 2000, nuclear power will supply over 50% of the energy produced.

Of utmost importance to the steam-electric power industry is available water for condenser cooling. Estimated water use and projected requirements, by purpose, for the U.S. was forecasted in the 1968 report of the Water Resources Council. In 1965, the steam-electric power industry used approximately 33% of the total water withdrawals. In 1980, the electric power industry will use about 44% of the total water withdrawals, and the forecast for water withdrawal for the year 2020 will be 67% of the total. Projected consumptive use (nonreusable) of the total water withdrawal is about 25%, while projected consumptive use for water withdrawal for steam-electric power is only slightly greater than 1%.

Waste heat rejected to cooling water will be a function of the thermal efficiency of the particular steam-electric plant. With the steam temperatures currently in use in large fossil-fueled plants, the maximum theoretical thermal efficiency is slightly above 60%. The thermal efficiency of the best operating fossil-fueled plants is presently about 40%.

Because of a lower thermal efficiency for nuclear plants (about 33%) cooling water requirements are presently greater than for fossil-fueled plants of the same electrical generation capacity. Approximately 10% of the gross waste heat is dissipated directly to the atmosphere through the stack in the fossil-fueled plant, while none is dissipated in this manner for the nuclear-fueled plant. Thus, about 50% more waste heat is rejected to the condenser cooling water from the nuclear plant.

Any method of reducing waste heat discharged into aquatic ecosystems would be useful where a temperature rise in receiving waters is unacceptable. Several options can reduce waste heat discharged from steam-electric plants into the aquatic ecosystem. Although thermal efficiencies from fossil-fueled steam plants have reached a plateau, molten salt breeder reactors and high-temperature gas reactors should increase thermal efficiencies for nuclear plants almost to 45%. However, these improvements will probably not be available for at least a decade. Since a dramatic increase in thermal efficiency for steam-electric plant is not forecast for the immediate future, recycling or retaining condenser cooling water may be necessary to reduce waste heat effects on aquatic ecosystems.

By utilizing projections of both fossil- and nuclear-fueled electrical generation capacity, data on thermal efficiencies of steam-electric plants, and water withdrawal forecasts, the quantity of waste heat that will be dissipated into the condenser cooling waters of steam-electric plants can be determined. The total quantity of waste heat discharged to condenser cooling waters by the electric utility industry will more than double from the year 1967 to the year 1980. The contribution of heated effluents from nuclear-fueled power plants in this time period increases from 1% to 45%, while contribution of heated effluents from fossil-fueled power plants decreases from 99% to 55%.

These waste heat values should be placed in proper perspective. For example, the total quantity of water used for steam-electric power for 1980 (assuming once-through cooling water) is estimated to be 193 million gallons per day, while the estimated annual heat rejection for steam-cycle systems for the

same year is 11,700 trillion Btu's. This quantity of heat, assuming a once-through cooling cycle, will raise the temperature of the cooling water approximately 20°F. Temperature increase in the condenser cooling water for condensers installed in the past ranges between 10° and 30°F. Thus, the estimated 20°F rise in once-through condenser cooling water seems to be a reasonable estimate although this will vary according to each specific site location.

Most studies directly concerning the effects of heated effluents on aquatic biota at the site of electrical power generating stations are relatively recent, and few results have been published to date. Most field investigations are presently in progress.

Continuing studies of the ecological effects of thermal discharges have been conducted at the Hanford Nuclear Complex on the Columbia River (Wash.). These studies conducted over the last 25 years were mainly oriented toward the salmonid fishes because of their high value to the Columbia River commercial and sports fisheries. Although the temperature of the undiluted reactor effluent would be lethal to the fish, waste heat discharged by the Hanford reactors to the Columbia adds only a relatively small heat increment to the widely variable seasonal river temperature (less than 40°F to greater than 65°F). Also, because of the hydraulic characteristics at the outfall and the swimming behavior of the fish, many seaward migrant salmonids may be swept to cooler waters and not actually experience the direct effluent plume.

Laboratory and field studies concerning biological effects of Hanford waste heat on salmonids shows no demonstrable evidence of damage to the salmonid resources. There simply has not been any evidence to indicate kills or unreasonable risks despite a long history of heated discharges from the Hanford reactors. However, direct extrapolation of Hanford's results to another site, even in the Columbia River system, must be made only with due consideration for the uniqueness of each ecosystem as the snow-fed Columbia River is a large, cool river and not typical of many U.S. river systems.

The Chalk Point fossil-fueled steam generating plant on the Patuxent River (Md.) has been studied since 1963. Two 335-MW units use estuary water for condenser cooling with a once-through cooling system. The condenser cooling water temperature increase is designed to be 23°F under winter operating conditions and 11.5°F during summer conditions. While no major deterimental effects of thermal additions have been noted, changes have occurred in various populations which may be attributed to heated cooling water discharges. Eqifaunal populations in the intake and effluent canals of the Chalk Point plant provide a number interesting results. Among them was: .A higher rate of production was found in the effluent canal than in the intake canal during all months studied - average production in the effluent canal was nearly three times as great as production in the intake . an increase in the maxiumum size of the barnacle, *Balanus*, was noted in the intake and effluent canals over those in the Patuxent River itself. During July and August, the warmest months, there was a decline in the number of species in the effluent canal and the anemone, *Sagartia*, and, the tunicate, *Molgula*, were not noted in the effluent canal, although both were in abundance just outside the effluent canal.

The power plant has not added enough heat to the Patuxent River to exceed the thermal tolerance of the zooplankton species studied. On the other hand, phytoplankton destruction and productivity suppression have been reported in the cooling water supply of the Chalk Point plant, although chlorination may be partly responsible for the mortality. Also, oysters in the Patuxent River have high copper levels. The rate of copper uptake in the oysters could have been enhanced by the water temperature increase, or concentrations in the water may have increased due to operation of the Chalk Point plant. However, no major effects on growth, condition, or gonad development were shown by oysters on natural bars near the plant.

At the Contra Costa Power Plant (1298 MW) on the San Joaquin River, (Calif.), studies showed that passing young salmon and striped bassthrough cooling condensers was far less hazardous than screening them at the intake. At the same plant, young salmon could tolerate an instantaneous temperature increase to 25°F for 10 min with no mortality.

At the Morro Bay Power Plant (1030 MW) (Calif.) on the Pacific Ocean, healthy populations of the pismo clam, *Tivela stultorum*, have been maintained over the full 13 years that the plant has been in operation.

The Humboldt Bay Nuclear Plant (172 MW) in California is the first nuclear plant in the U.S. utilizing estuarine waters for cooling and is located

on the Pacific Ocean about five miles from an important shellfish area. Studies at Humboldt Bay showed that the elevated temperature regime of the discharge canal was favorable for the natural setting of native oysters (*Ostrea lurida*), cockles (*Cardium corbis*), littleneck clams (*Protothaca staminae*), butter clams (*Saxidomus giganteus*), gaper clams (*Tresus nuttalli*), and a half dozen other bivalves (even though some passed through the plant's condenser system).

The effects of heated discharges from the Connecticut Yankee Nuclear Plant into the Connecticut River (Conn.) are examples of a well-documented study started in 1965, about 2 1/2 years before the plant began operation. The plant was designed to produce 562 MW with a temperature rise of 20°F in the condenser cooling water. The major thermal study areas were fish studies; benthic organisms studies; bacteriology, micro-biology, and algae studies; hydrology studies; and temperature distribution predictions and measurements.

The Connecticut Yankee Plant has now been in operation for about four years. No drastic changes have been observed to date in the overall ecology of the Connecticut River as a direct result of the addition of thermal effluents.

However, a statement in the summary of all the environmental studies that were done at Connecticut Yankee, emphasizes that as yet no information is available on the possible sublethal effects of the thermal discharge. Although no fish kills have occurred since the plant operation began, the white and brown bullhead catfishes undergo a marked weight loss (average of 20%) in the warm water of the effluent canal despite a constant availability of food in the canal.

Studies are being conducted at Turkey Point in Biscayne Bay, Fla., where two fossil-fueled units of 432 MW each are in operation, and two nuclear plants of 721 MW each are scheduled to begin operation. Heated effluents from the plant have reduced the diversity and abudnance of algae and animals in small areas adjacent to the mouth of the effluent canal. Many plants and animals in a 125-acre area where temperatures have risen 4°C (7.2°F) above ambient have been killed or greatly reduced in number. In a second zone of about 170 acres, corresponding to the +3°C (5.4°F) isotherm, algae have been damaged, and species diversity and abundance have been reduced. In the latter area, mollusks and crustaceans increased somewhat, but the number of fishes decreased.

Studies at the Martins Creek Plant on the Delaware River (Pa.) showed that the heated waters appeared to have attracted fish and enabled them to actively feed throughout the colder months of the year to a greater extent than they normally would, although there was no conclusive evidence that heated waters actually increased fish production or growth rates.

Studies at the Petersburg, Ind. Plant (220 MW) on the White River (Ind.), report that there is no evidence that any adverse effects on fishes, such as death, impaired growth, insufficient reproduction, increased disease, and movement or lack of movement are being observed at Petersburg or in the entire White River with the exception of fish movement away from water above 93°F.

The White River has a sandy bottom and is quite turbid. The principal pollutants are floodwater and suspended material in the water. The major aquatic species at Petersburg are the spotfin shiner, bullhead minnow, spotted bass, longear sunfish, gizzard shad, carp, and white crappie. Since sand and silt are deposited when floodwaters recede researchers who studied the White River believe that money for thermal pollution abatement could be better *"applied to the certain and very real need for flood and bank control."*

Recommendations

The result of several ecological studies around actual operating power plants is that, with a few exceptions, there has not been any major damage to the aquatic environment from the heated effluents of existing power plants. However, in the future years, as larger power plants become operational, accompanied by multiple units at a single site, environmental management of heated effluents at these sites will become more difficult.

Standards for limiting the thermal loads imposed on aquatic systems have evolved with the expansion of the electrical generating industry. However, without feasible alternate methods to produce electrical power without waste heat, there are only a limited number of alternatives. At one exteme is employing methods which recycle cooling water and add no waste heat to natural waters. This extreme is not required to ensure well-balanced aquatic communities. The other extreme is to permit unlimited thermal loading on aquatic systems which would, no doubt, be disastrous (based on the projected use of marine and freshwater resources for

industrial cooling purposes). The only option remaining is discharging waste heat to waters in amounts approaching the assimilative capacity of the waters in question. Heat generated beyond those amounts will have to be dissipated by methods which recycle cooling water. Based on the knowledge available at the present time, the last option seems to be the only reasonable approach.

Pursuing this course requires total commitment to determine the assimilative capacities of fresh water and marine resources. Management and surveillance programs will be essential as will cooperation between industry and regulatory agencies. Many factors contribute to receiving capacities, and requirements for producers of waste heat will be highly variable depending on their location. Power plant sites should be chosen with the advice of competent ecologists, and base line ecological surveys should begin as soon as a suitable site is selected.

While lethal effects of heated water discharges on fish and other aquatic organisms should present little problem, assuming proper discharge procedures, the sublethal effects of these heated water discharges may produce significant changes in populations. These sublethal effects could produce physiological changes that would decrease growth rate and prevent reproduction. Future studies should be designed to obtain a better understanding of sublethal effects.

The entire food chain is of extreme importance in the balanced aquatic ecosystem. Particular aquatic organisms or plants that fish eat can be affected by waste heat from power plants. Eliminating a single component of this ecosystem would affect the feeding and growth of organisms on all higher tropic levels.

Data are not yet sufficient to permit a proper understanding of the dynamics of this ecosystem. Many laboratory studies have led to understanding many of the physical-chemical functions of aquatic organisms as well as dispersion in water systems. Consequently, regulations based on these studies will be designed to minimize all possible risks of catastrophic kills of desirable organisms. Field studies are necessary to determine the *"real-life"* mechanisms occurring in the aquatic ecosystems. While laboratory studies are a necessary part of understanding, extrapolating laboratory measurements to field conditions must be done cautiously.

Answers to considerations which could alter regulations will have to be provided from nongovernmental sources such as the electric utilities. As the assimilation capacity of the environment is reached, it is increasingly important to consider long-term effects. Modest investment programs looking at the ecosystem to develop and verify predictive capabilities could themselves pay handsome dividends.

To utilize more fully the assimilative capacities of natural waters to dissipate waste heat, greater ecological management will be required, and operators of steam-electric stations will have to play an important role. In addition to considering effects of heat rejection during normal plant operation, attention must be focused on the effects of temperature changes, even though the actual temperatures may be below the lethal limit.

An effort should be made to establish the assimilative capacity of all natural waters to be utilized for cooling purposes. Based on predictions from the biological, chemical, and physical studies, limiting conditions should be established to accommodate the idiosyncrasies of each site. There is no substitute for on-site experimentation utilizing the resident populations and the local water. After a new unit comes on-line, a less intense program of surveillance should become a matter of routine at all plant sites.

As more of the larger power plants become operative and as more sites are required, the ability to predict the response of the aquatic ecosystem to the heated water discharges must be improved. The systems approach to study ecosystem dynamics offers a valuable tool to individuals who make decisions concerning siting and design criteria for power plants.

Criteria and regulations can only be altered with confidence when accurate predictions can be made. The pre- and post-construction studies by the utilities, if expanded to consider predictive aspects, offer an opportunity to obtain needed data on the system and to verify the predictions.

The satisfactory performance of existing steam-electric plants supports the belief that controlled amounts of heated water can be added to aquatic systems without producing adverse biological consequences. Therefore, in the absence of evidence of damage to the ecosystem involved, it would be difficult to justify requiring steam-electric stations, which have been operating for some time, to install cooling devices because they are not meeting newly adopted state or federal regulations. A careful

investigation of the issue at each specific plant site should be done prior to any action being taken.

In order to understand the dynamic behavior of the aquatic ecosystem some long-term studies are required. Of course, there are many and varied types of aquatic ecosystems so that typical rivers, lakes, estuaries, and ocean systems should be studied in a variety of climates. Industry, and, in particular, the steam-electric industry, should participate in these studies since the power plants will be the major waste heat contributor to the aquatic ecosystem. Waste heat from the power plants will become a more significant discharge to the aquatic ecosystem in the future. It may be that the effects of waste heat could be beneficial when other pollutants, such as sewage and industrial waste, are limited or removed (as reported for the Thames River in England).

Although there has been no apparent major damage to the aquatic ecosystems by cooling water discharge, there have been ecological changes. The complex interrelationships of species, populations, and communities in an ecosystem is the result of years of evolutionary trial and error. Therefore, although no major mortalities are noted, shifts in species diversity or abundance might upset delicate balances which exist, and results might not be known for years.

There are some bodies of water presently capable of accommodating more thermal loading without incurring adverse effects on the aquatic boota, while the assimilative capacities of some others have already been exceeded. Thus, it is imperative to evaluate dynamic changes which are presently taking place in aquatic ecosystems, and to be able to predict what is likely to occur as the electrical generating capacity of the nation increases.

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COOLING TOWERS BOOST WATER REUSE

Environmental Science & Technology, March, 1971.

Water, the colorless, transparent liquid in rivers, lakes, and oceans, is a major environmental concern. Water use and pollution increase as population and industry grow, until man is made aware of the necessity for conserving this precious natural resource. U.S. industrial manufacturers require 42 billion gallons of water per day (gpd); agriculture's demand is even greater, 140 billion gpd. Utilities require 95 billion, and household use of water totals 36 billion gpd. Although the water consumption figure will jump to 500 billion gpd by 1980, there will be *"no water famine if it is intelligently used,"* says Bob Cunningham of Calgon Corp.

One major but relatively unpublicized means to conserve water--through recycling as well as reducing the incidence of chemical and thermal pollution--is through the use of cooling towers. Cooling towers--their uses, problems, and the growth potential of the industry--were discussed at the annual meeting of the Cooling Tower Institute in January held in Houston, Tex. Since effluent volumes and subsequent treatment costs can be reduced by use of cooling towers, this means of increasing the cycles of water use can *"save industry millions of dollars per year,"* Jim Axsom of Sun Oil Co. Emphasizes. A major Gulf Coast chemical processor further asserts that cooling towers are generally more economical than a dry air cooling system.

Design

A cooling tower is a component of an open recirculating cooling system which is generally used for cooling water that has been heated by passage through process heat-exchange equipment. (A heat exchanger is a metal device consisting of a large cylindrical shell with tubes inside the shell. As a hot process fluid passes through the shell and cool water flows through the tubes, or vice versa, heat exchange takes place across the tube wall.)

Hot water, pumped to the top of the tower, trickles through the fill--redwood boards or polyvinyl chloride placed in a crisscross pattern in the tower--which in turn spreads the water uniformly and assists the cooling process. Air is pulled into the base or sides of the tower and exhausted through the fan stack. As air and hot water mix, the water is evaporating and condensing thus causing cooling. Finally, the droplets fall into the sump (concrete collection basin at the bottom of the tower), and the cooled water is ready for recycling through the heat-exchange equipment. Chemicals are added to the water to prevent scaling or corrosion of the cooling system components due to various problems aggravated by the chemicals in the water and the high temperatures.

The open recirculation system is compared with two other types of water systems--the once-through system and the closed-recirculating system. The once-through system merely borrows water, usually from a surface stream, warms it a few degrees, and discharges it further downstream. Of course, chemical treatment is required to prevent pollution, and these costs can become excessive due to the large volumes of water treated.

The closed-recirculating system is used, for example, in office building heating and cooling refineries, and chemical plants. There is no intentional water loss; therefore, little makeup water is required, allowing more exotic chemical treatment than would be feasible in one of the other systems. Typical chemical treatments in this system are usually very high in chromates (up to 2000 ppm) and boraxnitrite mixtures (2000 ppm).

Prototype

The forerunner of the modern cooling tower was a spray pond where water was sprayed into the air to be cooled. However, high drift rates (water droplets carried by the air) hindered this early method, so the first towers were built. These original "atmospheric towers" were narrow and tall (56-ft high and 12 to 13-ft wide), depended on the wind velocity moving through the tower to cool the water trickling down, and were usually inefficient. Fans were later mounted at the bottom of these towers to blow the air up through the structure (forced draft). However, the air velocity coming out of the tower could be so low that wind sometimes forced the air back into the tower, cutting efficiency by as much as 50%.

Then fans were mounted on top of the tower to pull the air through (induced draft). This operation is the most widely used in the U.S. today. *"The forced draft tower is only built periodically--just for special orders. No manufacturer has a forced draft as a standard model,"* says Jim Willa, vice president of Lilie-Hoffman Cooling Towers, Inc. However, under certain installation parameters, the forced draft

tower is the most feasible model to install, according to a spokesman for the Marley Co.

There are two types of induced-draft cooling towers:

In the counterflow tower, water enters as a spray at the top of the tower and trickles through the fill down to the sump. Air is sucked through inlet air louvers in both sides of the tower, travels up through the tower, and flows out of the top. The air and water mixtures travel counter to each other–the water down, the air up.

The induced-draft crossflow tower still has water entering the top, but only at each side. The center of the tower, where the fan is located, is left open. As the water falls through the fill on each side of the tower, the air is pulled through the fill across the water. The air moves horizontally–through the side louvers, the fill, and then to the center of the tower. Here, it makes a 90° turn and flows out the top. The air moving horizontally across the water moving vertically creates a crossflow.

Tower Costs

The typical image but recent example of a cooling tower is the natural draft or hyperbolic tower which is, though tall and graceful, expensive and perhaps unreliable in this country. These towers have a large chimney rather than a fan to force or induce the air. Air densities inside and outside the chimney create a differential in pressure that causes a draft to be sucked through the cooling area.

The only justification for building this tower, Will contends, is its low power requirement for a 20-year period or more. The hyperbolic tower costs 5 to 10 times more to build than the crossflow or counterflow unit. However, other major companies contend that the ratio rarely goes higher than 2:1 or 3:1. Presently, the major market for these towers is the eastern electric utility plants that previously used rivers and lakes to cool their hot water. Not one client in the U.S. who has ever owned a standard cooling tower has purchased a hyperbolic tower, says Willa. Besides the prohibiting difference in cost, the hyperbolic tower is not efficient functionally in the U.S. Designed, introduced, and built in parts of Europe where latitude is equivalent to that of Labrador, the hyperbolic tower (in the U.S.) may yield the least performance at the peak period of demand–during the hottest days of the summer months (because of the small pressure differential), according to Willa. (Willa's company, Lilie-Hoffman, does sell and build hyperbolic cooling towers, incidentally). On the other hand, Marley Co. customers are ordering additional hyperbolic towers as well as the mechanical draft models.

Cooling tower prices range from cheap models (untreated wood or plywood fill, galvanized steel hardware), whose cost is estimated at $5 per gallon of water it will eventually recyle, to the more expensive ones (pressure-pretreated redwood fill, and yellow brass, silica bronze, 304 or 316 stainless steel hardware), which will cost $12 to $13 per gallon of recycled water. Performance requirements also affect the cost considerably. Short range, long approach (large temperature difference between the cold water leaving the tower and the wet bulb temperature of the air), easy-duty cooling towers are naturally less expensive than the long range, close approach, heavy-duty tower. For example, petroleum and petrochemical industries capitalize only on a five-year basis. If the tower cost cannot be justified in five years, the system stands a good chance of being obsolete.

Water Treatment

Cooling towers have four common operational problems: corrosion, scale, deposition fouling, and microbiological attack. In cooling tower systems, the problems are related to cooling tower blowdown (the intentional removal of a portion of the recirculated water in the cooling system to limit the buildup of dissolved solids beyond a certain concentration), high temperatures, and the air scrubbing action of the cooling tower itself. The untreated makeup water added after blowdown to maintain constant volume may also cause these problems.

Corrosion is an electrochemical phenomenon occurring in the system's piping, heat-exchange equipment, and other metallic components. Water soluble corrosion inhibitors, added to the water to reduce corrosion, for a monomolecular film at the metal-water interface. These compounds are:

- Inorganic polyphosphates.
- Inorganic polyphosphates plus zinc.
- Chromate-zinc and chromate-zincphosphate.
- Nonchromate inhibitors, which include amino-methylene-phosphonate (AMF) plus zinc, polyol-ester phosphate with or without zinc, and poloyacrylamide-silica polymers.

The choice of treatment depends upon the existing water pollution control laws, since some cooling water will reach receiving streams during blowdown. A high-phosphate chemical also contributes to pollution problems. Usually, corrosion is controlled with a mixture of chomate and zinc, with or without additives.

Scale formation is a result of precipitation of limited solubility salts. Essentially, during continuous recycling, a salt reaches a concentration that exceeds it's solubility product, and it is deposited as scale (usually $CaCo_3$ of $CaSO_4$). Scale formation can be prevented by pH control. If the cycles of concentration cannot be economically reduced in a system, various phosphates are used to alter the crystalline structure of the precipitate and to prevent deposition, or to cause the deposit to form a soft sludge which can be easily washed away. However, using phosphates in cooling towers with high temperatures and long residence times may cause reversion. (The metaphospahte that controls scale can revert to orthophosphate, forming an insoluble salt with calcium that will deposit in the system.) Sulfuric acid addition will lower the pH to prevent scale, but this will accelerate corrosion. Using phosphate-zinc combination lowers the amount of potentially revertible phosphate; however, much emphasis today is placed on AMP, which is resistant to reversion and can therefore be used with little or no pH control.

Fouling occurs when silt, mud, and debris accumulate in the cooling tower system. Silt is treated with a synthetic polymer to *"fluff up"* the material, thus creating a larger surface area. The particle size expands allowing the force of the flowing water to scrub effectively the lower velocity areas. Dispersants have also been used to prevent deposition. *"A major break-through for pollution control, performance, and ease of control,"* explants Paul Puckerius of W. E. Zimmie, Inc., *"is obtained with a combination of organic polymers with inorganic polymers. These treatments with effective scale inhibitors, give a complete scale, fouling, and corrosion control system."*

Microbiological attachers–fungi, bacteria, and slime–get into the cooling system through the makeup water or air. These organisms can foul lines as well as damage wood fill. The most effective and least expensive biocide available is chlorine. With proper pH control and correct dosages, chlorine will not cause wood deterioration and will prevent pollution in the blowdown effluent. Over 90% of industrial cooling tower users favor chlorine treatment. Many nonoxidizing microbiocodes, chlorophenols, or organo mettallics, can also be used for good microorganism control without significant contribution to wood deterioration.

Market growth

The major cooling tower manufacturers (Marley, Lilie-Hoffman, and Fluor) forecast rapid growth for the industry. Air-conditioning uses contribute to this growth. Cooling towers are now widely used in the petroleum and petrochemical industries, especially with the present drive for pollution control. The largest market for cooling towers is electrical plants. Electrical power use doubles every 10 years, and the number of cooling towers required by the electrical industry will grow proportionately. Cooling towers and their contribution to environmental control will become more evident as time passes.

NUCLEAR WASTE MANAGEMENT: AN OVERVIEW OF CURRENT PRACTICE

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INTRODUCTION

The continued growth of competitive nuclear power in the U.S. and greatly increased public interest in the quality of our environment have provided a focus on the importance and necessity of satisfactory long-term waste management for effluents from the entire nuclear energy industry. Particularly during the past two years, the industry's effluent control programs have been the subject of controversy and criticism by many environmental and conservation groups. The rationale behind these criticisms is difficult to understand when technical assessments for more than 25 years of operating experience within the AEC complex and 10 years experience in the nuclear power industry continue to show that waste management operations are being carried out at only a small percentage of international radiation protection standards.

With this thought in mind, and as a starting point for our session on nuclear waste management this morning, I will summarize some of the waste management approaches which have been used in the AEC complex and nuclear energy industry, the experience which has been obtained, and also some of the changes which have taken place during the past few years. In general, the results of this operating experience and extensive research and development during the 1960's have provided the technical basis for present trends and actions in nuclear waste management which are becoming more apparent as we proceed into the 1970 period that has been termed by many as a *"decade for environmental action."*

APPROACHES TO RADIOACTIVE EFFLUENT CONTROL

In intitating our overview discussion of nuclear waste management, it is noted that the nuclear energy industry in the U.S. has developed to its present state in a period of approximately 25 years. At the core of the industry is the AEC's large nuclear enterprise. Of the operations involved, such as mining and milling of uranium ore, chemical purification of fissionable material, fabrication of fuel elements, operation of nuclear reactors, chemical reprocessing of spent fuel, and research and development activity associated with each of these nuclear fuel cycle steps, most are performed in an integrated industrial operation conducted under contract for the Atomic Energy Commission. Large-scale research and production facilities such as Oak Ridge, Savanna River Plant, the Hanford Works, Los Alamos Scientific Laboratory, and the National Reactor Testing Station perform many diversified nuclear operations.

As would be expected in any complex industrial operation, various kinds and quantities of gaseous, liquid, and solid waste materials are generated in each part of the fuel cycle. Unfortunately, the term *"radioactive waste"* continues to be considered by most people as a single uncategorized entity. In order to properly evaluate the design requirements of any radioactive effluent control system, certain fundamental factors must be considered:

- the specific nature (physical, chemical, and radiometric), quantity, and origin of the radioactive waste material being processed;
- the characteristics (physical, chemical, and biological) of the receiving environment; and
- basic radiation protection standards or criteria.

Although the basic principles of radioactive effluent control and environmental and public health protection in the nuclear industry are similar to those which apply to other chemical or heavy industries, there is one significant difference from this industry and others. From its inception, the nuclear industry was acutely aware of the potential hazardous effects of its wastes and has focused detailed attention on these problems. In this regard, three basic approaches to radioactive effluent control have been practiced in the United States. It is important to understand at the outset that these approaches have related directly to the location of the nuclear facility and the particular site selected for an installation has had a major influence on determining the type of waste management system to be used. For example, large

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installations located in isolated or remote areas such as Hanford, Washington, and the National Reactor Testing Station in Idaho through use of extensive monitoring and environmental research have safely operated under less restrictive effluent standards than could be utilized by smaller facilities in urban areas. Plant location has then been a major factor in determining the extent of usage of any of the following waste management concepts:

1. The first of these concepts known as concentrate and contain has primarily been used for high activity wastes orginating from chemical processing of irradiated reactor fuel. These wastes are confined or isolated in a controlled area in specially designed underground storage tanks away from man and his natural resources. Containment is essential for high activity wastes because small volumes would require excessive amounts of environmental dilution. Twenty-five years experience with high-level liquid waste storage at major AEC sites has shown it to be a practicable means of interim handling. During this time, over 80 million gallons of first cycle, fuel reprocessing waste have been satisfactorily handled at Hanford, Savannah River, and the Idaho Chemical Processing Plant. In the past year, the concentrate and contain concept of waste management is receiving wider application in nuclear power plant operations in an effort to further minimize the total quantity of radioactivity released to the environment.

2. A second waste management concept, which is diametrically opposite in application, is referred to as dilute and disperse. This concept has been used with only low-hazard potential wastes in which the radioactivity has been reduced to acceptable levels (either directly or following treatment) by dilution in nature - air or water. Approximately 20 years of quantitative physical, chemical, and biological data and knowledge have been obtained on dispersion phenomena and reconcentration factors; this research, coupled with extensive monitoring, has demonstrated the validity of using this approach without compromising health and safety standards. While this procedure has permitted a safe development of the nuclear energy industry at research and production sites within the AEC complex, it has not been used in nuclear power station solid waste and liquid effluent control.

3. A third waste management approach is characterized by the phrase delay and decay, which has principally been used in the discharge of certain types of radioactive waste materials into the ground at isolated AEC sites. Soil holdup and/or exchange capacity are used in this concept. Either direct discharge to the environment or release after conventional treatment may be involved. In the use of this concept, the Atomic Energy Commission has supported extensive research and development in the past 15 years in geohydrologic studies at its operating installations and universities and in cooperation with other governmental agencies. The U.S. Geological Survey, with specific competency in radiogeohydrology, has contributed significantly to the development of safe parameters to be utilized in quantitatively assessing the lithosphere to receive safely certain quantities of radioactive materials.

In general, at AEC sites, extensive research has been carried out and broad operating experience obtained on the processing of large-volume, low-activity waste by single or multiple state treatment systems involving filtration, chemical precipitation, ion exchange, evaporation, calcination and fixation in glass or ceramic materials, concrete solidification, vermiculite absorption, and tank storage. Other research and development have also been carried out on newer treatment techniques such as foam separation, electrodialysis, and asphalt solidification.

Where suitable geohydrologic conditions exist, ground disposal of these wastes with or without treatment is utilized. For example, at Hanford, through careful operating and monitoring control, it has been possible to dispose of large quantities of slightly contaminated liquid waste to the ground. Before the liquids reach the groundwater table some 200-300 feet below the land surface, the significant radionuclides are effectively retained in the earth overburden and sedimentary rocks through which the liquid percolates. In this sense, the operation is not disposal but ground storage, inasmuch as it utilizes

the capacity of natural earth materials to retain the significant radioactive contaminants by ion exchange, adsorption, and holdup in pores. In another ground disposal operation, Oak Ridge has used a petroleum industry technique known as hydrofracturing.[1] The method involves mixing radioactive waste with cement and other additives and then pumping the grout into a bedded shale formation 700-1,000 feet below the ground. Full-scale engineering testing of the concept has been completed, and the technique is now being used on an operational basis at Oak Ridge. Wastes are processed by the method at each site which provides, in accordance with acceptable health and safety standards, the required decontamination at the lowest cost.

Air and gas cleaning for the nuclear energy industry differs in two major respects from general industrial air cleaning: the high degree of toxicity of the radioactive contaminants and the contamination of the cleaning device itself. The latter creates a potential health hazard due to radiation or disposal of the collected materials.

Radioactive gases and particulate material are generated in most nuclear research laboratories where a variety of chemical, metallurical, and biological operations are carried out. Exhaust gases are discharged through high efficiency filters that are capable of routinely removing 99.95 per cent of particles 0.3 microns in diameter.

In the gaseous effluents from fuel reprocessing operations, the predominating isotopes are radioiodine and the noble gases, although ruthenium is also present. The discharge of iodine is controlled by a combination of aging the fuel elements for 90-120 days prior to processing to allow radioactive decay and retention or removal of most of the volatilized iodine by activated charcoal or silver reactor systems. Rutherium has been removed by caustic scrubbing.

LAND BURIAL

The continuing expansion of the overall U.S. atomic energy program during the past 25 years has resulted in several significant developments in the disposal of solid radioactive waste by land burial. During this time, the principal AEC installations have operated and maintained suitably located land burial grounds for the disposal of solid radioactive waste generated in the course of their own operations. These burial grounds are located at Aiken, South Carolina; NRTS, Idaho; Richalnd, Washington; Oak Ridge, Tennessee; Los Alamos and Sandia, New Mexico; the Nevada Test Site and Tonapah Range, Nevada; Portsmouth, Ohio; and Puducah, Kentucky. These operations use conventional sanitary landfill procedures similar to that used for municpal refuse disposal.

Throughout the U.S. atomic energy industry, there are over 5,600 establishments that perform operations resulting in the generation of increasingly large amounts of slightly contaminated solid waste materials. These establishments range in size from the largest AEC production site, through modest commercial and industrial isotope users, to small hospital and university research laboratories. The wastes include chemical precipitates, evaporator slurries, and ion exchange resins from the processing of low-level liquid wastes, as well as other wastes of low-hazard potential from laboratory and routine reactor operations such as contaminated glassware and equipment, paper wipes, rags, animal carcasses, filters, and fuel element endboxes.

The 1960 decade was marked by the entrance of commercial industry into land burial operations, i.e., industrial services were initiated for the collection, packaging transport, and disposal of low-hazard potential solid wastes. A decision was made in December 1959 that regional disposal sites other than the existing AEC installations could be established, as required, on state or Federal Government-owned land. Two interim land burial sites, one at Oak Ridge, Tennessee, and the other at NRTS, Idaho, were established pending the later designation of permanent regional sites to serve various areas of the country. During the period from 1960-63, the AEC carriedout an *"interim land burial program"* during which time the radioactive waste burial grounds at Oak Ridge, Tennessee, and the NRTS, Idaho, were available for the disposal of solid radioactive waste materials from (1) licensed users of nuclear materials, (2) other government agencies, and (3) certain AEC contractors. In the three years during which the interim land burial program was in operation, over 7 million cubic feet of solid radioactive wastes were disposed of by land burial.

Effective August 12, 1963, the AEC withdrew from its interim low-level waste burial program for licensees, based upon the availability of commercial service from Nuclear Engineering Company (NECO) burial sites at Beatty, Nevada, and Morehead, Kentucky. In November 1963, Nuclear Fuel Services, Inc. (NFS) established a low-level waste disposal facility near West Valley, New York. Other

commercial burial grounds were established by California Nuclear, Inc. (CNI) in 1965 and 1967 at Richland, Washington, and Sheffield, Illinois, respectively. CNI merged with NECO in August 1968 with Nuclear Lngineering becoming the surviving company. In April 1971, a sixth commercial land burial ground was established by Chem-Nuclear Services, Inc. in Barnwell County, South Carolina. Some indication of the magnitude of radioactive waste burial operations in the U.S. during the past decade is shown in Table I. From this table, it can be seen that AEC solid waste burial operations have been maintained at an approximate rate of about 1.6 million cubic feet per year since 1963 while commercial waste burials have increased approximately 50 per cent over the past 5 years to around 0.75 million cubic feet per year.

As part of a continuing effort to upgrade waste management operations within the Atomic Energy Commission complex, the AEC is, in concert with its operating contractors, developing long-range waste management plans for each of the Commission sites. A major focus of these efforts during the past two years has been directed at improving the overall management of long-lived transuranic or alpha contaminated wastes. As a result of these efforts, the AEC has required its own operating sites during the past year to segregate these types of wastes from other solid wastes and to store these waste materials in such a manner that they can be readily retrieved within a 20 year period. In this way, accumulation of large quantities of plutonium, such as might occur in conventional trench-type burial grounds, may be prevented.

The volume of alpha waste generated in AEC facilities over the next 30 years is anticipated to decrease due to program changes at waste generation sites, improved technology and economics for scrap recovery, more efficient packaging and handling of solid wastes, and the cost of special handling and long-term storage. Studies are continuing, which include further engineering analysis of waste handling techniques, particularly volu e reduction, through sorting, compaction, and incineration. The studies to date indicate over 50 per cent of the radioactive solid wastes currently being generated at AEC sites are compactible and can be reduced in volume by factors ranging from 2-10. A variety of compaction equipment is commercially available; however, it is only one component to be considered in a total waste management system.

As a possible alternative, the disposal of low-level combustible solid wastes by incineration merits further investigation. This method of volume reduction has been practiced at various AEC and power reactor facilities during the past 15 years with only nominal success. Operating problems in combustion, air cleaning, and corrosion all have required careful study and control in order to achieve satisfactory operating results.

Continued emphasis will be placed on improved management of long-lived, low-level radioactive wastes in the 1970's, particularly those contaminated with transuranic materials. The reducing of waste volumes by more stringent control at the industrial source and improved incineration and compaction technology will facilitate the handling and long-term disposal of these waste materials.

SEA DISPOSAL

In the early period of atomic energy development in the U.S. (1946-62), the Atomic Energy Commission disposed of small quantities of solid, packaged waste materials at designated locations in the Atlantic and Pacific Oceans. With the advent of commercial land burial operations in the early 1960's, a steady decline of sea disposal has occurred, as can be seen in Table II.[2]

This strong industrial interest resulted in the establishment of the first commercial land burial site at Beatty, Nevada, in 1962, and the subsequent establishment of five other land burial operations as previously described. Because of the availability of commercial land burial services of low-level radioactive waste materials, the AEC requested all of its contractors in 1963 to evaluate the economics of both disposal methods for their specific operation. Based on the operating experience of land burial operations at AEC sites for 15 years and the results of several field monitoring surveys of the sea disposal sites used during the 1957-61 period, both disposal methods have been considered from a technical standpoint as being equally safe and acceptable. However, in the economic analysis of both disposal methods, the unit costs for preparation, handling, and disposal of these wastes at sea were found to be considerably greater than for land burial. A major factor in this cost differential is that in sea disposal approximately 3/4 of the disposal container volume is required for concrete ballast in order to obtain the necessary container density to assure its sinking to the 1,000 fathom depth in the ocean.

As might be expected, the existence of privately operated land burial sites and the resulting economies of land disposal have essentially eliminated U.S. sea disposal operations. This development is timely and consistent with the recent findings and recommendations of the Council on Environmental Quality concerning the establishment of a national policy for more stringent control of *"ocean dumping.."*3 It appears that for sometime in the future commercial land burial operations and the proposed national salt mine repository will be adequate for the disposal of solid, packaged radioactive waste materials from all atomic energy uses in the U.S.

However, it is noted that the European Nuclear Energy Agency (ENEA) has carried out two large-scale sea disposal operations during 1967 and 1969 off the coasts of Portugal and the United Kingdom, respectively. These operations totaling approximately 60,000 containers with about 30,000 curies of beta/gamma activity were disposed at a depth of about 5,000 meters of water. At a recent IAEA Meeting on Low-Level Wastes it was learned that Japan has also carried out several rather extensive sea disposal operations off the coast of Japan involving low-level wastes from radioisotope use. While the pressure for banning all forms of sea disposal will increase during the 1970s, it would appear that this method of low-level radioactive waste disposal will be required in countries where suitable land disposal sites may not be available. Continued marine ecology research in this country and within the IAEA and ENEA can provide the technical basis for possible future sea disposal operations in situations where sea disposal would offer less potenital harm to man or to the environment than any other method of disposal.

POWER REACTOR WASTE MANAGEMENT EXPERIENCE

The most significant development in the U.S. atomic energy program during the 1960s has been the rapid expansion of the commercial nuclear power program. As of July 1, 1971, over 9 million kilowatts of nuclear plant capacity was in operation and another 90 million kilowatts of nuclear power is under construction or contract. This rate of nuclear power growth during the 1970s will result in an estimated 150 million kilowatts of nuclear plant capacity by the end of the forthcoming Environment Decade or approximately 25 per cent of the total electric power generated in the United States.

While waste management at nuclear power stations was not expected in the beginning to impede the development of large-scale, widespread nuclear power generation and 10 years of operating experience has thus far exceeded expectations, there is still a continuing clamor for further reduction of radioactive releases and, in some cases, *"zero radioactive effluents"* are demanded.

Detailed evaluations of waste systems operating experience at civilian nuclear power plants have been presented in numerous reports and technical society meetings. I will not attempt to discuss the details of this experience except to indicate that all plants have been able to operate well within their operating limits and generally at a small fraction of radiation protection standards. In fact, when one compares the effluent releases from nuclear power plants with internationally accepted air and water radiation standards, it is readily apparent that no other industrial effluent control record can match the nuclear power industry. Extensive treatment and storage systems at presently operating water reactors (and those planned for the expanding industry in the next decade) include decay holdup tanks, evaporators, ion exchange, steam stripping, catalytic recombination of hydrogen and oxygen, fixation of solids and liquids in concrete, incineration, baling, charcoal filtration, and cryogenic distillation.

Effluent release data for the nuclear power industry for 1967-69 have been reported elsewhere (4) (5) and 1970 experience is now being evaluated. On an average, the plants have released less than 5 per cent of established radiation protection standards. These data, when used to analyze the potential radiation exposure to a surrounding populace of a reactor plant, indicate that the average exposures to the total population living within a radius of 50 miles of the plant would be only a small fraction of 1 millirem/yr. This may be compared to an annual exposure of about 100-125 millirem/yr received by the population at sea level in the United States. These radiation exposure assessments of nuclear power plant operations have been confirmed by individual and cooperative environmental monitoring programs which have been carried out by the reactor plants, state health departments, the Bureau of Radiological Health of the U.S. Public Health Service (6) (now EPA), and the AEC. Some of the results of environmental studies carried out by the Public Health Service during the past several years will be reported at this meeting.

Despite the unexcelled effluent control record of the nuclear power industry, the environmental controversy has persisted during the past two years over the siting and operation of nuclear power plants, and continued criticism has been directed at the AEC's regulations pertaining to quantities of radioactive materials permitted to be released under the regulations. The major point of argument has been that if technology is available to reduce radioactivity concentrations in effluents to a small fraction of established limits, then the radiation standards or release limits should be lowered to these levels. In this connection, the Atomic Energy Commission's regulatory program in its continuing effort to keep its regulations in tune with the rapid growth of nuclear power and increasing uses of radioactive materials and other radiation sources adopted, as of January 2, 1971, amendments to its radiation protection standards and facility licensing codes (Parts 20 and 50, respectively, of the Code of Federal Regulations). [7] Part 20 calls for water reactor licensees to *"make every reasonable effort"* to keep radiation exposures and release of radioactive materials to as low as practicable. While AEC standards have always subscribed to this Federal Radiation Council guideline, this FRC advice had not been included in previous regulations.

Similarly, the reactor licensing regulation (Part 50) has been amended to specify design and operating requirements which will minimize the release of radioactive materials to the environment. In order to provide numerical guidance for the nuclear power industry, the AEC announced on June 7, 1971,[8] that new plants should be designed to limit radioactivity in effluents to levels that would keep radiation exposure near the plants to less than 5 per cent of the average natural background radiation. Existing reactors would have up to three years to modify their systems along with others now in the design and construction stages. With the average exposure from natural background radiation in the U.S. between 100-125 millirem/yr. radiation exposures to persons living near nuclear power plants would be less than 5 millirem/yr or about 1 per cent of Federal radiation protection guides for individual members of the public.

In order to meet the environmental revolution taking place, industrial efforts have been intensified during the past year to develop and install improved radioactive waste management systems which will further reduce the quantities of radioactive wastes being discharged to our biological environment. Both the Westinghouse Corporation and General Electric Company have announced the availability of advances in waste treatment plant design that substantially reduce effluent radioactivity levels during normal operating conditions.

In the case of boiling water reactors (BWRs), catalytic hydrogenoxygen recombiners, high pressure storage tanks, charcoal filters, and cryogenic distillation units are being designed and installed to reduce gaseous discharges by at least a factor of 100. The principal reactor operating experience with these systems has been the use of charcoal beds at ambient temperature, which has been developed and successfully operated for more than five years at the Gundremmingen Station in Germany. In pressurized water reactors (PWRs), since there is no large source of radiolytic gases and the condenser air in-leakage source is absent, holdup times of 60 days or greater are commonly obtained using compressed gas storage systems.

In liquid waste treatment, both PWRs and BWRs are expanding their radwaste systems with the goal of maximizing water recycle of plant wastes. In order to achieve this objective, the control and disposal of tritium have become the major design and operating problems in water reactors. This radionuclide has been identified in the primary coolant of all light-water power reactor plants. [9] In addition to its formation by activation of hydrogen and naturally occurring deuterium in the reactor coolant, it is known to be produced by ternary fission of ^{235}U and by neutron reactions with boron and lithium. In the absence of chemical additives, the tritium derives mainly from fission and it appears in the coolant after having diffused through the fuel and fuel cladding. From reactor effluent data, it appears that such diffusion is more pronounced with stainless steel than with zircaloy cladding, probably due to the hydriding *("tritiding")* of zirconium by the tritium. Since current and future generations of light water reactors will apparently all use zircaloy clad fuel, it is of interest to note that most (approximately 99 per cent) of the tritium formed in the fuel will remain with the fuel until being reprocessed.

Liquid effluent data on tritium from operating water reactors in the U.S. during the past four years (1967-70) are summarized in Table III.[10] During this period, it can be seen that PWRs on the average have released tritium to the environment in the range of 100-7,400 curies a year for plants in the size of 200-500 MW_e. Comparable size BWRs have released

between 3-50 curies of tritium per year. Advanced designs for a typical 1,000 MW_e PWR indicate that less than 1,000 ciroes pf tritium will be generated in the primary coolant system and a comparably size BWR would produce in the range of 100 curies per year.

In order to minimize the release of tritium in PWR liquid effluents, present radwaste design deals with the tritium problem by purifying the primary coolant with an evaporator so as to enable its recyclying along with the tritium. A newly developed temperature-sensitive resin allows for economizing the use of boron as well as the volume of coolant thus minimizing the size of the evaporator. In general, PWRs are installing larger evaporators and increased storage capacity plus additional pretreatment with filtration and demineralizers to improve evaporator performance.

Although tritium is relatively more prevalent in PWRs, additional liquid waste processing is also being incorporated in BWRs. Newer BWR plants are providing evaporators in waste systems as a supplement to their former dependence on filtration and ion exchange. It is hoped that this additional high decontamination system will permit further reduction of liquid releases, although evaporator operation at nuclear plants to date has not been overwhelmingly successful in many instances.

R & D TO IMPROVE CURRENT PRACTICES

Present day nuclear waste management operations have been carried out at a small fraction of acceptable radiation protection standards. Development of new and improved waste systems is a continuing R&D objective.

Of primary concern in developing a policy in the siting of industrial fuel reprocessing plants was the need to restrict, in the interest of public health and safety, the quantities and mobility of the high-level radioactive wastes stored on-site at fuel reprocessing plants. During the past 15 years the AEC has been carrying out research and development programs aimed at developing methods for effectively and permanently removing these wastes from man's biological environment. Major emphasis in these programs has been directed toward the conversion of liquid waste into solid forms suitable for interim on-site storage, safe transport, and disposal in selected deep geologic formations. Two papers in this morning's session highlight the results of research on high-level waste solidification and establishment of a national salt repository.

SUMMARY ANALYSIS OF CURRENT PRACTICE: FUTURE TRENDS

In the preceeding discussion I have attempted to summarize the basic approaches to waste management which have been used during the past quarter century within the Atomic Energy Commission complex and the current practice and experience which has been obtained in the commercial nuclear power industry during the past decade. Some of the historical developments on the use of land burial and sea disposal for packaged solid waste during the 1960s have also been briefly discussed. In closing, I would like to relate some of our past operating experience to possible future trends in waste management noting, where more stringent environmental quality criteria may require, further improvements in operational control and treatment systems.

In the basic approaches to waste management which have been used in the past, it is increasingly evident that the *"concentrate and contain"* approach is becoming more of a design objective or requirement for other types of radioactive wastes besides the first cycle, high activity waste from chemical processing. Its application to power reactor waste management is becoming almost universal. A reasonable use of the environment for waste disposal purposes is becoming unacceptable and the conservationist slogan *"Dilution is no solution to pollution"* is receiving broader acceptance.

From a land burial standpoint, it is obvious that increased quantities of solid contaminated radioactive waste materials will be generated with the increasing number of nuclear power plants, fuel fabrication facilities, and chemical processing plants. One of the papers in this session will deal principally with the future requirements and projections in waste management, but a few brief observations in this area appear appropriate.

In the area of solid waste management, the control and long-term disposal of transuranic contaminated materials will require continued, careful assessment during the coming years. It is anticipated that the quantity of plutinium contaminated waste, which will be generated by the commercial nuclear fuel cycle, will significantly increase in the future as a result of fuel fabrication and fuel recovery activities. By the year 2000, it is estimated that approxmately 2.5 million cubic feet of alpha contaminated waste will have been produced in both industrial and AEC operations.

With the present trend of building 800-1,000 MW_e nuclear power plants but based on operating experience from plants about 250 MW_e in size, it is estimated that approximately 1-2,000 cubic feet of solid waste material will be generated in a 1,000 MW_e nuclear power plant. This would result in a volume of low-level solid waste from the nuclear power industry in the range of 2-3 million cubic feet by 1980, which is approximately equivalent to the quantity of these type wastes that has been satisfactorily handled in previous years in the AEC complex. In consideration of low-level wastes from all atomic energy applications, it has been estimated that 6 million cubic feet of low-hazard potential solid wastes will require disposal by 1980. As previously noted, continued emphasis and engineering study will be placed on improved management of long-lived, low-level radioactive wastes in the 1970's. The reduction of waste volumes by more stringent control at the industrial source and the improvement of incineration and compaction technology should provide the means for satisfactorily handling these waste materials in the future.

In a related area, it has been noted that commercial land burial operations and its resulting economies have essentially eliminated U.S. sea disposal operations. However, it is observed that the expanding nuclear energy programs in Western Europe and Japan will likely result in an increased use of the sea for the disposal of solid packaged radioactive waste materials. At present and in the immediate future, it appears that commercial land burial operations and the proposed national salt repository will be adequate for the disposal of solid packaged waste materials from all atomic energy uses in the United States.

Concerning liquid waste treatment, I noted earlier that commercial water reactors are expanding their radwaste systems with the goal of maximizing water recycle of plant waste. In this way, plant operators would concentrate and contain radioactivy within the reactor system itself for long periods of time. In new PWR designs, the release of tritium during normal plant operation would be completely eliminated. Tritium in the form of tritiated water is confined within the plant system, and it is estimated that off-site disposal of tritiated water would be required only once or twice during the approximate forty-year lifetime of a nuclear plant.

With a trend towards tritium recycle in power reactor systems, there has been some concern expressed that the in-plant hazard this might cause for operating and maintenance personnel may result in a greater total radiation exposure than would have been incurred by the normal releases of tritium to the environment. You may recall that these releases have been considerably less than 1 per cent of maximum permissible limits as previously shown in Table III.[11] When one uses the *"man-rem"* concept for evaluating overall radiation exposure (this number is obtained by multiplying the radiation dose by the number of people receiving it), it is estimated that the proposed water reactor design objective of a 5 millirem dose would result in an upper limit of 400 man-rems per 1,000 MW_e of installed nuclear capacity.[12] In this regard then, the total nuclear power man-rem dose in 1970 was about 2,400 - less than one ten-thousandth of natural background. Similar analysis of reactor in-plant exposure due to maintenance and refueling operations has been estimated at about 2,000 man-rems during the 1969 period. When one considers the increased radiation exposure which will be required by additional in-plant maintenance on evaporators or other contaminated fluid systems, solid waste handling, etc., it is possible that this increased worker exposure may eliminate whatever benefit might be derived from the proposed further reduction of residual public exposure.

The problem of ultimate tritium disposal still remains. Techniques for incorporating relatively large volumes of tritiated water into some form of solid media may become technically feasible. Possible establishment of regional deep well disposal installations which could handle tritiated water from a large number of reactor sites may merit further consideration and study. Deep well disposal has been widely used for many other industrial wastes but because of its stringent site requirements and geohydrologic limitations, it has not been generally applicable for radioactive waste disposal operations.

In the case of fuel reprocessing plants, improved waste management systems for tritium effluents may also be required. At the present time, tritium retained in the fuel elements will be released to the dissolver solution during the processing of the spent fuel. The bulk of this tritium is eventually released to the low-level liquid waste system. Under current practices, this waste is either discharged to surface waters or vented to the atmosphere in the form of tritiated water vapor. The reprocessing plant case represents the largest potential source of waste released to the environment from a single source. Considering a five-ton per day processing plant, the tritium release from such a facility may be on the order of one megacurie per year.

It appears technically feasible to modify fuel reprocessing plants such that tritium would not be discharged to the environment. Recycling of plant water with periodic draining and storage thereof could be considered. It is more likely, however, that future control of tritium release in reprocessing plants will be accomplished with special head-end treatments currently under development for fast breeder reactor fuels.

The release of radioactive noble gases from operating nuclear facilities has, in general, been substantially below the limits prescribed by applicable radiation protection standards. It has been recognized, however, that removal systems may be required which would provide the means for further reducing such releases to a practical minimum. It has been indicated previously that such systems are now being designed and installed in various light water reactors; the status of this technology is to be covered in another paper at this session.

However, as the world's nuclear power production increases, the buildup of krypton-85 in the atmosphere may become important.(13) Estimates of potential radiation exposure to the year 2000 from a uniform worldwide distribution of krypton have been made. Assuming a complete mixing of krypton-85 in the air throughout the first eight miles of the atmosphere, it has been estimated that a maximum whole body exposure from krypton-85 of 1.8 millirem per year in the first 1/4 mile of the atmosphere would be obtained. This figure is well within present plant design objectives; however, continued assessment of the future significance of krypton-85 to overall radiation exposure is considered desirable.

CONCLUSIONS

Extensive operating experience on waste management systems in both the AEC complex and the commercial nuclear power industry has shown that radioactivity releases can be maintained at small fractions of established radiation protection guides. In addition, during the 1960s an extensive research, development, and demonstration program was carried out on the treatment and disposal of all types of gaseous, liquid, and solid waste. During the 1970s, major emphasis in the radioactive waste management program will be placed on industrial application of this control technology. This technology is also being utilized in the establishment of waste management policy and modified regulatory procedures. It is believed this approach represents a continuing example of how the nuclear industry is combining long-range planning and technolgical development for assuring proper effluent control and compliance with applicable environmental quality standards.

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AEC ANNOUNCES PLANS FOR MANAGEMENT OF HIGH-LEVEL RADIOACTIVE WASTES

News Release from AEC, May 18, 1972

The Atomic Energy Commission said today it proposes to design and build engineered surface facilities capable of storing the solidified high-level radioactive wastes produced by the nuclear power industry.

These facilities will be available for use when the first quantities of waste are ready for delivery to the AEC, expected in 1979 or 1980.

At the same time the AEC's research and development program on storage of wastes in salt beds several hundred feet underground, or in other selected geologic formations, is being reoriented toward construction of a pilot plant to verify the information generated by years of laboratory and field experiment work.

All waste stored in both the engineered surface facilities and the underground pilot plant will be under surveillance and control at all times and will be easily retrievable should this be required.

In addition, the Commission will evaluate other waste management options that are not technically feasible at this time but offer potential advantages for later use.

With respect to the overall plan for the management of commercial high-level radioactive waste, AEC Chairman James R. Schlesinger made the following statement: "We are surveying a variety of options for long-term storage of radioactive wastes and will proceed virgorously with a proved method – engineered surface storage – so that the public as well as industry has complete confidence that adequate and safe facilities are available for handling the wastes for the foreseeable future. The acceptability of storing wastes in solidified form in man-made surface facilities has been proved by nearly 10 years of safe operation in such facilities at the AEC's Idaho site.

"The engineered surface facilities will be designed and operated so that the waste can be safely isolated for centuries if necessary. However, the wastes could be moved to goeologic storage facilities, reducing the burden of continued surveillance and control, at any time that geologic storage facilities prove to be acceptable.

"More than fifteen years of laboratory and field work has shown that sealing the wastes in selected geologic formations such as salt offers a high probability of providing the same degree of safety and protection of the environment as surface storage. This, plus the potential advantage of a marked reduction in surveillance and control, make geologic storage attractive as a solution for isolating the wastes from man for the long period of time required.

"We intend to consider requesting authorization and funding from the Congress in the Fiscal Year 1975 budget for initial modules of engineered surface storage facilities and for the pilot facility in a selected geologic formation. Depending on the experience gained in operation of engineered surface storage facilities and the pilot operation in a geologic formation, decisions could be made by the mid 1980s on which of these two options should be expanded."

An AEC contractor at the Commission's Hanford plant near Richland, Washington – Atlantic Richfield Company – will be responsible for conceptual design and development of engineered surface facilities capable of handling industrial high-level radioactive wastes as they are generated. The location of the engineered surface storage facilities will be determined later.

The AEC's Oak Ridge National Laboratory in Tennessee will continue its development program on the use of bedded salt deposits in Kansas for storage of radioactive wastes, including further examination of questions raised with regard to the Lyons, Kansas, salt mine which has been under study by the AEC. ORNL with the help of the U.S. Geological Survey and others will also expand its search for locations in salt and other geological formations outside Kansas. Selection of an acceptable location for the pilot facility is expected to be made in about a year.

The Commission has assigned to Battelle Northwest Laboratories in Richland, Washington, the task of evaluating other concepts of waste management that have been proposed by various AEC laboratories, other government agencies, and private organizations and individuals. These include concepts such as storing of the wastes in very deep holes in the earth or converting the transuranic radioisotopes to shorter-lived materials.

HEATED EFFLUENT WATER FINDS PRODUCTIVE USES

Applying cooling-water effluent to cultivation of fish and plants may help aovid thermal problems

An industrial waste–excess heat produced by electric utilities and manufacturing plants–may find important uses in agriculture and fish culture and at the same time help to solve one of the world's growing pollution problems. This was the conclusion reached by participants at a symposium on beneficial uses of heated effluent water, part of the 32nd annual conference of the Chemurgic Council, held in Washington, D.C.

Thermal pollution–from heated industrial and power plant cooling water poured into the nation's lakes and streams–is a relative latecomer in public concern about pollution, Now, however, despite multiplying demands for electrocity, utilities are encountering strong objections to building power plants–from Biscayne Bay, Fla., and Chesapeake Bay, Md., to Lake Michigan (C&EN, Sept. 28, page 49). Federal industrial heat quotas are already being devised.

By-product. Dispersion of waste heat, like cleanup of potential industrial chemical pollutants, is often approached as simply disposal of a waste product. However, as with many chemical pollutants, waste heat-which must be dealt with otherwise by costly cooling towers or cooling lakes–also presents the opportunity for valuable by-product recovery (C&EN, July 13, page 18). And symposium chairman William C. Yee, Oak Ridge National Laboratory, notes that power companies presently discharge about two thirds of their energy as thermal pollution.

Few agricultural pilot projects using heated water have yet been attempted. Successful results from one of the first were reported at the symposium by Herman H. Miller, Jr., Vitro Corp. of American, Portland, Ore.

Mr. Miller described a field-demonstration project already going for two years on 170 acres in Springfield, Ore. Heated water (between 90° and 130°F.) from a condensing process at a nearby Weyerhaeuser pulp and paper plant is used by seven participating farmers for irrigation, frost protection, cooling crops in summer, and extending the growing season by heating soil in spring and fall.

Expansion to a full-fledged project has now been proposed by Rep. Al Ullman (D.-Ore.). Rep. Ullman suggests establishing a multiuse nuclear power complex in Oregon's Umatilla River basin–experimenting with use of its heated effluent over wide areas.

Greenhouses. A further agricultural use of heated water was described by Carle O. Hodge, Carl N. Hodges, and Merle H. Jensen, University of Arizona, Tucson. Mr. Hodge notes that as much as two thirds of the energy of reciprocating diesel engines–a common energy source at remote settlements–is wasted as heat. In a demonstration project started in 1967 at Puerto Penasco, on the desert coast of northwest Mexico, the Uscson trio is exploiting this thermal energy from diesel generators to desalt sea water. They then use the desalinated water, with added nutrients, to grow high-quality fruits and vegetables within controlled-environment, polyethylene-covered greenhouses. With the aid of the Arizona group, construction is now under way on a similar large-scale power/water/food system (5 acres of greenhouses) in the Arab sheikhdom of Abu Dhabi.

Fish farms. Fish culture has perhaps even greater potential than agriculture for use of heated effluent water. The Japanese are especially advanced in both aquaculture (using fresh water) and mariculture (using sea water). Dr. Won-Tack Yang, University of Miami, told how the Japanese are raising fish and shrimp using power plant effluent waters. In the U.S., a bright future is predicted for aquaculture by symposium participant Alexander Gordeuk of Merck & Co., Inc. (C&EN, Jan. 12, page 49). He also foresees exploitation of heated water in large-scale animal production.

Cases of thermal pollution can be expected to increase drastically in the next few years. Mr. Gordeuk points out that by 1980, electric power plants may require 200 billion gallons of fresh water daily for cooling–one fifth of all the fresh water available in the U.S. Moreover, demand for electricity is doubling every six to 10 years. Mr. Yee, the proponent of multipurpose nuplexes (C&EN, June 8, page 16), therefore strongly urges that more support be given by utility companies, industry, and the Federal Government for use of thermal effluents on a large scale.

ASH–THE USABLE WASTE

Chemical Engineering, April 16, 1973

It may not be long before flyash is considered a "byproduct "rather than a "waste product "of coal- and oil-burning power plants. Likewise for bottom ash and boiler slag.

Jon E. Browning
Senior Associate Editor

Speakers at last month's Third International Ash Utilization Symposium in Pittsburgh often sounded more like salesmen with a product than managers with a problem. As the leadoff speaker, C. E. Brackett, vice-president of Southern Electric Generating Co., put it: *"It now appears as if we are on the threshold of making significant progress in the utilization of ash."*

Statistics back up the optimism: The latest annual figures available show that ash utilization in the U.S. climbed sharply from 1970 to 1971, going from 13% to 20.1%. Translating these percentages into hard numbers–usage rose from 5.1 million tons/yr. to 8.6 million tons/yr., out of total annual productions of 39.2 million tons and 42.8 million tons.*

Much of this increase can be traced to maturing markets for ash sold (Table I) or given away (Table II). As can be seen, the largest usage has been, and continues to be, as fill material for roads, construction sites, etc. But less-obvious applications are beginning to account for significant volumes too, with several recently moving toward commercialization.

Significant in 1972–Brackett summed up some developments of the past year that have high-tonnage potential:

1. A material composed of lime, flyash and sulfate or sulfite sludges was used to pave some access roads and parking areas at Dulles International Airport (Washington, D.C.) for the Transpo '72 exhibition.

2. Two cement companies announced new plants and programs to market for general construction purposes a portland pozzolan cement that is a blend of portland cement and flyash. *"Many parts of the country experienced severe cement shortages during the past summer,"* says Brackett, *"and we are now being told that several other cement companies are looking at these operations with an eye toward increasing their production and improving their product."*

3. A new project in northern West Virginia will use 250,000 tons of bottom ash and boiler slag as aggregate for a new portion of West Virginia's Route 2. Besides conserving dwindling supplies of local natural aggregates, this use of ash is expected to save $500,000 in material costs.

4. Ontario Hydro commenced operation of its flyash processing plant at Mississauga, Ont., to make pozzolan, aggregate, magnetite and carbon products. Also, International Brick and Tyle's flyash brick plant near Edmonton, Alta., has started production; it is designed to initially provide 6.25 million units annually to the face-brick and paving-tile market in western Canada. (Another speaker at the meeting said that the process being used was developed by the Coal Research Bureau of West Virginia University, and that this process will also be used in Czechoslovakia in a plant that will consume about 100,000 tons/yr. of flyash.)

And at the federal level, a specification for *"lime-flyash-aggegate"* base material has been finalized. The specification will become part of the Federal Aviation Administration's construction guidelines. Already, says Brackett, *"Newark and JFK Airports have utilized this type of material in the construction of runways for new, heavier aircraft. Similar pavements are being designed for airports at other locations."*

Transpo '72–Providing the technical expertise and knowhow for the paving project at Dulles was the G. & W. H. Corson Co., Plymouth Meeting, Pa. (acquired by IU Conversion Systems, Inc. in March 1972). The firm has been a pioneer in the development of flyash-aggregate road-base applications.

In describing the test program at Dulles, IU Conversion's executive vice-president, L. John Minnick, says that there were seven basic compositions supplied to the Transpo '72 project, each of which utilized flyash together with other industrial waste materials. The latter included sulfur oxide sludge, acid-mine-drainage sludge, and

*These ash production figures are for electrical utilities, which account for 60% of the bituminous coal and 80% of the ash-producing oil that is consumed in the U.S.

sulfur-oxide waste discharge from a chemical plant. Despite heavy rainfalls that produced less than ideal conditions for the paving operation, *"after one year, careful inspection has indicated that the base is in good condition,"* says Minnick.

He adds: *"Based on these projects, several supplementary programs are now being organized, and it is believed that a number of these composition will find widespread use in the construction field not only as road base, but for embankments, reservoirs, dams, land improvement projects, etc."*

Research in Progress--An extensive look at current research in the U.S. was provided in a paper prepared by John F. Slonaker (Project Supervisor) and Joseph W. Leonard (Director) of the Coal Research Bureau, School of Mines, West Virginia University (Morgantown). Here is a sampling of projects (and their investigators) that may result in broader ash usage:

Agriculture Fertilizer. Revegetation of coal-mine spoil through use of flyash as a neutralizing agent and diluent at an estimated cost of $300/acre (U.S. Bureau of Mines); addition of flyash to soils subjected to continuous usage (camping areas, hiking trails, etc.) to increase the soils' moisture-holding capability and enhance the growth of grass (U.S. Park Service); determination of plant nutrient factors in flyash (Virginia Polytechnic Institute and State University).

Brick Manufacture. Addition of 25% Western Flyash to clay to extend the use of clay (or shale) deposits (North Dakota University). Further development of a process for making high-quality bricks (Coal Research Bureau, West Virginia University).

Aggegate Substitute Lignite ash is being produced as a synthetic aggregate (Texas A&M University); lignite flyash is being investigated as a filler in asphaltic concrete (North Dakota University).

Reclamation, Land and Water. Plans are to spread 9,350 tons of flyash over five acres of sanitary landfill (Dept. of Civil Engineering, West Virginia University); research into the use of flyash as structural fill for soils that have poor water drainage (University of Illinois); study of the use of flyash to remove phosphates and to seal bottom mud so as to prevent the release of pollutants and reclaim small eutrophic or algae-overgrown lakes (Notre Dame University); further development of a process that uses ash for water ,treatment, where ash addition increases the rate of growth of flocs, enhances steeling, and acts as a physical aid to condition waste sludge by removing phosphates and absorbing organic molecules from solution (Polytechnic Institute of Brooklyn).

Fire Control. Control of spontaneous combustion in mine-refuse piles, using a mixture of 25% flyash and 75% mine refuse (American Electric Power Service Corp.); investigation of forest-fire extinguishing with flyash (Seaboard Flyash Co.).

CHAPTER 7

PLANT SITE CONSIDERATIONS

A. OBJECTIVES

1. The student will describe the ecological, geological, meteorological, geographical, and demographic considerations which must be taken into consideration in plant site selection.

2. The student will describe future siting possibilities for nuclear plants.

B. ACTIVITIES

1. Hold a class discussion of the advantages and disadvantages of an underground *"energy center"* rather than presently existing sites.

2. Have several students prepare reports describing the advantages and disadvantages of offshore nuclear plant sites.

3. Bring in an outside speaker from a state or federal agency to discuss power plant site selection.

4. Consider the following problem:

   a. Locate 3 (or any other number you choose) new generating plants in your state. Establish their exact sites.

   b. Determine the type of fuel to be used in the plants. Be able to defend your choice.

   c. Try to benefit lower socio-economic groups when you pick the sites. Describe how you plan to do this.

   d. What might the reactions to each site be from a banker, an educator, an industrialist, an conservation club president, a hospital manager, a realtor, and a supermarket owner? What are your own reactions?

C. AUDIO-VISUAL MATERIALS

1. *"Earthquake"* 16mm sound, 13 1/2 min. Describes earthquake studies and engineering adaptations in building construction. Available from Film Associates.

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BACKGROUND INFORMATION FOR THE TEACHER

POWER PLANT SITING ACT OF 1971
DRAFT OF PROPOSED FEDERAL GUIDELINES

SECTION 1 - SCOPE

These proposed guidelines are intended to serve as the basis for meeting the requirements set out in the Power Plant Siting Act of 1971, legislation submitted to the Congress by the President on February 10, 1971, and designated H.R. 5277 and S. 1684 (hereinafter *"the Act"*).

SECTION 2 - PURPOSE

The purpose of these guidelines is to assure the establishment of State or regional certifying agencies capable of providing the judgments required under the Act. To this end, these guidelines provide the basis for the establishment of a decision-making process and timely and effective procedures within each certifying agency to assure competent, prompt determination and resolution of environmental and power issues within its jurisdiction. Additionally, these guidelines are designed (i) to intergrate, to the extent possible, any associated review, licensing, and permit granting activities of the Federal Government with the State or regional procedures, so as to achieve as close to a complete one-stop certification procedure as is possible; and (ii) to provide guidance for the certification procedure of the Federal certifying agency.

SECTION 3 - POLICY

The policy intended to be carried out by these guidelines is to allow the States (or groups of States which elect to act as a regional certifying agency) maximum flexibility within the requirements of this Act to experiment and to develop those procedures for the certification of sites, routes, and facilities which best fit the particular conditions and requirements of each jurisdiction. The primary requirement is that the certifying agency be capable of professionally evaluating and balancing both the need for electric power facilities and the need to protect environmental values.

SECTION 4 - COMPOSITION OF THE STATE OR REGIONAL CERTIFYING AGENCY

a. *Type of Agency* - These guidelines seek to provide the framework for a broad variety of options to State governments in the formation of State and regional certifying agencies. These decision-making bodies may be existing agencies, newly created agencies, or boards consisting of members from an appropriate spectrum of existing State agencies. The decision-making authority may be located with the State Public Utilities Commission, although in such cases care must be taken to insure adequate consideration of environmental aspects through the requirements for participation discussed hereafter and in the manner discussed in Sections 7 and 8 of the Act. It may be located within a State environmental protection agency, although in such cases care must be taken to insure adequate consideration of the need for facilities through participation requirements hereafter. Other possibilities with perhaps greater potential for balancing power and environmental needs would be the State land-use planning agency, the State natural resources agency, or a State siting agency with representatives from the interested existing State agencies. In some cases, States may wish to place final authority with the Governor. To the extent possible, the Federal certifying agency shall allow each State to adopt a State body that best serves the purposes of the Act within its jurisdiction.

In some cases, a pre-existing agency of the State government may be qualified as the State certifying agency, or may serve as the basic agency to which a new office is attached to carry out the functions assigned under the Act. Where the pre-existing agency has a clear identification with either aspect of the power-environment equation, extreme care must be taken to insure that the criteria set out in this section are fully met. It is the intention of this section to encourage the formation of a State or regional certifying agency meriting the confidence of the public as to its competence and objectivity with respect to both electric power needs and environmental protection.

b. *Participation* - Section 5(a) of the Act requires participation in the decision-making process of the certifyingagency by environmental protection, natural resource, planning, and electric power regulatory agencies of the State government and authorizes participation by members of the public.

"Participation" by components of State government means either taking part as a voting member of the decision-making body of the certifying agency or acting in an advisory capacity to that agency with respect to the aspect of its decision within the participant's area of competence. Where such participation is limited to an advisory capacity in the participant's area of special competence, such advice shall be submitted in writing and made public and the certifying agency may depart from such advice only if it determines and can demonstrate that departure is necessary to accomplish tne overall objectives of the certification process. In any event certifying agencies must ascertain that all applicable Federal standards, permits, or licenses for the project have been satisfied or obtained as required by Section 7 of the Act. In the case of Federal water and air quality standards, the satisfaction shall be determined by the duly authorized State water and air pollution control agencies. *"Federal standards"* means standards established or approved by a Federal agency.

"Participation" with respect to the public means by making comments or being permitted to become a party to proceedings involving applications in which such person has an interest.

c. *Staff* - the State or regional certifying agency must have a competent and interdisciplinary professional and technical staff capable of dealing with those environmental and power issues which come before it. The Governor, in his request for a Certificate of Qualification from the Federal certifying agency shall describe the composition of the staff. In some cases, the State or regional certifying agency may find that employment of such a staff on a full-time basis would not be justified based on the anticipated work-load. Where this occurs, the Governor shall specify the manner in which the State or regional certifying agency will call upon consultants or experts from other agencies of Government to assure a balanced determination of issues.

d. *Finance* - The State or regional certifying agency shall be authorized to assess and collect fees from electric entities within its jurisdiction to cover the cost of administration of its functions under the Act. The application for a Certificate of Qualification must show to the satisfaction of the Federal certifying agency how the State or regional certifying agency will be financed in a manner adequate to carry out the purposes of the Act.

SECTION 5 - REVIEW AND COMMENT ON LONG-RANGE PLANS

Section 8(a) of the Act sets out the responsibilities of the certifying agencies to review and comment upon the long-range plans prepared and filed pursuant to Section 4 thereof. Each electric entity operating within the jurisdiction of a certifying agency shall file with it the annual long-range planning document by April 1 of each year. Electric entities will be encouraged to combine plans into a single regional plan in coordination with the procedures outlined in Order 383-2 of the Federal Power Commission, authorizing voluntary annual reports from electric reliability councils covering the continental United States. The Act, however, requires the provision of information not now requested under the FPC procedures, including the preliminary identification of sites and routes planned for use within the next five years, an analysis of efforts to meet environmental protection goals, and other requirements outlined in Section 4 of the Act.

Each certifying agency shall compile and publish by September 1 of each year its review and comments on the annual plans filed with it by the preceding April 1. The intent of this publication is to summarize the long-range plans of electric entities operating within its jurisdiction, their relation to adjoining jurisdictions, and to evaluate the adequacy of these plans from the point of view of providing adequate electric power while maintaining environmental values. The publication and distribution of this report by the certifying agency shall be according to the requirements set forth in Section 8(a) of the Act.

SECTION 6 - PRELIMINARY REVIEW AND HEARINGS ON PROPOSED SITES

As part of its September 1 report on long-range planning by the electric entities within its jurisdiction, the certifying agency shall also publish the compilation of proposed power plant sites and general locations of transmission lines as required in Section 4(a) (2) and Section 8(b) of the Act for all facilities, construction of which is planned to commence within five years. With respect to proposed power plant sites, public hearings shall be held during the period September 1 to December 15 of each year on each newly-identified site, and the certifying agency shall determine whether or not such site is to be placed on the list of approved sites by February 15 of the next year, less than one year after

such appeared on the plans of the electric entity. The decision of the certifying agency shall be according to the standards set out in Section 8(c) of the Act. Each site shall receive either:

(1) preliminary approval as a site, subject to review at the time of application for certification only with respect to changed conditions (other factors not considered in this preliminary review such as the facility design would, of course, be reviewed during the certification procedure); or

(2) preliminary conditional approval as a site, subject to review at the time of application for certification with respect to changed conditions, and with respect to conditions placed on the nature or extent of the facilities to be placed thereon. (Approval here would be the same as (1) except that site may be conditioned for a nuclear or fossil fueled plant only, for example); or

(3) suspension pending further study, because the construction of any bulk power facility on the site might unduly impair important environmental values. Such suspension may extend for no more than three years during which time the electric entity together with appropriate environmental agencies must actively seek to determine whether important environmental values would be impaired. Following the period of suspension the site may be resubmitted and the certifying agency must give preliminary approval, prelimmary conditional approval, or disapproval of the site; or

(4) disapproval as a site because the construction of any bulk power facility on the site would unduly impair important environmental values. Such disapproval shall be final and not subject to resubmission for consideration as a site unless there is clear evidence of changed conditions.

SECTION 7 - CERTIFICATION OF FACILITIES

For all bulk power facilities covered by this Act, the appropriate electric entity shall apply for certification of site and facility at least two years prior to planned commencement of construction, as provided for in Sections 6 and 7 of the Act. In addition to any other such information which the certifying agency may require, the electric entity shall provide with its application a detailed statement on:

i. The environmental impact of the proposed facility.

ii. Any adverse environmental effect which cannot be avoided if the facility is constructed and operated as proposed.

iii. Alternative locations, measures, or other actions.

iv. The relationship between the short-term environmental impact of the proposed facility and the maintenance and enhancement of long-term productivity.

v. Any irreversible and irretrievable commitments of resources if the proposed facility is constructed.

Notice of receipt of such application shall be made as provided in Section 8(d) of the Act, and the two-year period shall be considered to begin to run from the time of first publication, which shall in all cases occur within 30 days of the actual receipt of a valid application. Hearings to consider the proposed certification shall commence within 6 months of publication and to the extent possible a decision of the certifying agency shall be reached and published within one year. Failure to reach such conclusion or to indicate that a decision is imminent after a one-year period has passed from date of publication shall be grounds for the electric entity to petition the Federal certifying agency under Section 6 (d) of the Act. Except where, for good cause shown, the site has not been drawn from the list of approved sites as provided for under Section 6(b) of the Act, the review of the power plant site shall be limited as described above in Section 6 of these Guidelines.

SECTION 8 - ONE-STOP PROCEDURE

a. *State or Regional Certifying Agency* - the Act is intended to provide in a single procedure final decisions on all State and local government approvals required for the construction and operation of bulk power supply facilities. It also attempts to coordinate and integrate all necessary reviews of environmental concerns by Federal agencies so as to achieve as close to a complete one-stop procedure as is possible.

Section 7(a) of the Act states that the judgment of the appropriate certifying body shall be conclusive on all questions of siting, land use, State air and water quality standards, public convenience and necessity, aesthetics, and any other State or local requirement. *"Judgment. ..shall be conclusive"* means that the State has provided through appropriate use of its

legislative and/or executive authority for the issuance of a Certificate of Site and Facility by a qualified State or regional cerifying agency which shall certify that all Federal permits, licenses, or standards have been satisfied or obtained and which shall incorporate or supersede any requirements for the issuance of any permit, license, or certificate for the facility involving environmental and power supply concerns required under a State or local statute such that:

(1) the requirements of such State or local permit, license, or certificate are specifically considered in the application for and the issuance of the Certificate of Site and Facility;

(2) the State or local agency responsible for issuing any such permit, license, or certificate participates in the decision-making process as defined in Section 4(b) of these Guidelines; and

(3) the facility is designed, built, and operated in accordance with the specifications provided by the applicant as modified by any further conditions imposed by the certifying agency in the Certificate of Site and Facility.

Where standards of air or water quality established or approved by a Federal agency are to be applied the determination of whether or not a proposed facility will meet such standards shall be with the duly authorized State air or water pollution control agency. In cases whereby under Federal or State laws or regulations a permit, license, or certificate is dependent upon the granting of another such permit, license, or certificate, the State certifying agency shall provide for any necessary flow of information to assure an orderly and timely certification process.

In order to facilitate efficient consideration of applications for certification, each State or regional certifying agency shall develop a consolidated application form which shall be the sole application necessary for all approvals of State and local governments. All requests for further information and all other correspondence related to the certification shall be made only by or through or with the prior approval of the authorized certifying agency.

All Federal agencies with statutory authority for granting licenses, certificates, or permits prior to the construction or operation of a bulk power facility shall, to the fullest extent possible, coordinate their activities, including the time and place of any public hearings and related reviews, with the appropriate State or regional certifying agency. Federal agencies with advisory authority shall supply such advice directly to the certifying agency in compliance with its timetable. Federal agencies shall reduce to an absolute minimum the information required of appliccants above that already presented in the consolidated application to the certifying agency. Such agencies are not required to prepare the detailed statements of environmental impact contemplated in Section 102 (2) (C) of the National Environmental Policy Act of 1969 where the certifying agency has followed a substantially comparable procedure.

b. *Federal Certifying Agency* - In those cases in which the Federal certifying agency exercises jurisdiction either because of the absence of a qualified State certifying agency or upon appeal pursuant to Section 6(d) of the Act, the Federal certifying agency shall provide a one-stop procedure except for license applications before the Atomic Energy Commission which shall be coordinated with the review of the Federal certifying agency. Any other Federal licenses or permits or approvals which may be required shall be considered and decided as an integral part of the review by the Federal certifying agency. The Federal certifying agency, the Environmental Protection Agency, the U.S. Army Corps of Engineers, and any affected Federal land management agencies shall hold any hearings on each application jointly and shall fully coordinate reviews and approvals required by their respective responsibilities under Federal law. Other Federal agencies shall render written advice in their areas of special competence with respect to environmental or power supply aspects of the project and the Federal certifying agency may depart from such advice in its decision only if it determines and can demonstrate that departure is necessary to accomplish the overall objectives of the certification process.

The Federal certifying agency shall operate under these Guidelines except where they are inapplicable and shall develop a consolidated application form, except for the AEC license application, to cover all Federal statutory requirements. The decision of the Federal certifying agency shall be rendered within the one-year period after receipt of an application and, if not, the agency will be required to issue a statement explaining why it has failed to act. The Federal certifying agency shall promulgate procedures

and schedule hearings to assure time for a final decision within the two-year period contemplated in the Act. The Federal certifying agency shall have exclusive jurisdiction over the application applying Federal standards only, as provided in Section 5(c) of the Act and such certificate shall supersede any requirements of State or local law with respect to permits, licenses, or standards applicable to the project but such certificate shall be issued only if the Federal certifying agency has ascertained that all Federal permits, licenses, or standards have been satisfied or obtained as required by Section 7 of the Act. Federal standards mean standards established by or approved by a Federal agency.

SECTION 9 - EVALUATIVE CRITERIA

In evaluating long-range plans, conducting preliminary site reviews, and evaluating the application for certification of bulk power supply facilities, the certifying agency shall give consideration to the following factors where applicable:

a. *Electric Energy Needs*
(major emphasis of long-range plan reviews)

(1) Growth in demand and projections of need.

(2) Availability and desirability of non-electric alternative sources of energy.

(3) Availability and desirability of alternative sources of electric power to this facility or to this type of facility.

(4) Promotional activities of the electric entity which may have given rise to the need for this facility.

(5) Socially beneficial uses of the output of this facility, including its use to protect or enhance environmental quality.

(6) Conservation activities which could minimize the need for more power.

(7) Research activities of the electric entity or new technology available to it which might minimize environmental impact.

b. *Land Use Impacts*
(major emphasis of preliminary site reviews)

(1) Area of land required and ultimate use.

(2) Consistency with any State and regional land use plans.

(3) Consistency with existing and projected area land use.

(4) Alternative uses of the site.

(5) Impact on population already in the area; population attracted by construction or operation of the facility itself; impact of availability of power from this facility on growth patterns and population dispersal.

(6) Geologic suitability of the site or route.

(7) Seismologic characteristics.

(8) Construction practices.

(9) Extent of erosion, scouring, wasting of land–both at site and as a result of fossil fuel demands of the facility.

(10) Corridor design and construction precautions for transmission lines.

(11) Scenic impacts.

(12) Effects on natural systems, wildlife, plant life.

(13) Impacts on important historic, architectural, archeological, and cultural areas and features.

(14) Extent of recreation opportunities and related compatible uses.

(15) Public recreation plan for the project.

(16) Public facilities and accommodation.

c. *Water Resources Impacts*
(major emphasis during preliminary site reviews and facility certification)

(1) Hydrologic studies of adequacy of water supply and impact of facility on stream flow, estuarine and coastal waters, and lakes and reservoirs.

(2) Hydrologic studies of impact of facilities on ground water.

(3) Cooling system evaluation including consideration of alternatives.

(4) Inventory of effluents including physical, chemical, biological, and radiological characteristics.

(5) Hydrologic studies of effects of effluents on receiving waters, including mixing characteristics of receiving waters, changed evaporation due to temperature differentials, and effect of discharge on bottom sediments.

(6) Relationship to water quality standards.

(7) Effects of changes in quantity and quality on water use by others, including both withdrawal and in situ uses; relationship to projected uses, relationship to water rights.

(8) Effects on plant and animal life, including algae, macroinvertebrates, and fish population.

(9) Effects on unique or otherwise significant ecosystems; e.g., wetlands.

(10) Monitoring programs.

d. *Air Quality Impacts*
(major emphasis during preliminary site reviews and facility certification)

(1) Meterology–wind direction and velocity, ambient temperature ranges, precipitation values, inversion occurrence, other effects on dispersion.

(2) Topography–factors effecting dispersion.

(3) Standards in effect and projected for emissions, design capability to meet standards.

(4) Emissions and controls.

a. Stack design
b. Particulates
c. SO_x
d. NO_x

(5) Relationship to present and projected air quality of the area.

(6) Monitoring program.

e. *Solid Wastes Impact*
(major emphasis during facility certification)

(1) Solid waste inventory.

(2) Disposal program.

(3) Relationship of disposal practices to environmental quality standards.

(4) Capability of disposal sites to accept projected waste loadings.

f. *Radiation Impacts*
(major emphasis during preliminary site review and facility certification)

(1) Land use controls over development and population.

(2) Wastes and associated disposal program for solid liquid and gaseous wastes–criteria set by AEC and EPA.

(3) Analyses and studies of the adequacy of engineering safeguards and operating procedures–determined by AEC.

(4) Monitoring–adequacy of devices and sampling techniques.

g. *Noise Impacts*
(major emphasis during facility certification)

(1) Construction period levels.

(2) Operational levels.

(3) Relationship of present and projected noise levels to existing and potential stricter noise standards.

(4) Monitoring–adequacy of devices and methods.

SECTION 10 - EVALUATION OF RELATIVE ENVIRONMENTAL EFFECTS OF ALTERNATIVE SITES AND ROUTES

To the extent possible, only those sites and routes meeting acceptable standards in relation to the criteria outlined in Section 9 of these Guidelines should receive certification from the appropriate certifying agency. Regularly, however, it will be necessary in order to meet recognized electric power needs that a site or route be chosen from a set of alternatives, all of which will present some adverse environmental effects. In such cases it will be necessary for the certifying agency to establish priorities among the evaluative criteria employed. For example in the case of transmission lines, the priority might be assigned to the land use criteira outlined in Section 9 above; in the case of fossil-fueled power plants the air quality criteria might prevail; and the water quality criteria might prevail for nuclear plants. Assignment of such priorities is not intended to eliminate full consideration of other criteria listed in Section 9, but merely provides guidance for the resolution of difficult cases where a choice among alternatives would otherwise be impossible.

SECTION 11 - FORMATION OF REGIONAL CERTIFYING AGENCY

At any time during the period that this Act is in force, including the two-year period during which programs are being established under it, two or more States may join together and apply for a Certificate of Qualification for a regional certifying agency. Such a regional agency shall be subject to all provisions of these guidelines, except that in the case of facilities located entirely within one State and with no impacts on other member States, the participation required under Section 5(a) of the Act may be limited to governmental components of that one State. It is the intention of this Section to provide maximum flexibility to States in the formation of multi-State certifying agencies under the Act.

SECTION 12 - MULTI-STATE IMPACTS

In those cases where the certifying agency authorized to operate in a State or region believes that an application under consideration by the certifying agency of an adjacent State or region will have potentially harmful effects on the environment within its jurisdiction if granted, or potentially harmful effects on the power needs within its jurisdiction if denied, it may in its own judgment choose one of the following means of involvement:

(1) Where it considers the harm to be of a major nature or conditional upon the occurrence of events considered unlikely, the certifying agency which believes its jurisdiction affected may send a letter of comment to the reviewing cerifying agency of the adjacent jurisdiction.

(2) Where it considers the harm to be considerable and likely to occur, the certifying agency may enter as an intervenor the proceedings of the reviewing certifying agency of the adjacent jurisdiction.

NUCLEAR POWER PLANT LICENSING REGULATIONS PERTAINING TO ENVIRONMENTAL RADIOACTIVITY

THE CALVERT CLIFFS DECISION

On July 23, 1970 the U.S. Court of Appeals for the District of Columbia Circuit ruled on the case of the Calvert Cliffs Coordinating Committee, Inc., et al., petitioners, vs the United States Atomic Energy Commission and the United States of America, respondents. This appeal concerned an alleged failure of the AEC to implement the National Environmental Protection Act. The court found fault with the Atomic Energy Commission on four counts:

1. The procedural rules of the Atomic Energy Commission prohibit the raising of non-radiological environmental issues at any hearing if the hearing notice appeared in the Federal Register before March 4, 1971.

2. The Atomic Safety and Licensing Board is prohibited from conducting an independent evaluation and balancing of certain environmental factors if other responsible agencies have already certified that their own environmental standards are satisfied.

3. That the Atomic Safety and Licensing Board hearing need not cover environmental issues unless specifically raised by outside parties or the Atomic Energy Commission.

4. That the AEC rules provide that when a construction permit has been issued prior to January 1, 1970, but an operating license has yet to be issued, the AEC will not formally consider environmental factors or require modifications in the proposed facility until the time of issuance of the operating license.

The Court held that:

1. Environmental issues must be considered at every stage of decision making, including ASLB Hearings.

2. The AEC must consider environmental issues in connection with all licensing actions that took place after January 2, 1970.

3. The AEC must evaluate and balance environmental standards even if other federal or state agencies have certified that their own standards are satisfied.

4. The AEC must conduct a National Environmental Protection Act review and take appropriate action for cases in which construction permits have been issued before January 1, 1970, but for which operating licenses have not yet been issued.

The Atomic Energy Commission did not appeal the Court decision and, in the Federal Register of September 9, 1971, issued new guidelines and regulations to meet all the demands of the court.

For your general background information concerning licensing of nuclear power plants, the following section of the *Federal Register* is suggested:

FEDERAL REGISTER, Vol. 36, No. 35-Saturday, February 20, 1971.

TITLE 10 -- ATOMIC ENERGY

Chapter 1-Atomic Energy Commission

PART 50-LICENSING OF PRODUCTION AND UTILIZATION FACILITIES.

General Design Criteria for Nuclear Power Plants

The Atomic Energy Commission has adopted an amendment to its regulations, 10 CFR Part 50, *"Licensing of Production and Utilization Facilities,"* which adds an Appendix A, *"General Design Criteria for Nuclear Power Plants."*

Section 50.34(a) of Part 50 requires that each application for a construction permit include the preliminary design of the facility. The following information is specified for inclusion as part of the preliminary design of the facility:

i. The principal design criteria for the facility
ii. The design bases and the relation of the design bases to the principal design criteria
iii. Information relative to materials of construction, general arrangement, and the approximate dimensions, sufficient to provide reasonable assurance that the final design will conform to the design bases with adequate margin for safety.

The *"General Design Criteria for Nuclear Power Plants"* added as Appendix A to Part 50 establish the minimum requirements for the principal design criteria for water-cooled nuclear power plants similar in design and location to plants

for which construction permits have been issued by the Commission. They also provide guidance in establishing the principal design criteria for other types of nuclear power plants. Principal design criteria established by an applicant and accepted by the Commission will be incorporated by reference in the construction permit. In considering the issuance of an operating license under Part 50, the Commission will require assurance that these criteria have been satisfied in the detailed design and construction of the facility and that any changes in such criteria are justified.

A proposed Appendix A, "General Design Criteria for Nuclear Power Plant Construction Permits" to 10 CFR Part 50 was published in the FEDERAL REGISTER (32 F.R. 10213) on July 11, 1967. The comments and suggestions received in response to the notice of proposed rule making and subsequent developments in the technology and in the licensing process have been considered in developing the revised criteria which follow.

The revised criteria establish minimum requirements for water-cooled nuclear power plants similar in design and location to plants for which construction permits have been issued by the Commission, whereas the previously proposed criteria would have provided guidance for applicants for construction permits for all types of nuclear power plants. The revised criteria have been reduced to 55 in number, include definitions of important terms, and have been rearranged to increase their usefulness in the licensing process. Additional criteria describing specific requirements on matters covered in more general terms in the previously proposed criteria have been added to the criteria. The Categories A and B used to characterize the amount of information needed in Safety Analysis Reports concerning each criterion have been deleted since additional guidance on the amount and detail of information required to be submitted by applicants for facility licenses at the construction permit stage is now included in § 50.34 of Part 50. The term "engineered safety features" has been eliminated from the revised criteria and the requirements for "engineered safety features" incorporated in the criteria for individual systems.

Further revisions of these General Design Criteria are to be expected. In the course of the development of the revised criteria, important safety considerations were identified, but specific requirements related to some of these considerations have not as yet been sufficiently developed and uniformly applied in the licensing process to warrant their inclusion in the criteria at this time. Their omission does not relieve any applicant from considering these matters in the design of a specific facility and satisfying the necessary safety requirements. These matters include:

(i) Consideration of the need to design against single failures of passive components in fluid systems important to safety.

(ii) Consideration of redundancy and diversity requirements for fluid systems important to safety. A "system" could consist of a number of subsystems each of which is separately capable of performing the specified system safety function. The minimum acceptable redundancy and diversity of subsystems and components within a subsystem and the required interconnection and independence of the subsystems have not yet been developed or defined.

(iii) Consideration of the type, size, and orientation of possible breaks in the components of the reactor coolant pressure boundary in determining design requirements to suitably protect against postulated loss of coolant accidents.

(iv) Consideration of the possibility of systematic, nonrandom, concurrent failures of redundant elements in the design of the protection systems and reactivity control systems.

In addition, the Commission is giving consideration to the need for development of criteria relating to protection against industrial sabotage and protection against common mode failures in systems, other than the protection and reactivity control systems, that are important to safety and have extremely high reliability requirements.

It is expected that these criteria will be augmented or changed when specific requirements related to these and other considerations are suitably identified and developed.

Pursuant to the Atomic Energy Act of 1954, as amended, and sections 552 and 553 of title 5 of the United States Code, the following amendment to 10 CFR Part 50 is published as a document subject to codification to be effective 90 days after publication in the FEDERAL REGISTER. The Commission invites all interested persons who desire to submit written comments or suggestions in connection with the amendment to send them to the Secretary, U.S. Atomic Energy Commission, Washington, D.C. 20545, Attention: Chief, Public Proceedings Branch, within 45 days after publication of this notice in the FEDERAL REGISTER. Such submissions will be given consideration with the view to possible further amendments. Copies of comments may be examined in the Commission's Public Document Room at 1717 H Street NW., Washington, DC.

1. Section 50.34(a)(3)(i) is amended to read as follows:

§ 50.34 Contents of applications; technical information.

(a) *Preliminary safety analysis report.* Each application for a construction permit shall include a preliminary safety analysis report. The minimum information to be included shall consist of the following:

* * * * *

(3) The preliminary design of the facility including:

(i) The principal design criteria for the facility.* Appendix A, General Design Criteria for Nuclear Power Plants, establishes minimum requirements for the principal design criteria for water-cooled nuclear power plants similar in design and location to plants for which construction permits have previously been issued by the Commission and provides guidance to applicants for construction permits in establishing principal design criteria for other types of nuclear power units:

* * * * *

2. A new Appendix A is added to read as follows:

APPENDIX A—GENERAL DESIGN CRITERIA FOR NUCLEAR POWER PLANTS

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* General design criteria for chemical processing facilities are being developed.

INTRODUCTION

Pursuant to the provisions of § 50.34, an application for a construction permit must include the principal design criteria for a proposed facility. The principal design criteria establish the necessary design, fabrication, construction, testing, and performance requirements for structures, systems, and components important to safety; that is, structures, systems, and components that provide reasonable assurance that the facility can be operated without undue risk to the health and safety of the public.

These General Design Criteria establish minimum requirements for the principal design criteria for water-cooled nuclear power plants similar in design and location to plants for which construction permits have been issued by the Commission. The General Design Criteria are also considered to be generally applicable to other types of nuclear power units and are intended to provide guidance in establishing the principal design criteria for such other units.

The development of these General Design Criteria is not yet complete. For example, some of the definitions need further amplification. Also, some of the specific design requirements for structures, systems, and components important to safety have not as yet been suitably defined. Their omission does not relieve any applicant from considering these matters in the design of a specific facility and satisfying the necessary safety requirements. These matters include:

(1) Consideration of the need to design against single failures of passive components in fluid systems important to safety. (See Definition of Single Failure.)

(2) Consideration of redundancy and diversity requirements for fluid systems important to safety. A "system" could consist of a number of subsystems each of which is separately capable of performing the specified system safety function. The minimum acceptable redundancy and diversity of subsystems and components within a subsystem, and the required interconnection and independence of the subsystems have not yet been developed or defined. (See Criteria 34, 35, 38, 41, and 44.)

(3) Consideration of the type, size, and orientation of possible breaks in components of the reactor coolant pressure boundary in determining design requirements to suitably protect against postulated loss-of-coolant accidents. (See Definition of Loss of Coolant Accidents.)

(4) Consideration of the possibility of systematic, nonrandom, concurrent failures of redundant elements in the design of protection systems and reactivity control systems. (See Criteria 22, 24, 26, and 29.)

It is expected that the criteria will be augmented and changed from time to time as important new requirements for these and other features are developed.

There will be some water-cooled nuclear power plants for which the General Design Criteria are not sufficient and for which additional criteria must be identified and satisfied in the interest of public safety. In particular, it is expected that additional or different criteria will be needed to take into account unusual sites and environmental conditions, and for water-cooled nuclear power units of advanced design. Also, there may be water-cooled nuclear power units for which fulfillment of some of the General Design Criteria may not be necessary or appropriate. For plants such as these, departures from the General Design Criteria must be identified and justified.

DEFINITIONS AND EXPLANATIONS

Nuclear power unit. A nuclear power unit means a nuclear power reactor and associated equipment necessary for electric power generation and includes those structures, systems, and components required to provide reasonable assurance the facility can be operated without undue risk to the health and safety of the public.

Loss of coolant accidents. Loss of coolant accidents mean those postulated accidents that result from the loss of reactor coolant at a rate in excess of the capability of the reactor coolant makeup system from breaks in the reactor coolant pressure boundary, up to and including a break equivalent in size to the double-ended rupture of the largest pipe of the reactor coolant system.[1]

Single failure. A single failure means an occurrence which results in the loss of capability of a component to perform its intended safety functions. Multiple failures resulting from a single occurrence are considered to be a single failure. Fluid and electric systems are considered to be designed against an assumed single failure if neither (1) a single failure of any active component (assuming passive components function properly) nor (2) a single failure of a passive component (assuming active components function properly), results in a loss of the capability of the system to perform its safety functions.[2]

Anticipated operational occurrences. Anticipated operational occurrences mean those conditions of normal operation which are expected to occur one or more times during the life of the nuclear power unit and include but are not limited to loss of power to all recirculation pumps, tripping of the turbine generator set, isolation of the main condenser, and loss of all offsite power.

[1] Further details relating to the type, size, and orientation of postulated breaks in specific components of the reactor coolant pressure boundary are under development.

[2] Single failures of passive components in electric systems should be assumed in designing against a single failure. The conditions under which a single failure of a passive component in a fluid system should be considered in designing the system against a single failure are under development.

CRITERIA

I. Overall Requirements

Criterion 1—Quality standards and records. Structures, systems, and components important to safety shall be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety functions to be performed. Where generally recognized codes and standards are used, they shall be identified and evaluated to determine their applicability, adequacy, and sufficiency and shall be supplemented or modified as necessary to assure a quality product in keeping with the required safety function. A quality assurance program shall be established and implemented in order to provide adequate assurance that these structures, systems, and components will satisfactorily perform their safety functions. Appropriate records of the design, fabrication, erection, and testing of structures, systems, and components important to safety shall be maintained by or under the control of the nuclear power unit licensee throughout the life of the unit.

Criterion 2—Design bases for protection against natural phenomena. Structures, systems, and components important to safety shall be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions. The design bases for these structures, systems, and components shall reflect: (1) Appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena and (3) the importance of the safety functions to be performed.

Criterion 3—Fire protection. Structures, systems, and components important to safety shall be designed and located to minimize, consistent with other safety requirements, the probability and effect of fires and explosions. Noncombustible and heat resistant materials shall be used wherever practical throughout the unit, particularly in locations such as the containment and control room. Fire detection and fighting systems of appropriate capacity and capability shall be provided and designed to minimize the adverse effects of fires on structures, systems, and components important to safety. Firefighting systems shall be designed to assure that their rupture or inadvertent operation does not significantly impair the safety capability of these structures, systems, and components.

Criterion 4—Environmental and missile design bases. Structures, systems, and components important to safety shall be designed to accommodate the effects of and to be compatible with the envrionmental conditions associated with normal operation, maintenance, testing, and postulated accidents, including loss-of-coolant accidents. These structures, systems, and components shall be appropriately protected against dynamic effects, including the effects of missiles, pipe whipping, and discharging fluids, that may result from equipment failures and from events and conditions outside the nuclear power unit.

Criterion 5—Sharing of structures, systems, and components. Structures, systems, and components important to safety shall not be shared among nuclear power units unless it can be shown that such sharing will not significantly impair their ability to perform their safety functions, including, in the event of an accident in one unit, an orderly shutdown and cooldown of the remaining units.

36 FR 12731

36 FR 3255

II. Protection by Multiple Fission Product Barriers

Criterion 10—Reactor design. The reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences.

Criterion 11—Reactor inherent protection. The reactor core and associated coolant systems shall be designed so that in the power operating range the net effect of the prompt inherent nuclear feedback characteristics tends to compensate for a rapid increase in reactivity.

Criterion 12—Suppression of reactor power oscillations. The reactor core and associated coolant, control, and protection systems shall be designed to assure that power oscillations which can result in conditions exceeding specified acceptable fuel design limits are not possible or can be reliably and readily detected and suppressed.

Criterion 13—Instrumentation and control. Instrumentation shall be provided to monitor variables and systems over their anticipated ranges for normal operation, for anticipated operational occurrences, and for accident conditions as appropriate to assure adequate safety, including those variables and systems that can affect the fission process, the integrity of the reactor core, the reactor coolant pressure boundary, and the containment and its associated systems. Appropriate controls shall be provided to maintain these variables and systems within prescribed operating ranges.

Criterion 14—Reactor coolant pressure boundary. The reactor coolant pressure boundary shall be designed, fabricated, erected, and tested so as to have an extremely low probability of abnormal leakage, of rapidly propagating failure, and of gross rupture.

Criterion 15—Reactor coolant system design. The reactor coolant system and associated auxiliary, control, and protection systems shall be designed with sufficient margin to assure that the design conditions of the reactor coolant pressure boundary are not exceeded during any condition of normal operation, including anticipated operational occurrences.

Criterion 16—Containment design. Reactor containment and associated systems shall be provided to establish an essentially leak-tight barrier against the uncontrolled release of radioactivity to the environment and to assure that the containment design conditions important to safety are not exceeded for as long as postulated accident conditions require.

Criterion 17—Electric power systems. An onsite electric power system and an offsite electric power system shall be provided to permit functioning of structures, systems, and components important to safety. The safety function for each system (assuming the other system is not functioning) shall be to provide sufficient capacity and capability to assure that (1) specified acceptable fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded as a result of anticipated operational occurrences and (2) the core is cooled and containment integrity and other vital functions are maintained in the event of postulated accidents.

The onsite electric power supplies, including the batteries, and the onsite electric distribution system, shall have sufficient independence, redundancy, and testability to perform their safety functions assuming a single failure.

Electric power from the transmission network to the onsite electric distribution system shall be supplied by two physically independent circuits (not necessarily on separate rights of way) designed and located so as to minimize to the extent practical the likelihood of their simultaneous failure under operating and postulated accident and environmental conditions. A switchyard common to both circuits is acceptable. Each of these circuits shall be designed to be available in sufficient time following a loss of all onsite alternating current power supplies and the other offsite electric power circuit, to assure that specified acceptable fuel design limits and design conditions of the reactor coolant pressure boundary are not exceeded. One of these circuits shall be designed to be available within a few seconds following a loss-of-coolant accident to assure that core cooling, containment integrity, and other vital safety functions are maintained.

Provisions shall be included to minimize the probability of losing electric power from any of the remaining supplies as a result of, or coincident with, the loss of power generated by the nuclear power unit, the loss of power from the transmission network, or the loss of power from the onsite electric power supplies.

Criterion 18—Inspection and testing of electrical power systems. Electric power systems important to safety shall be designed to permit appropriate periodic inspection and testing of important areas and features, such as wiring, insulation, connections, and switchboards, to assess the continuity of the systems and the condition of their components. The systems shall be designed with a capability to test periodically (1) the operability and functional performance of the components of the systems, such as onsite power sources, relays, switches, and buses, and (2) the operability of the systems as a whole and, under conditions as close to design as practical, the full operation sequence that brings the systems into operation, including operation of applicable portions of the protection system, and the transfer of power among the nuclear power unit, the offsite power system, and the onsite power system.

Criterion 19—Control room. A control room shall be provided from which actions can be taken to operate the nuclear power unit safely under normal conditions and to maintain it in a safe condition under accident conditions, including loss-of-coolant accidents. Adequate radiation protection shall be provided to permit access and occupancy of the control room under accident conditions without personnel receiving radiation exposures in excess of 5 rem whole body, or its equivalent to any part of the body, for the duration of the accident.

Equipment at appropriate locations outside the control room shall be provided (1) with a design capability for prompt hot shutdown of the reactor, including necessary instrumentation and controls to maintain the unit in a safe condition during hot shutdown, and (2) with a potential capability for subsequent cold shutdown of the reactor through the use of suitable procedures.

III. Protection and Reactivity Control Systems

Criterion 20—Protection system functions. The protection system shall be designed (1) to initiate automatically the operation of appropriate systems including the reactivity control systems, to assure that specified acceptable fuel design limits are not exceeded as a result of anticipated operational occurrences and (2) to sense accident conditions and to initiate the operation of systems and components important to safety.

Criterion 21—Protection system reliability and testability. The protection system shall be designed for high functional reliability and inservice testability commensurate with the safety functions to be performed. Redundancy and independence designed into the protection system shall be sufficient to assure that (1) no single failure results in loss of the protection function and (2) removal from service of any component or channel does not result in loss of the required minimum redundancy unless the acceptable reliability of operation of the protection system can be otherwise demonstrated. The protection system shall be designed to permit periodic testing of its functioning when the reactor is in operation, including a capability to test channels independently to determine failures and losses of redundancy that may have occurred.

Criterion 22—Protection system independence. The protection system shall be designed to assure that the effects of natural phenomena, and of normal operating, maintenance, testing, and postulated accident conditions on redundant channels do not result in loss of the protection function, or shall be demonstrated to be acceptable on some other defined basis. Design techniques, such as functional diversity or diversity in component design and principles of operation, shall be used to the extent practical to prevent loss of the protection function.

Criterion 23—Protection system failure modes. The protection system shall be designed to fail into a safe state or into a state demonstrated to be acceptable on some other defined basis if conditions such as disconnection of the system, loss of energy (e.g., electric power, instrument air), or postulated adverse environments (e.g., extreme heat or cold, fire, pressure, steam, water, and radiation) are experienced.

Criterion 24—Separation of protection and control systems. The protection system shall be separated from control systems to the extent that failure of any single control system component or channel, or failure or removal from service of any single protection system component or channel which is common to the control and protection systems leaves intact a system satisfying all reliability, redundancy, and independence requirements of the protection system. Interconnection of the protection and control systems shall be limited so as to assure that safety is not significantly impaired.

Criterion 25—Protection system requirements for reactivity control malfunctions. The protection system shall be designed to assure that specified acceptable fuel design limits are not exceeded for any single malfunction of the reactivity control systems, such as accidental withdrawal (not ejection or dropout) of control rods.

Criterion 26—Reactivity control system redundancy and capability. Two independent reactivity control systems of different design principles shall be provided. One of the systems shall use control rods, preferably including a positive means for inserting the rods, and shall be capable of reliably controlling reactivity changes to assure that under conditions of normal operation, including anticipated operational occurrences, and with appropriate margin for malfunctions such as stuck rods, specified acceptable fuel design limits are not exceeded. The second reactivity control system shall be capable of reliably controlling the rate of reactivity changes resulting from planned, normal power changes (including xenon burnout) to assure acceptable fuel design limits are not exceeded. One of the systems shall be capable of holding the reactor core subcritical under cold conditions.

Criterion 27—Combined reactivity control systems capability. The reactivity control systems shall be designed to have a combined capability, in conjunction with poison addition by the emergency core cooling system, of reliably controlling reactivity changes to assure that under postulated accident conditions and with appropriate margin for stuck rods the capability to cool the core is maintained.

Criterion 28—Reactivity limits. The reactivity control systems shall be designed with appropriate limits on the potential amount and rate of reactivity increase to assure that the effects of postulated reactivity accidents can neither (1) result in damage to the reactor coolant pressure boundary greater than limited local yielding nor (2) sufficiently disturb the core, its support structures or other reactor pressure vessel internals to impair significantly the capability to cool the core. These postulated reactivity accidents shall include consideration of rod ejection (unless prevented by positive means), rod dropout, steam line rupture, changes in reactor coolant temperature and pressure, and cold water addition.

Criterion 29—Protection against anticipated operational occurrences. The protection and reactivity control systems shall be designed to assure an extremely high probability of accomplishing their safety functions in the event of anticipated operational occurrences.

IV. Fluid Systems

Criterion 30—Quality of reactor coolant pressure boundary. Components which are part of the reactor coolant pressure boundary shall be designed, fabricated, erected, and tested to the highest quality standards practical. Means shall be provided for detecting and, to the extent practical, identifying the location of the source of reactor coolant leakage.

Criterion 31—Fracture prevention of reactor coolant pressure boundary. The reactor coolant pressure boundary shall be designed with sufficient margin to assure that when stressed under operating, maintenance, testing, and postulated accident conditions (1) the boundary behaves in a nonbrittle manner and (2) the probability of rapidly propagating fracture is minimized. The design shall reflect consideration of service temperatures and other conditions of the boundary material under operating, maintenance, testing, and postulated accident conditions and the uncertainties in determining (1) material properties, (2) the effects of irradiation on material properties, (3) residual, steady-state and transient stresses, and (4) size of flaws.

Criterion 32—Inspection of reactor coolant pressure boundary. Components which are part of the reactor coolant pressure boundary shall be designed to permit (1) periodic inspection and testing of important areas and features to assess their structural and leaktight integrity, and (2) an appropriate material surveillance program for the reactor pressure vessel.

Criterion 33—Reactor coolant makeup. A system to supply reactor coolant makeup for protection against small breaks in the reactor coolant pressure boundary shall be provided. The system safety function shall be to assure that specified acceptable fuel design limits are not exceeded as a result of reactor coolant loss due to leakage from the reactor coolant pressure boundary and rupture of small piping or other small components which are part of the boundary. The system shall be designed to assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished using the piping, pumps, and valves used to maintain coolant inventory during normal reactor operation.

Criterion 34—Residual heat removal. A system to remove residual heat shall be provided. The system safety function shall be to transfer fission product decay heat and other residual heat from the reactor core at a rate such that specified acceptable fuel design limits and the design conditions of the reactor coolant pressure boundary are not exceeded.

Suitable redundancy in components and features, and suitable interconnections, leak detection, and isolation capabilities shall be provided to assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure.

Criterion 35—Emergency core cooling. A system to provide abundant emergency core cooling shall be provided. The system safety function shall be to transfer heat from the reactor core following any loss of reactor coolant at a rate such that (1) fuel and clad damage that could interfere with continued effective core cooling is prevented and (2) clad metal-water reaction is limited to negligible amounts.

Suitable redundancy in components and features, and suitable interconnections, leak detection, isolation, and containment capabilities shall be provided to assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure.

Criterion 36—Inspection of emergency core cooling system. The emergency core cooling system shall be designed to permit appropriate periodic inspection of important components, such as spray rings in the reactor pressure vessel, water injection nozzles, and piping, to assure the integrity and capability of the system.

Criterion 37—Testing of emergency core cooling system. The emergency core cooling system shall be designed to permit appropriate periodic pressure and functional testing to assure (1) the structural and leaktight integrity of its components, (2) the operability and performance of the active components of the system, and (3) the operability of the system as a whole and, under conditions as close to design as practical, the performance of the full operational sequence that brings the system into operation, including operation of applicable portions of the protection system, the transfer between normal and emergency power sources, and the operation of the associated cooling water system.

Criterion 38—Containment heat removal. A system to remove heat from the reactor containment shall be provided. The system safety function shall be to reduce rapidly, consistent with the functioning of other associated systems, the containment pressure and temperature following any loss-of-coolant accident and maintain them at acceptably low levels.

Suitable redundancy in components and features, and suitable interconnections, leak detection, isolation, and containment capabilities shall be provided to assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure.

Criterion 39—Inspection of containment heat removal system. The containment heat removal system shall be designed to permit appropriate periodic inspection of important components, such as the torus, sumps, spray nozzles, and piping to assure the integrity and capability of the system.

Criterion 40—Testing of containment heat removal system. The containment heat removal system shall be designed to permit appropriate periodic pressure and functional testing to assure (1) the structural and leaktight integrity of its components, (2) the operability and performance of the active components of the system, and (3) the operability of the system as a whole, and, under conditions as close to the design as practical, the performance of the full operational sequence that brings the system into operation, including operation of applicable portions of the protection system, the transfer between normal and emergency power sources, and the operation of the associated cooling water system.

Criterion 41—Containment atmosphere cleanup. Systems to control fission products, hydrogen, oxygen, and other substances which may be released into the reactor containment shall be provided as necessary to reduce, consistent with the functioning of other associated systems, the concentration and quality of fission products released to the environment following postulated accidents, and to control the concentration of hydrogen or oxygen and other substances in the containment atmosphere following postulated accidents to assure that containment integrity is maintained.

Each system shall have suitable redundancy in components and features, and suitable interconnections, leak detection, isolation, and containment capabilities to assure that for onsite electrical power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) its safety function can be accomplished, assuming a single failure.

Criterion 42—Inspection of containment atmosphere cleanup systems. The containment atmosphere cleanup systems shall be designed to permit appropriate periodic inspection of important components, such as filter frames, ducts, and piping to assure the integrity and capability of the systems.

Criterion 43—Testing of containment atmosphere cleanup systems. The containment atmosphere cleanup systems shall be designed to permit appropriate periodic pressure and functional testing to assure (1) the structural and leaktight integrity of its components, (2) the operability and performance of the active components of the systems such as fans, filters, dampers, pumps, and valves and (3) the operability of the systems as a whole and, under conditions as close to design as practical, the performance of the full operational sequence that brings the systems into operation, including operation of applicable portions of the protection system, the transfer between normal and emergency power sources, and the operation of associated systems.

Criterion 44—Cooling water. A system to transfer heat from structures, systems, and components important to safety, to an ultimate heat sink shall be provided. The system safety function shall be to transfer the combined heat load of these structures, systems, and components under normal operating and accident conditions.

Suitable redundancy in components and features, and suitable interconnections, leak detection, and isolation capabilities shall be provided to assure that for onsite electric power system operation (assuming offsite power is not available) and for offsite electric power system operation (assuming onsite power is not available) the system safety function can be accomplished, assuming a single failure.

Criterion 45—Inspection of cooling water system. The cooling water system shall be designed to permit appropriate periodic inspection of important components, such as heat exchangers and piping, to assure the integrity and capability of the system.

Criterion 46—Testing of cooling water system. The cooling water system shall be designed to permit appropriate periodic pressure and functional testing to assure (1) the

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structural and leaktight integrity of its components, (2) the operability and the performance of the active components of the system, and (3) the operability of the system as a whole and, under conditions as close to design as practical, the performance of the full operational sequence that brings the system into operation for reactor shutdown and for loss-of-coolant accidents, including operation of applicable portions of the protection system and the transfer between normal and emergency power sources.

V. Reactor Containment

Criterion 50—Containment design basis. The reactor containment structure, including access openings, penetrations, and the containment heat removal system shall be designed so that the containment structure and its internal compartments can accommodate, without exceeding the design leakage rate and, with sufficient margin, the calculated pressure and temperature conditions resulting from any loss-of-coolant accident. This margin shall reflect consideration of (1) the effects of potential energy sources which have not been included in the determination of the peak conditions, such as energy in steam generators and energy from metal-water and other chemical reactions that may result from degraded emergency core cooling functioning, (2) the limited experience and experimental data available for defining accident phenomena and containment responses, and (3) the conservatism of the calculational model and input parameters.

Criterion 51—Fracture prevention of containment pressure boundary. The reactor containment boundary shall be designed with sufficient margin to assure that under operating, maintenance, testing, and postulated accident conditions (1) its ferritic materials behave in a nonbrittle manner and (2) the probability of rapidly propagating fracture is minimized. The design shall reflect consideration of service temperatures and other conditions of the containment boundary material during operation, maintenance, testing, and postulated accident conditions, and the uncertainties in determining (1) material properties, (2) residual, steady-state, and transient stresses, and (3) size of flaws.

Criterion 52—Capability for containment leakage rate testing. The reactor containment and other equipment which may be subjected to containment test conditions shall be designed so that periodic integrated leakage rate testing can be conducted at containment design pressure.

Criterion 53—Provisions for containment testing and inspection. The reactor containment shall be designed to permit (1) appropriate periodic inspection of all important areas, such as penetrations, (2) an appropriate surveillance program, and (3) periodic testing at containment design pressure of the leaktightness of penetrations which have resilient seals and expansion bellows.

Criterion 54—Piping systems penetrating containment. Piping systems penetrating primary reactor containment shall be provided with leak detection, isolation, and containment capabilities having redundancy, reliability, and performance capabilities which reflect the importance to safety of isolating these piping systems. Such piping systems shall be designed with a capability to test periodically the operability of the isolation valves and associated apparatus and to determine if valve leakage is within acceptable limits.

Criterion 55—Reactor coolant pressure boundary penetrating containment. Each line that is part of the reactor coolant pressure boundary and that penetrates primary reactor containment shall be provided with containment isolation valves as follows, unless it can be demonstrated that the containment isolation provisions for a specific class of lines, such as instrument lines, are acceptable on some other defined basis:

(1) One locked closed isolation valve inside and one locked closed isolation valve outside containment; or

(2) One automatic isolation valve inside and one locked closed isolation valve outside containment; or

(3) One locked closed isolation valve inside and one automatic isolation valve outside containment. A simple check valve may not be used as the automatic isolation valve outside containment; or

(4) One automatic isolation valve inside and one automatic isolation valve outside containment. A simple check valve may not be used as the automatic isolation valve outside containment.

Isolation valves outside containment shall be located as close to containment as practical and upon loss of actuating power, automatic isolation valves shall be designed to take the position that provides greater safety.

Other appropriate requirements to minimize the probability or consequences of an accidental rupture of these lines or of lines connected to them shall be provided as necessary to assure adequate safety. Determination of the appropriateness of these requirements, such as higher quality in design, fabrication, and testing, additional provisions for inservice inspection, protection against more severe natural phenomena, and additional isolation valves and containment, shall include consideration of the population density, use characteristics, and physical characteristics of the site environs.

Criterion 56—Primary containment isolation. Each line that connects directly to the containment atmosphere and penetrates primary reactor containment shall be provided with containment isolation valves as follows, unless it can be demonstrated that the containment isolation provisions for a specific class of lines, such as instrument lines, are acceptable on some other defined basis:

(1) One locked closed isolation valve inside and one locked closed isolation valve outside containment; or

(2) One automatic isolation valve inside and one locked closed isolation valve outside containment; or

(3) One locked closed isolation valve inside and one automatic isolation valve outside containment. A simple check valve may not be used as the automatic isolation valve outside containment; or

(4) One automatic isolation valve inside and one automatic isolation valve outside containment. A simple check valve may not be used as the automatic isolation valve outside containment.

Isolation valves outside containment shall be located as close to the containment as practical and upon loss of actuating power, automatic isolation valves shall be designed to take the position that provides greater safety.

Criterion 57—Closed system isolation valves. Each line that penetrates primary reactor containment and is neither part of the reactor coolant pressure boundary nor connected directly to the containment atmosphere shall have at least one containment isolation valve which shall be either automatic, or locked closed, or capable of remote manual operation. This valve shall be outside containment and located as close to the containment as practical. A simple check valve may not be used as the automatic isolation valve.

VI. Fuel and Radioactivity Control

Criterion 60—Control of releases of radioactive materials to the environment. The nuclear power unit design shall include means to control suitably the release of radioactive materials in gaseous and liquid effluents and to handle radioactive solid wastes produced during normal reactor operation, including anticipated operational occurrences. Sufficient holdup capacity shall be provided for retention of gaseous and liquid effluents containing radioactive materials, particularly where unfavorable site environmental conditions can be expected to impose unusual operational limitations upon the release of such effluents to the environment.

Criterion 61—Fuel storage and handling and radioactivity control. The fuel storage and handling, radioactive waste, and other systems which may contain radioactivity shall be designed to assure adequate safety under normal and postulated accident conditions. These systems shall be designed (1) with a capability to permit appropriate periodic inspection and testing of components important to safety, (2) with suitable shielding for radiation protection, (3) with appropriate containment, confinement, and filtering systems, (4) with a residual heat removal capability having reliability and testability that reflects the importance to safety of decay heat and other residual heat removal, and (5) to prevent significant reduction in fuel storage coolant inventory under accident conditions.

Criterion 62—Prevention of criticality in fuel storage and handling. Criticality in the fuel storage and handling system shall be prevented by physical systems or processes, preferably by use of geometrically safe configurations.

Criterion 63—Monitoring fuel and waste storage. Appropriate systems shall be provided in fuel storage and radioactive waste systems and associated handling areas (1) to detect conditions that may result in loss of residual heat removal capability and excessive radiation levels and (2) to initiate appropriate safety actions.

Criterion 64—Monitoring radioactivity releases. Means shall be provided for monitoring the reactor containment atmosphere, spaces containing components for recirculation of loss-of-coolant accident fluids, effluent discharge paths, and the plant environs for radioactivity that may be released from normal operations, including anticipated operational occurrences, and from postulated accidents.

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CHAPTER 8

ENERGY CONSERVATION: THE NEED FOR MORE EFFICIENT USE OF ENERGY

A. OBJECTIVES

1. The student will identify the modes of energy consumption in the United States, and the low efficiencies inherent in each area of consumption.

2. The student will identify methods which may be used to increase the efficiency of each area of energy consumption.

B. ACTIVITIES

1. Have your students discuss the advances in automobile engines which may be more efficient than our present internal combustion engines (e.g. the Wankle engine).

2. The mandatory addition of anti-pollution devices to automobiles has reduce gasoline mileage on most American cars to about 10 miles per gallon. This is an example of a trade-off: less efficient fuel use for cleaner air. Is this a wise decision at a time of critical gasoline shortages? Discuss this on a risk-to-benefit basis.

3. Have your students design a mass transit system for your community. How would this reduce pollution while increasing efficiency of fuel use?

C. AUDIO-VISUAL MATERIALS

1. *"Trees and the Energy Crisis,"* 15 min. audiotape. On conservation. American Forest Institute, Attention Phyllis Rock, Education Division, 1619 Massachusetts Avenue, N.W., Washington, D.C., 20036.

2. *"The Energy-Environment Game,"* a simulation dealing with society's demand for energy and its effect on the environment. Edison Electric Institute, 90 Park Avenue, New York, New York, 10016

3. *"Environmental Health: Energy and the Environment,"* a teaching kit including records and filmstrips prepared for Southern California Edison Company by H.R.A., Inc., P.O. Box 3036, Granada Hills, Calif. 91344

D. REFERENCES

1. *"Energy Conservation through Effective Utilization,"* Charles A. Berg, **Science**, Vol. 181, July 13, 1973.

2. *A Consumer's Guide to Efficient Energy Use in the Home,"* a free booklet from Consumer Affairs, American Petroleum Institute, 1801 K Street, N.W., Washington, D.C., 20006.

BACKGROUND INFORMATION FOR THE TEACHER

EFFICIENCY OF ENERGY USE IN THE UNITED STATES,

Eric Hirst and John Meyers, Science, March 30, 1973.

Conflicts between the demand for energy and environmental quality goals can be resolved in several ways. The two most important are (i) development and use of pollution control technologies and of improved energy-conversion technologies, and (ii) the improvement in efficiency of energy use. Increased efficiency of energy use would help to slow energy growth rates, thereby relieving pressure on scarce energy resources and reducing environmental problems associated with energy production, conversion, and use.

Between 1950 and 1970, U.S. consumption of energy resources (coal, oil, natural gas, falling water, and uranium) doubled (1), with a average annual growth rate of 3.5 percent–more than twice the population growth rate.

Energy resources are used for many purposes in the United States (2) (Table 1). In 1970, transportation of people and freight consumed 25 percent of total energy, primarily as petroleum. Space heating of homes and commercial establishments was the second largest end-use, consuming an additional 18 percent. Industrial uses of energy (process steam, direct heat, electric drive, fuels used as raw materials (3), and electrolytic processes) accounted for 42 percent. The remaining 15 percent was used by the commercial and residential sectors for water heating, air conditioning, refrigeration, cooking, lighting, operation of small appliances, and other miscellaneous purposes.

During the 1960's, the percentage of energy consumed for electric drive, raw materials, air conditioning, refrigeration, and electrolytic processes increased relative to the total. Air conditioning showed the largest relative growth, increasing its share of total energy use by 81 percent, while the other uses noted increased their shares of the total by less than 10 percent in this period.

The growth in energy consumption by air conditioners, refrigerators, electric drive, and electrolytic processes–coupled with the substitution of electricity for direct fossil fuel combustion for some space and water heating, cooking, and industrial heat–accounts for the rapid growth in electricity consumption. Between 1960 and 1970, while consumption of primary energy (1) grew by 51 percent, the use of electricity (4) grew by 104 percent. The increasing use of electricity relative to the primary fuels is an important factor accounting for energy growth rates because of the inherently low efficiency of electricity generation, transmission, and distribution which averaged 30 percent during this decade (1,4). In 1970, electrical generation (1) accounted for 24 percent of energy resource consumption as compared to 19 percent in 1960.

Industry, the largest energy user, includes manufacturing; mining; and agriculture, forestry, and fisheries. Six manufacturers–of primary metals; of chemicals; of petroleum and coal; of stone, clay, and glass; of paper; and of food–account for half of industrial energy consumption (5), equivalent to 20 percent of the total energy budget.

Energy consumption is determined by at least three factors: population, affluence, and efficiency of use. In this article we describe three areas in which energy-efficiency improvements (the third factor) might be particularly important: (i) transportation of people and freight, (ii) space heating, and (iii) space cooling (air conditioning).

Energy efficiency varies considerably among the different passenger and freight transport modes. Shifts from energy-intensive modes (airplanes, trucks, automobiles) to energy-efficient modes (boats, pipelines, trains, buses) could significantly reduce energy consumption. Increasing the amount of building insulation could reduce both space-heating and air-conditioning energy consumption in homes and save money for the homeowner. Energy consumption of air conditioning could be greatly reduced through the use of units that are more energy efficient.

Transportation

Transportation of people and goods consumed 16,500 trillion British thermal units (6) in 1970 (25 percent of total energy consumption) (1). Energy requirements for transportation increased by 89 percent between 1950 and 1970, an average annual growth rate of 3.2 percent.

Increases in transportation energy consumption (7) are due to (i) growth in traffic levels, (ii) shifts toward the use of less energy-efficient transport modes, and (iii) declines in energy efficiency for individual modes. Energy intensiveness, the inverse of energy efficiency, is expressed here as British thermal units per ton-mile for freight and as British thermal units per passenger-mile for passenger traffic.

Table 2 shows approximate values (8) for energy consumption and average revenue in 1970 for intercity freight modes; the large range in energy efficiency among modes is noteworthy. Pipelines and waterways (barges and boats) are very efficient; however, they are limited in the kinds of materials they can transport and in the flexibility of their pickup and delivery points. Railroads are slightly less efficient than pipelines. Trucks, which are faster and more flexible than the preceding three modes, are, with respect to energy, only one-fourth as efficient as railroads. Airplanes, the fastest mode, are only 1/60 as efficient as trains.

The variation in freight prices shown in Table 2 closely parallels the variation in energy intensiveness. The increased prices of the less efficient modes reflect their greater speed, flexibility, and reliability.

Table 3 gives approximate 1970 energy and price data for various passenger modes (8). For intercity passenger traffic, trains and buses are the most efficient modes. Cars are less than one-half as efficient as buses, and airplanes are only one-fifth as efficient as buses.

For urban passenger traffic, mass transit systems (of which about 60 percent are bus systems) are more than twice as energy efficient as automobiles. Walking and bicycling are an order of magnitude more efficient than autos, on the basis of energy consumption to produce food. Urban values of efficiency for cars and buses are much lower than intercity values because of poorer vehicle performance (fewer miles per gallon) and poorer utilization (fewer passengers per vehicle).

Passenger transport prices are also shown in Table 3. The correlation between energy intensiveness and price, while positive, is not as strong as for freight transport. Again, the differences in price reflect the increased values of the more energy-intensive modes.

The transportation scenario for 1970 shown in Table 4 gives energy savings that may be possible through increased use of more efficient modes. The first calculation uses the actual 1970 transportation patterns. The scenario—entirely speculative—indicates the potential energy savings that could have occurred through shifts to more efficient transport modes. In this hypothetical scenario, half the freight traffic carried by truck and by airplane is assumed to have been carried by rail; half the intercity passenger traffic carried by airplane and one-third the traffic carried by car are assumed to have been carried by bus and train; and half the urban automobile traffic is assumed to have been carried by bus. The load factors (percentage of transport capacity utilized) and prices are assumed to be the same for both calculations. The scenario ignores several factors that might inhibit shifts to energy-efficient transport modes, such as existing land-use patterns, capital costs, changes in energy efficiency within a given mode, substitutability among modes, new technologies, transportation ownership patterns, and other institutional arrangements.

The hypothetical scenario requires only 78 percent as much energy to move the same traffic as does the actual calculation. This savings of 2800 trillion Btu is equal to 4 percent of the total 1970 energy budget. The scenario also results in a total transportation cost that is $19 billion less than the actual 1970 cost (a 12 percent reduction). The dollar savings (which includes the energy saved) must be balanced against any losses in speed, comfort, and flexibility resulting from a shift to energy-efficient modes.

To some extent, the current mix of transport modes is optimal, chosen in response to a variety of factors. However, noninternalized social costs, such as noise and air pollution and various government activities (regulations, subsidization, research), may tend to distort the mix, and, therefore, present modal patterns may not be socially optimal.

Present trends in modal mix are determined by personal preference, private economics, convenience, speed, reliability, and government policy. Emerging factors such as fuel scarcities, rising energy prices, dependence on petroleum imports, urban land-use problems, and environmental quality considerations may provide incentives to shift transportation patterns toward greater energy efficiency.

Space Heating

The largest single energy consuming function in the home is space heating. In an average all-electric

home in a moderate climate, space heating uses over half the energy delivered to the home; in gas- or oil-heated homes, the fraction is probably larger because the importance of thermal insulation has not been stressed where these fuels are used.

The nearest approach to a national standard for thermal insulation in residential construction is *"Minimum Property Standards (MPS) for One and Two Living Units,"* issued by the Federal Housing Administration (FHA). In June 1971, FHA revised the MPS to require more insulation, with the stated objectives of reducing air pollution and fuel consumption.

A recent study (9) estimated the value of different amounts of thermal insulation in terms both of dollar savings to the homeowner and of reduction in energy consumption. Hypothetical model homes (1800 square feet) were placed in three climatic regions, each representing one-third of the U.S. population. The three regions were represented by Atlanta, New York, and Minneapolis.

As an example of the findings of the study, Table 5 presents the results applicable to a New York residence, including the insulation requirements of the unrevised and the revised MPS, the insulation that yields the maximum economic benefit to the homeowner, and the monetary and energy savings that result in each case. The net monetary savings are given after recovery of the cost of the insulation installation, and would be realized each year of the lifetime of the home. A mortgage interest rate of 7 percent was assumed.

The revised MPS provide appreciable savings in energy consumption and in the cost of heating a residence, although more insulation is needed to minimize the long-term cost to the homeowner. A further increase in insulation requirements would increase both dollar and energy savings.

The total energy consumption of the United States (1) in 1970 was 67,000 trillion Btu, and about 11 percent was devoted to residential space heating and 7 percent to commercial space heating (2). Table 5 shows reductions in energy required for space heating of 49 percent for gas-heated homes and 47 percent for electric-heated homes in the New York area by going from the MPS-required insulation in 1970 to the economically optimum amount of insulation. The nationwide average reductions are 43 percent for gas-heated homes and 41 percent for electric-heated homes. An average savings of 42 percent, applied to the space heating energy requirements for all residential units (single family and apartment, gas and electric), would have amounted to 3,100 trillion Btu in 1970 (4.6 percent of total energy consumption). The energy savings are somewhat understated—as insulation is added, the heat from lights, stoves, refrigerators, and other appliances becomes a significant part of the total heat required. The use of additional insulation also reduces the energy consumption for air conditioning as discussed later.

Electrical resistance heating is more wasteful of primary energy than is direct combustion heating. The average efficiency for electric power plants (1) in the United States is about 33 percent, and the efficiency (4) of transmitting and distributing the power to the customer is about 91 percent. The end-use efficiency of electrical resistance heating is 100 percent; so the overall efficiency is approximately 30 percent. Thus, for every unit of heat delivered in the home, 3.3 units of heat must be extracted from the fuel at the power plant. Conversely, the end-use efficiency of gas- or oil-burning home heating systems is about 60 percent (claimed values range from 40 to 80 percent), meaning that 1.7 units of heat must be extracted from the fuel for each unit delivered to the living area of the home. Therefore, the electrically heated home requires about twice as much fuel per unit of heat as the gas- or oil-heated home, assuming equivalent insulation.

The debate about whether gas, oil, or electric-resistance space heating is better from a conservation point of view may soon be moot because of the shortage of natural gas and petroleum. The use of electricity generated by nuclear plants for this purpose can be argued to be a more prudent use of resources than is the combustion of natural gas or oil for its energy content. Heating by coal-generated electricity may also be preferable to heating by gas or oil in that a plentiful resource is used and dwindling resources are conserved.

The use of electrical heat pumps could equalize the positions of electric-, oil-, and gas-heating systems from a fuel conservation standpoint. The heat pump delivers about 2 units of heat energy for each unit of electric energy that it consumes. Therefore, only 1.7 units of fuel energy would be required at the power plant for each unit of delivered heat, essentially the same as that required for fueling a home furnace.

Heat pumps are not initially expensive when installed in conjunction with central air conditioning; the basic equipment and air handling systems are the same for both heating and cooling. A major impediment to their widespread use has been high maintenance cost associated with equipment failure. Several manufacturers of heat pumps have carried out extensive programs to improve component reliability that, if successful, should improve acceptance by homeowners.

Space Cooling

In all-electric homes, air conditioning ranks third as a major energy-consuming function, behind space heating and water heating. Air conditioning is particularly important because it contributes to or is the cause of the annual peak load that occurs in the summertime for many utility systems.

In addition to reducing the energy required for space heating, the ample use of thermal insulation reduces the energy required for air conditioning. In the New York case, use of the economically optimum amount of insulation results in a reduction of the electricity consumed for air conditioning of 26 percent for the gas home or 18 percent for the electric home, compared to the 1970 MPS-compliance homes.

The popularity of room air conditioners is evidienced by an exponential sales growth with a doubling time of 5 years over the past decade; almost 6 million were sold in 1970. The strong growth in sales is expected to continue since industry statistics show a market saturation of only about 40 percent.

There are about 1,400 models of room air conditioners available on the market today, sold under 52 different brand names (10). A characteristic of the machines that varies widely but is not normally advertised is the efficiency with which energy is converted to cooling. Efficiency ranges from 4.7 to 12.2 Btu per watt-hour. Thus the least efficient machine comsumes 2.6 times as much electricity per unit of cooling as the most efficient one. Figure 1 shows the efficiencies of all units having ratings up to 24,000 Btu per hour, as listed in (10).

From an economic point of view, the purchaser should select the particular model of air conditioner that provides the needed cooling capacity and the lowest total cost (capital, mainenance, operation) over the unit's lifetime. Because of the large number of models available and the general ignorance of the fact that such a range of efficiencies exists, the most economical choice is not likely to be made. An industry-sponsored certification program requires that the cooling rating and wattage input be listed on the nameplate of each unit, providing the basic information required for determining efficiency. However, the nameplate is often hard to locate and does not state the efficiency explicitly.

The magnitude of possible savings that would result from buying a more efficient unit is illustrated by the following case. Of the 90 models with a capacity of 10,000 Btu per hour, the lowest efficiency model draws 2100 watts and the highest efficiency model draws 880 watts. In Washington, D.C., the average room air conditioner operates about 800 hours per year. The low-efficiency unit would use 976 kilowatt-hours more electricity each year than the high-efficiency unit. At 1.8 cents per kilowatt-hour, the operating cost would increase by $17.57 per year. The air conditioner could be expected to have a life of 10 years. If the purchaser operates on a credit card economy, with an 18 percent interest rate, he would be economically jusitified in paying up to $79 more for the high-efficiency unit. If his interest rate were 6 percent, an additional purchase price of $130 would be justified.

In the above example, the two units were assumed to operate the same number of hours per year. However, many of the low-priced, low-efficiency units are not equipped with thermostats. As a result, they may operate almost continuously, with a lower-than-desired room temperature. This compounds the inefficiency and, in addition, shortens the lifetime of the units.

In addition to the probable economic advantage to the consumer, an improvement in the average efficiency of room air conditioners would result in appreciable reductions in the nation's energy consumption and required generating capacity. If the size distribution of all existing room units is that for the 1970 sales, the average efficiency (10) is 6 Btu per watt-hour, and the average annual operating time is 886 hours per year, then the nation's room air conditioners consumed 39.4 billion kilowatt-hours during 1970. On the same basis, the connected load was 44,500 megawatts. and the annual equivalent coal consumption was 18.9 million tons. If the assumed efficiency is changed to 10 Btu per watt-hour, the annual power consumption would have been 23.6 billion kilowatt-hours, a reduction of

15.8 billion kilowatt-hours. The connected load would have decreased to 26,700 megawatts, a reduction of 17,800 megawatts. The annual coal consumption for room air conditioners would have been 11.3 million tons, a reduction of 7.6 million tons, or at a typical strip mine yield of 5000 tons per acre, a reduction in stripped area of 1500 acres in 1970.

Other Potential Energy Savings

Energy-efficiency improvements can be effected for other end uses of energy besides the three considered here. Improved appliance design could increase the energy efficiency of hot-water heaters, stoves, and refrigerators. The use of solar energy for residential space and water heating is technologically feasible and might some day be economically feasible. Alternatively, waste heat from air conditioners could be used for water heating. Improved design or elimination of gas pilot lights and elimination of gas yard lights would also provide energy savings (11). Increased energy efficiency within homes would tend to reduce summer air-conditioning loads.

In the commercial sector, energy savings in space heating and cooling such as those described earlier are possible. In addition, the use of total energy systems (on-site generation of electricity and the use of waste heat for space and water heating and absorption air conditioning) would increase the overall energy efficiency of commercial operations.

Commercial lighting accounts for about 10 percent of total electricity consumption (12). Some architects claim that currently recommended lighting levels can be reduced without danger to eyesight or worker performance (13). Such reduction would save energy directly and by reducing air-conditioning loads. Alternatively, waste heat from lighting can be circulated in winter for space heating and shunted outdoors in summer to reduce air-conditioning loads.

Changes in building design practices might effect energy savings (13). Such changes could include use of less glass and of windows that open for circulation of outside air.

Waste heat and low temperature steam from electric power plants may be useful for certain industries and for space heating in urban districts (14). This thermal energy (about 8 percent of energy consumption in 1970) (15) could be used for industrial process steam, space heating, water heating, and air conditioning in a carefully planned urban complex.

The manufacture of a few basic materials accounts for a large fraction of industrial energy consumption. Increased recycle of energy-intensive materials such as aluminum, steel, and paper would save energy. Saving could also come from lower production of certain materials. For example, the production of packaging materials (paper, metal, glass, plastic, wood) requires about 4 percent of the total energy budget. In general, it may be possible to design products and choose materials to decrease the use of packaging and to reduce energy costs per unit of production.

Implementation

Changes in *energy prices*, both levels and rate structures, would influence decisions concerning capital versus life costs, and this would affect the use of energy-conserving technologies. *Public education* to increase awareness of energy problems might heighten consumer sensitivity toward personal energy consumption. Various local, state, and federal *government policies* exist that, directly and indirectly, influence the efficiency of energy use. These three routes are not independent; in particular, government policies could affect prices or public education (or both) on energy use.

One major factor that promotes energy consumption is the low price of energy. A typical family in the United States spends about 5 percent of its annual budget on electricity, gas, and gasoline. The cost of fuels and electricity to manufacturers is about 1.5 percent of the value of their total shipments. Because the price of energy is low relative to other costs, efficient use of energy has not been of great importance in the economy. Not only are fuel prices low, but historically they have declined relative to other prices.

The downward trend in the relative price of energy has begun to reverse because of the growing scarcity of fuels, increasing costs of both money and energy-conversion facilities (power plants, petroleum refineries), and the need to internalize social costs of energy production and use. The impact of rising energy prices on demand is difficult to assess.

The factors cited above (fuel scarcity, rising costs environmental constraints) are likely to influence energy price structures as well as levels. If

these factors tend to increase energy prices uniformly (per Btu delivered), then energy price structures will become flatter; that is, the percentage difference in price between the first and last unit purchased by a customer will be less than that under existing rate structures. The impact of such rate structure changes on the demand for energy is unknown, and research is needed.

Increases in the price of energy should decrease the quantity demanded and this is likely to encourage more efficient use of energy. For example, if the price of gasoline rises, there will probably be a shift to the use of smaller cars and perhaps to the use of public transportation systems.

Public education programs may slow energy demand. As Americans understand better the environmental problems associated with energy production and use, they may voluntarily decrease their personal energy-consumption growth rates. Experiences in New York City and in Sweden with energy-conservation advertising programs showed that the public is willing and able to conserve energy, at least during short-term emergencies.

Consumers can be educated about the energy consumption of various appliances. The energy-efficiency data for air conditioners presented here are probably not familiar to most prospective buyers of air conditioners. If consumers understood energy and dollar costs of low-efficiency units, perhaps they would opt for more expensive, high-efficiency units to save money over the lifetime of the unit and also to reduce environmental impacts. Recently, at least two air-conditioner manufacturers began marketing campaigns that stress energy efficiency. Some electric utilities have also begun to urge their customers to use electricity conservatively and efficiently.

Public education can be achieved through government publications or government regulations, for example, by requiring labels on appliances which state the energy efficiency and provide estimates of operating costs. Advertisements for energy-consuming equipment might be required to state the energy efficiency.

Federal policies, reflected in research expenditures, construction of facilities, taxes and subsidies, influence energy consumption. For example, the federal government spends several billion dollars annually on highway, airway, and airport construction, but nothing is spent for railway and railroad construction. Until recently, federal transportation research and development funds were allocated almost exclusively to air and highway travel. Passage of the Urban Mass Transportation Act, establishment of the National Railroad Passenger Corporation (AMTRAK), plus increases in research funds for rail and mass transport may increase the use of these energy-efficient travel modes.

Similarly, through agencies such as the Tennessee Valley Authority, the federal government subsidizes the cost of electricity. The reduced price for public power customers increases electricity consumption over what it would otherwise be.

Governments also influence energy consumption directly and indirectly through allowances for depletion of resources, purchase specifications (to require recycled paper, for example), management of public energy holdings, regulation of gas and electric utility rate levels and structures, restrictions on energy promotion, and establishment of minimum energy performance standards for appliances and housing.

The federal government spends about $0.5 billion a year on research and development for civilian energy, of which the vast majority is devoted to energy supply technologies (16):

> ...Until recently only severely limited funds were available for developing a detailed understanding of the ways in which the nation uses energy.....The recently instituted Research Applied to National Needs (RANN) Directorate for the National Science Foundation.....has been supporting research directed toward developing a detailed understanding of the way in which the country utilizes energy. ...This program also seeks to examine the options for meeting the needs of society at reduced energy and environmental costs.

Perhaps new research on energy use will reveal additional ways to reduce energy growth rates.

Summary

We described three uses of energy for which greater efficiency is feasible: transportation, space heating, and air conditioning. Shifts to less energy-intensive transportation modes could substantially reduce energy consumption; the magnitude of such savings would, of course, depend

on the extent of such shifts and possible load factor changes. The hypothetical transportation scenario described here results in a 22 percent savings in energy for transportation in 1970, a savings of 2800 trillion Btu.

To the homeowner, increasing the amount of building insulation and, in some cases, adding storm windows would reduce energy consumption and provide monetary savings. If all homes in 1970 had the *"economic optimum"* amount of insulation, energy consumption for residential heating would have been 42 percent less than if the homes were insulated to meet the pre-1971 FHA standards, a savings of 3100 trillion Btu.

Increased utilization of energy-efficient air conditioners and of building insulation would provide significant energy savings and help to reduce peak power demands during the summer. A 67 percent increase in energy efficiency for room air conditioners would have saved 15.8 billion kilowatt-hours in 1970.

In conclusion, it is possible–from an engineering point of view–to effect considerable energy savings in the United States. Increases in the efficiency of energy use would provide desired end results with smaller energy inputs. Such measures will not reduce the *level* of energy consumption, but they could slow energy growth *rates*.

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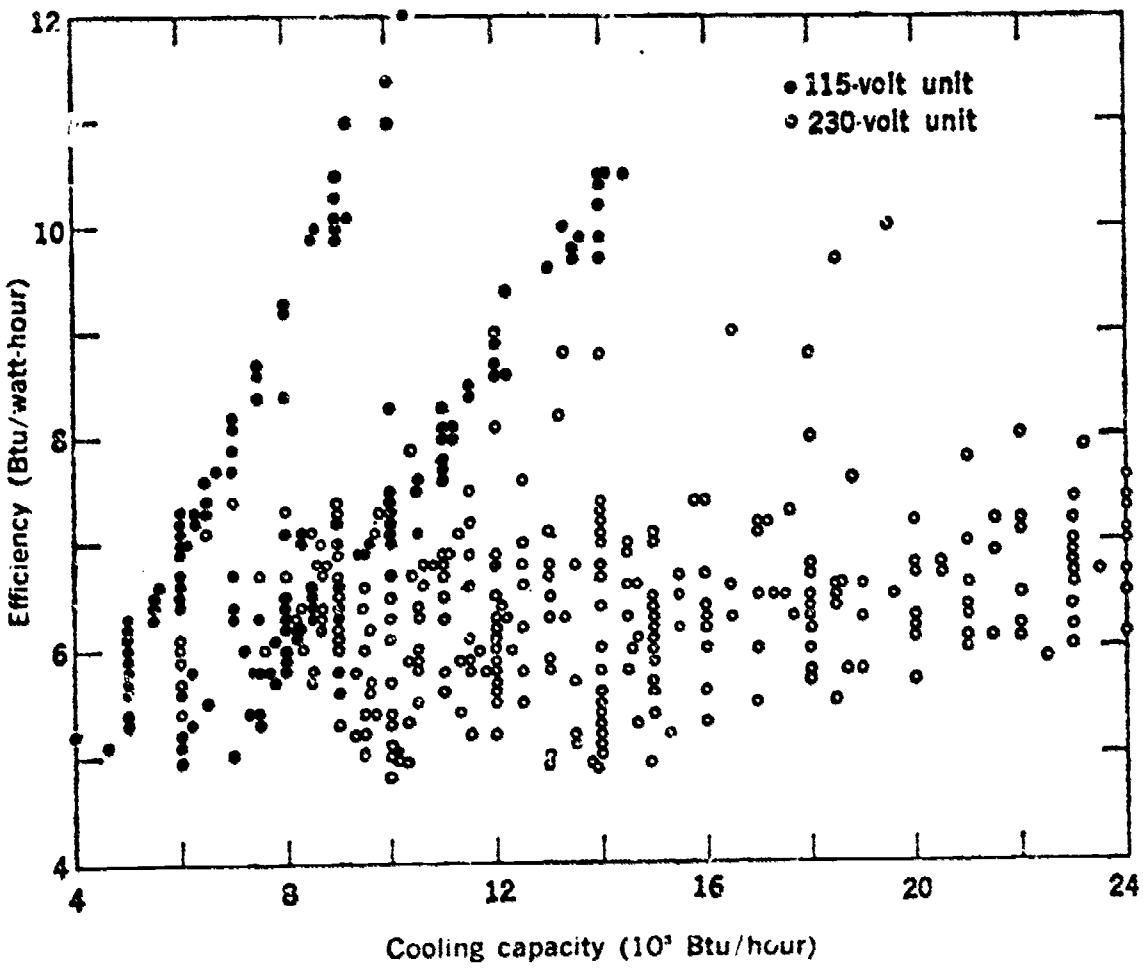


Fig. 1. Efficiency of room air conditioners as a function of unit size.

Table 1. End-uses of energy in the United States.

Item	1960* (%)	1970† (%)
Transportation	25.2	24.7
Space heating	18.5	17.7
Process steam	17.8	16.4
Direct heat	12.9	11.0
Electric drive	7.4	8.1
Raw materials	5.2	5.6
Water heating	4.0	4.0
Air conditioning	1.6	2.9
Refrigeration	2.1	2.3
Cooking	1.5	1.2
Electrolytic processes	1.1	1.2
Other‡	2.7	4.9

* Data for 1960 obtained from Stanford Research Institute (SRI) (2). † Estimates for 1970 obtained by extrapolating changes in energy-use patterns from SRI data. ‡ Includes clothes drying, small appliances, lighting, and other miscellaneous energy uses.

Table 2. Energy and price data for intercity freight transport.

Mode	Energy (Btu/ton-mile)	Price (cents/ton-mile)
Pipeline	450	0.27
Railroad	670	1.4
Waterway	680	0.30
Truck	2,800	7.5
Airplane	42,000	21.9

Table 3. Energy and price data for passenger transport.

Mode	Energy (Btu/passenger-mile)	Price (cents/passenger-mile)
	*Intercity**	
Bus	1600	3.6
Railroad	2900	4.0
Automobile	3400	4.0
Airplane	8400	6.0
	Urban†	
Mass transit	3800	8.3
Automobile	8100	9.6

* Load factors (percentage of transport capacity utilized) for intercity travel are about: bus, 45 percent; railroad, 35 percent; automobile, 48 percent; and airplane, 50 percent. † Load factors for urban travel are about: mass transit, 20 percent; and automobile, 28 percent.

Table 4. Actual and hypothetical energy consumption patterns for transportation in 1970.

	Total traffic	Percentage of total traffic						Total energy (10^{18} Btu)	Total cost (10^{9} \$)
		Air	Truck	Rail	Waterway and pipeline	Auto	Bus*		
				Intercity freight traffic					
Actual	2210†	0.2	19	35	46			2400	45
Hypothetical	2210	0.1	9	44	46			1900	33
				Intercity passenger traffic					
Actual	1120‡	10		1		87	2	4300	47
Hypothetical	1120	5		12		58	25	3500	45
				Urban passenger traffic					
Actual	710‡					97	3	5700	68
Hypothetical	710					49	51	4200	63
				Totals					
Actual								12,400	160
Hypothetical								9600	141

* Intercity bus or urban mass transit. † Billion ton-miles. ‡ Billion passenger-miles.

Table 5. Comparison of insulation requirements and monetary and energy savings for a New York residence.

Insulation specification	Unrevised MPS*		Revised MPS*		Economic optimum	
	Gas	Electric	Gas	Electric	Gas	Electric
Wall insulation thickness (inches)	0	1⅞	1⅞	1⅞	3½	3½
Ceiling insulation thickness (inches)	1⅞	1⅞	3½	3½	3½	6
Floor insulation	No	No	Yes	Yes	Yes	Yes
Storm windows	No	No	No	No	Yes	Yes
Monetary savings (\$/yr)	0	0	28	75	32	155
Reduction of energy consumption (%)	0	0	29	19	49	47

* Minimum property standards (MPS) for one and two living units.

SUMMARY

At this point the student must proceed to synthesize the concepts which have been presented to him in the various chapters of the course. He should arrive at decisions which, in his own mind, are logical and based upon the information which he has learned. These decisions should include:

1. Do we wish to maintain our standard of living, or do we wish to give up some or all of the conveniences and products we now enjoy?
2. Do we wish to continue as we are, ignoring the environmental cost? If we do, are we willing to pay the ultimate price?
3. How can we produce the electricity we need at the least expenditure of our mineral resources and at the least cost to our environment?
4. What are the alternatives to the nuclear generation of power? Will these be sufficient for our needs?
5. Are the advantages of nuclear generation (or any other method of generation) worth the price?

As the student formulates these decisions, do not attempt to guide him in any way, nor to bias his judgments to conform to your own personal attitudes or opinions. Your task is to *"tell it like it is,"* and then to turn the decision-making process over to the student. This, of course, is difficult. We as teachers tend by our statements, facial expressions and gestures to communicate our own value judgments to our students, but in this case we must absolutely refrain from doing so, even though we will undoubtedly undergo some emotional strain as we watch our students making what may be, to us, the *"wrong"* decision. However, each student should decide for himself, or as a member of a group of his peers. This, after all, is the democratic process.

Have your students engage in the decision-making process. Use the *Flowchart of Basic Decision-Making Model* for resolution of environmental problems found in Appendix III of the student manual and reproduced here.

Flowchart of Decision-Making Model

The reader has been confronted with numerous issues regarding the conflict between enjoying the supposed benefits of a technological society and reducing the quality of our environment to intolerable levels. Decisions to resolve the conflict must be made; they will be made. If knowledgeable people refuse to make these decisions, less knowledgeable persons will. The attitude of *"letting George do it"* is a gross shirking of responsibility.

But how does a person with a bit of knowledge about the problem (such as that acquired through this minicourse) make such decisions? How does he evaluate the available data? How does he know when he has surveyed all the data? How does he test for logical inconsistencies within the reports? The problem of analyzing large sets of information and formulating workable solutions to problems perceived is one of the most mind-boggling and difficult endeavors of the human mind; it is also one of the most rewarding.

A model or guide to this decision-making process is presented in Figure 1. This model is presented in the form of an instructional flowchart and suggests things to do (rectangles) and includes crucial questions (diamonds) which help pinpoint errors in interpretation of the data and conclusions. The rectangles and diamonds are logically interconnected by arrows which suggest which way to proceed.

Each of the main points in the flowchart requires a brief explanation. First, one enters the intellectual process with an awareness of environmental problems of electrical generation and an interest in the identification of solutions to these problems.

Stage 1. *Survey your knowledge of power resources and environment* to acquire factual information and understanding of the basic issues involved. Completion of the minicourse is useful here.

Stage 2. *Identify questions you may have about the issues* for further refinement and analysis.

Stage 3. *Have others raised similar questions?* Answering this question can provide access to discussions of the issue which have already been completed and tends to reduce the phenomenon of *"reinventing the wheel."* In addition, the knowledge that may be raising a relatively new question can be an enlightening and rewarding experience.

Note: Diamonds represent decisions in the form of questions which lend themselves to Yes, No, or ? answers. The path one takes through the flowchart is determined by the answer to the question.

Stage 4. *Have solutions been posed?* If Stage 3 has been answered in the affirmative, we now begin to investigate the merits of the solutions.

Stage 5. *Are solutions based on solid evidence?* If Stage 4 has been answered in the affirmative, we can now ask if there is substantial and logical evidence to support the solution under question.

Stages 6-9. A negative response in either Stage 3, 4 or 5 directs the decision-maker into the key branch of the flowchart. Stage 6 directs the learner to *Survey information related to the problem (or solution)*, or to examine specific issues which relate to the problem under consideration. Caution must be used here to avoid the temptation of switching to a related problem. Stick to the issue at hand! In Stage 7. *List alternative solutions to the problem.* That is, determine, without excessive evaluation at this point, if there are other possible solutions to the problem. In Stage 8, start the process of evaluating the main and alternative solutions from Stage 7 by *Listing advantages and disadvantages of each solution.*

Now that you have examined the evidence and tabulated the pros and cons of the problem or solution, evaluate each as to its practicability and feasibility. Then *"Rank solutions from best to poorest."* (Stage 9) In ranking, one arranges the solutions from the best to the poorest.

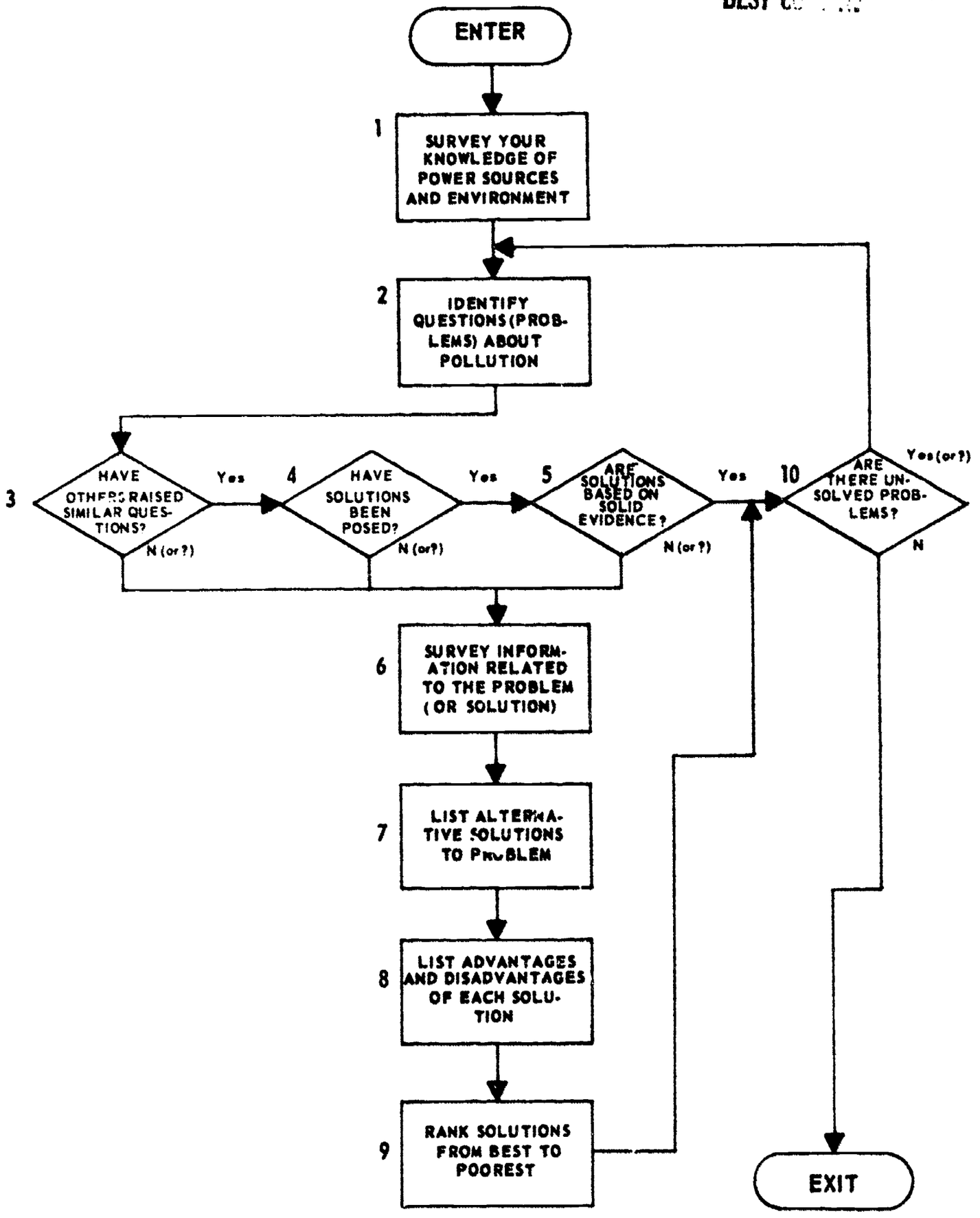
After Stage 9, the flow is cycled back to Stage 10.

Stage 10. *Are there unsolved problems?* Presuming affirmative answers to Stages 3, 4 and 5, we are now at the point where we see if all important questions have been asked. While it is recognized that the words *"important questions"* obviously involve value (subjective) judgments, but value judgments in technological applications are unavoidable.

A negative answer to Stage 10 recycles the flow back to Stage 2, and a positive response sends one to the EXIT of the decision-making program.

Two additional comments regarding this decision-making flowchart are in order. First, it represents a series of intellectual processes and you must try it to understand it.

Second, the flowchart is only a first approximation (only representative) of the complex mental process involved in human problem-solving. It is hoped that it will be most valuable when considered in its present form which is neither exceedingly simple nor excessively complicated.



Flowchart of Basic Decision-Making Model for Resolution of Environmental Problems

APPENDIX I

LABORATORY SAFETY

If you plan to use radioactive materials as part of your laboratory exercises, certain safety precautions must be observed to reduce the exposure to radiation which your students may receive.

The following rules are taken from the Pennsylvania Department of Education publication, *Nuclear Science: A High School Course.*

LABORATORY SAFETY PRECAUTIONS FOR WORKING WITH RADIOACTIVE MATERIALS.

A. All possible precautions must be taken in order to prevent inhalation, ingestion or skin contact with radioisotopes. Therefore, the following rules will be in effect:

1. There will be no eating, drinking or smoking in this laboratory.

2. Keep your hands away from your mouth, nostrils and eyes.

3. All work with unsealed sources must be done in the fiberglass work trays. These trays will be lined with non-absorbent paper to retain spills and facilitate decontamination.

4. Laboratory coats must be worn at all times when working in this laboratory.

5. Rubber gloves will be worn at all times when handling unsealed solutions. These gloves must be monitored, washed with detergent and water, remonitored, and rewashed if contaminated before removal. The hands will then be washed and monitored.

6. Signs indicating radioactivity must be in prominent display during any experiment with unsealed sources.

7. All contaminated materials must be plainly labeled.

8. Radioactive waste will be placed in the plainly marked *"hot"* waste can. No other type of waste will be placed in this can, and no radioactive materials will be disposed of elsewhere.

9. The instructor will be consulted before any radioisotopes may be disposed of, to insure proper disposal.

10. There must be no pipetting by mouth. A propipetter or hypodermic syringe should be used.

11. All spills must be reported immediately, and decontamination procedures initiated under immediate supervision of the instructor.

12. All radioactive sources must be sealed before handling or counting.

If rules similar to this are inaugurated and enforced, there should be complete safety from contamination in the laboratory, barring human error.

Contamination of the equipment, the furniture, and the laboratory itself must be avoided in order to prevent the contamination of other students, and to prevent raising the background count in the laboratory to the extent that it interferes with the proper functioning of the sensitive Geiger-Muller counters. In order to achieve this, the teacher must be familiar with the general rules of radioisotope safety techniques.

All work with unsealed radioisotopes should be done in nonporous trays of a chemically inert substance, such as fiberglass or heat-resistant plastic. The tray should be lined with non-absorbent paper. Any material spilled on the paper can then be rolled up and properly disposed. Any material spilled on other surfaces should be blotted, the surface scrubbed with detergent and water, dried, monitored, and rescrubbed if necessary to remove the contamination. The scrubbing and monitoring should be continued until no trace of activity remains. Of course, the activity of the isotopes used in a high school laboratory is so low that decontamination is a rather simple matter.

"...Decontamination is considered complete when radioactivity from radioisotope groups I and II is not in excess of one millirep per hour average as measured in a small volume of air above any two square inch area. This corresponds to approximately one thousand counts per minute when a Geiger counter is placed as close as possible to the contaminated area... Note that in many high school experiments the actual counting rate will not greatly exceed that which meets the AEC definition of uncontaminated."[6]

A clearly marked radioactive waste can should be available for the deposition of all contaminated materials. A twenty gallon covered trash can is quite suitable for this purpose. The container should not be emptied with uncontaminated trash, but should be subject to special handling. The paper can be safely incinerated, thus dissipating the activity, while the other material can be buried. Another method is to store the can and its contens for a one year period. At the end of this period, the activity will be reduced by normal radioactive decay. Small animal carcasses contaminated with radioactivity should be placed in glass containers and buried. The containers will prevent the carcasses from being dug up and scattered by foraging animals.

Isotope solutions of the low activity which would be used in the high school laboratory may safely be flushed down the sink. If the tap is allowed to run for five minutes previous to pouring the isotope and twenty minutes after, the activity will be so diluted as to be practically undetectable. It would be well for each indivudual teacher to contact his local health or civil defense authorities concerning this matter.

Any vaporization or sample drying of radioactive material should be done in a hood to prevent the inhalation of radioisotopes.

All laboratory glassware used for radioactive material should be rinsed, washed with detergent, and stored separately from non-contaminated glassware.

The supply of radioisotopes should be stored in a plainly labeled, locked metal container. A metal chest lined with cinder brick has proven to be quite satisfactory for this purpose. The cinder brick acts as a protective shielding, and also gives the box sufficient weight to prevent its being moved.

In order to prevent careless handling, all contaiminated substances should be clearly marked with warning tape.

During the laboratory period, one student should be assigned as laboratory safety officer, whose duty would be the constant monitoring of the laboratory for spills or any other contamination. He should immediately report any spills and aid in decontamination procedures. This will also, by the way, aid in teaching proper safety techniques. The instructions for the safety officer will be found with the experiments.

At this point it should be reiterated that radioisotopes used in conjunction with the proper safety precautions are no more dangerous than the corrosive acids which are used as a routine part of every high school chemistry course.

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[6]Miner et. al. *Teaching With Radioisotopes*, U.S.A.E.C. Washington, D.C.; 1959.

APPENDIX II

ENVIRONMENTAL ACTION ORGANIZATIONS

I. PRIVATE ORGANIZATIONS

1. National Intervenors
   153 E Street, S.E.
   Washington, D.C. 20003

2. Sierra Club
   1050 Miles Tower
   San Francisco, California 94104

3. Scientists Institute for Public Information
   30 East 68th Street
   New York, New York 10021

II. GOVERNMENT AGENCIES

1. United States Environmental Protection Agency
   Washington, D.C. 20202

2. United States Atomic Energy Commission
   Washington, D.C. 20202

APPENDIX III

ACHIEVEMENT TEST

Part 1: Multiple Choice

1. Which of the following concepts now being studied uses electrocially conductive gases from the combustion of fossil fuels to make a highly efficient source of electricity?

   a. Coal Gasification
   b. Fusion
   c. Magnetohydrodynamics
   d. Thermal Conversion

2. The breeder reactor depends on the conversion of ---------material to--------- material.

   a. Non-radioactive, radioactive
   b. Radioactive, fertile
   c. Fertile, fissionable
   d. Radioactive, fissionable

3. Which of the following has been a recent development in fossil fuel electrical generation?

   a. Increased efficiencies by use of higher steam pressures and temperatures
   b. Increased plant size
   c. Higher stacks
   d. All of the above

4. What is the average radiation dosage from natural background and man-made sources for persons in the U.S.?

   a. 2000 rem/year
   b. 2 mrem/year
   c. 200 mrem/year
   d. 20 rem/year

5. The most severe hazard and most complex technical problem in readioactive waste management is presented by

   a. Solid wastes from reprocessing plants
   b. Liquid wastes from reprocessing plants
   c. Release of radioactivity into the air
   d. Shipping of radioactive wastes

6. Which of the following would result in the largest energy savings and be the easiest to accomplish?

   a. Educating people to use less electricity in their homes
   b. Rationing electricty
   c. Better design of heating, lighting, and air conditioning in homes and commercial buildings
   d. Replacing pilot lights with electric starters

7. Which of the following fuels provided the greatest amount of electrical energy in 1972?

   a. Gas
   b. Coal
   c. Oil
   d. Uranium

8. During radioactive decay, three principal types of radiation are emitted from an atom. Which of the following is not one of these types?

   a. Gamma- and x-rays
   b. Beta particles
   c. Alpha particles
   d. Deuterons

9. Which plant type requires the largest land area?

   a. Coal
   b. Oil
   c. Gas
   d. Nuclear

10. Which of the following is a factor which influences the biological effects of radiation?

   a. Rate at which dose was received
   b. Part of the body irradiated
   c. Both a and b
   d. Neither a nor b

11. Nuclear power plants have more of a problem with waste heat disposal than fossil fueled plants because

   a. Nuclear plants generally have a greater generating capacity than fossil fueled plants
   b. Nuclear plants are less efficient
   c. Nuclear plants discharge nearly all their waste heat into their cooling water
   d. All of the above

12. In a water moderated power reactor, what would happen if the rate of fission were to increase significantly?

   a. The excess heat from the fissions would cause a decrease in the number of neutrons available to be captured by fissioning atoms, and the rate of fission would automatically slow down.
   b. The reactor would explode
   c. The core would melt from excess heat
   d. It is not possible for the rate of fission to increase significatntly in a water moderated power reactor.

13. What is the basic difference between most types of electrical generating plants?

   a. Amount of thermal pollution
   b. Cost of fuel supply
   c. Source of energy to produce steam
   d. Operating temperatures and pressures

14. The component of a nuclear reactor that acts as a *"neutron sponge"* is the

a. Moderator
b. Fuel rods
c. Core
d. Control rods

15. Which of the following is a problem associated with the use of coal as a fuel for electrical generation?

a. Its geographic distribution
b. Mining hazards
c. Shortage of railroad cars
d. All of the above

16. When one or more electrons is separated from an atom, the atom is said to be

a. An isotope
b. Ionized
c. Electrolized
d. None of the above

17. The *"acute radiation sickness syndrome"* refers to

a. Any symptons of biological damage from radiation
b. Any radiation exposure causing death
c. An illness afflicting uranium miners
e. Effects of large sudden whole-body doses of radiation

18. Which of the following must be considered the only way of finally disposing of radioactive materials?

a. Delay and decay
b. Dilute and disperse
c. Concentrate and contain
d. All of the above

19. A----------of radioactive materials will sustain nuclear---------by capturing neutrons.

a. Stable mass, decay
b. Critical mass, fission
c. Fragment, fission
d. Critical mass, decay

20. The term *"fast"* in fast breeder reactors refers to

a. The rate of fuel consumption
b. The rate of electrical production
c. The average velocity of the fission neutrons
d. None of the above

21. What offers the best long-term solution to the problems of short gas supplies?

a. Gas from oil
b. Coal gasification
c. Importing liquified natural gas
d. Use of biological wastes

Part 2: True-False

1. The multiple barrier concept in reactor systems is designed to guard against the escape of radioactive substances into the environment.

2. The health effects of the oxides of sulfur are related to injury to the blood-forming organs.

3. In the United States, most of an individual's per capita consumption of electricity is for industrial processes to maintain our standard of living.

4. Rapidly dividing cells are especially radiosensitive.

5. In the case of both radiation and traditional air pollutants, most of the data on human effects was obtained by experimenting with small doses.

6. Certain air pollutants may interact with each other to cause more serious biological problems than they would cause alone.

7. About half of all uranium is fissionable uranium-235.

8. The *"roentgen equivalent man"* is a measure of energy deposited by radiation and also its resulting biological effect.

9. The basic difference between the light water reactors and the gas cooled reactor is the type of fuel used.

10. Every power plant built should construct a cooling water tower to end thermal pollution.

11. It is predicted that by 1990 there will be no natural gas available for use as fuel for electric utilities.

12. It is possible for a coal-burning plant to release more radioactivity into the environment than a nuclear plant.

13. The main reason for the increasing demand for electrical production in the United States is our growing population.

14. Exposure limits for radioation are set using very conservative assumptions because the effects of low-level chronic exposure to radiation are hard to measure.

Answers:

Part 1

1.	c	8.	d	15.	d
2.	c	9.	a	16.	b
3.	d	10.	c	17.	d
4;	c	11.	d	18.	a
5.	b	12.	a	19.	b
6.	c	13.	c	20.	c
7.	b	14.	d	21.	b

Part 2

1.	T	8.	T
2.	F	9.	F
3.	T	10.	F
4.	T	11.	T
5.	F	12.	T
6.	T	13.	F
7.	F	14.	T