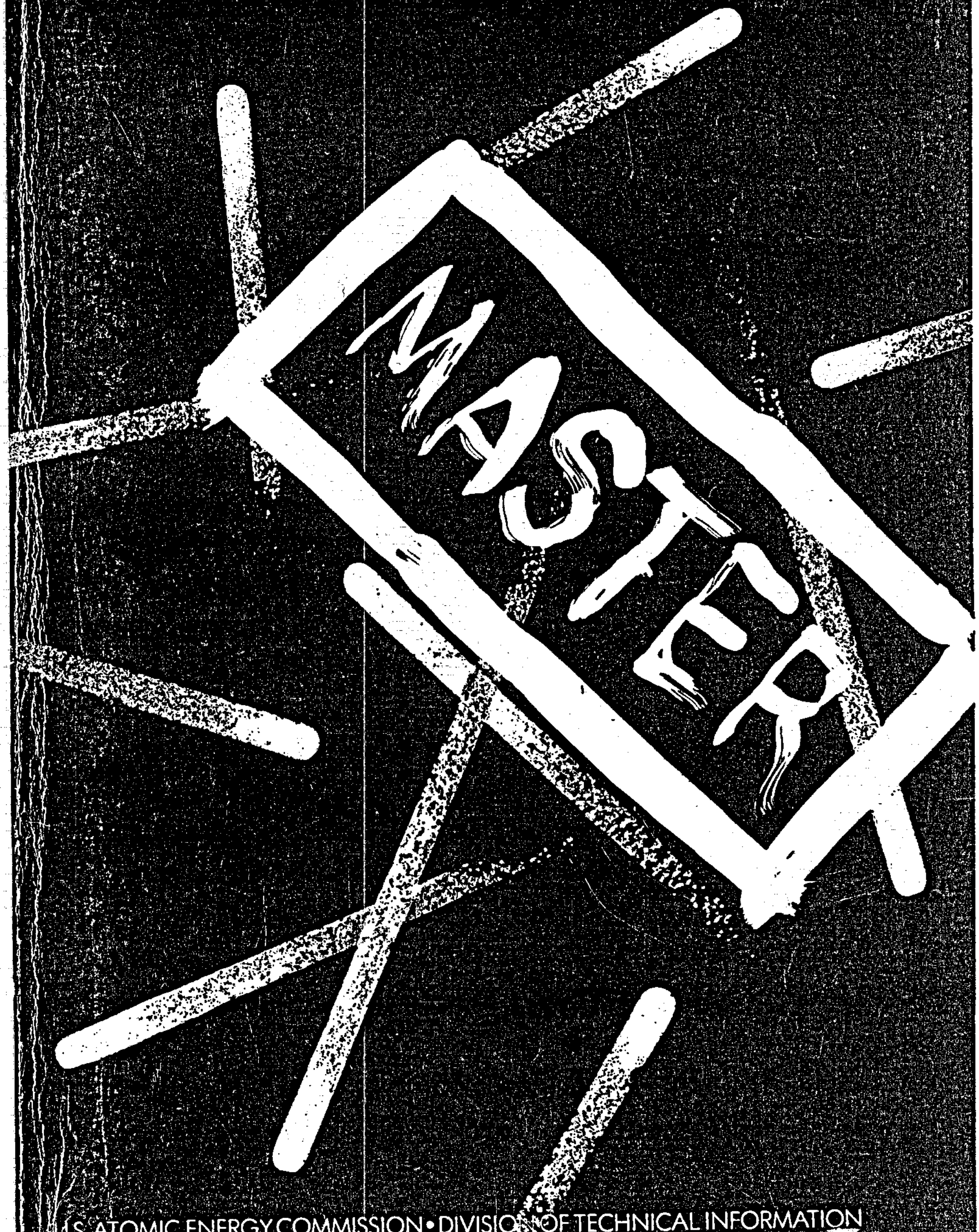
PEACEFUL USES OF NUCLEAR ENERGY

SPEECHES BY GLENN T. SEABORG



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PEACEFUL USES OF NUCLEAR ENERGY

A COLLECTION OF SPEECHES BY
GLENN T. SEABORG
CHAIRMAN
UNITED STATES
ATOMIC ENERGY COMMISSION

JULY
1970

U.S. ATOMIC ENERGY COMMISSION / DIVISION OF TECHNICAL INFORMATION

Single copies of this booklet may be obtained free from

Division of Technical Information Extension
U. S. Atomic Energy Commission
P. O. Box 62
Oak Ridge, Tennessee 37830

Printed in the United States of America
USAEC Division of Technical Information Extension, Oak Ridge, Tennessee
July 1970

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Introduction

It is now a quarter of a century since nuclear energy was introduced to the public. Its introduction was made in the most dramatic, but unfortunately in the most destructive way—through the use of a nuclear weapon.

Since that introduction enormous strides have been made in developing the peaceful applications of this great and versatile force. Because these strides have always been overshadowed by the focusing of public attention on the military side of the atom, the public has never fully understood or appreciated the gains and status of the peaceful atom.

This booklet is an attempt to correct, in some measure, this imbalance in public information and attitude. It is a compilation of remarks, and excerpts of remarks, that I have made in recent years in an effort to bring to the public the story of the remarkable benefits the peaceful atom has to offer man. This is a story that grows with the development and progress of the peaceful atom. It must be told so that we can learn to use the power of nuclear energy wisely and through this use help to build a world in which the military applications of the atom will never again be a threat to mankind.

Glenn T. Seaborg

*The need for nuclear power**

We must face the fact that a growing world population with both rising standards of living and volatile rising expectations will demand a huge amount of power in the years ahead. By the year 2000 this country will require the production of 130 quadrillion British thermal units of all types of energy per year to supply the wants of 300 million people. The world will need many times this number. If we assume world use at one-quarter of the U.S. per capita consumption, this would, in the year 2000, amount to 650 quadrillion units of energy needed for six or seven billion people, a staggering total.

No doubt a large amount of this energy, particularly in terms of oil for the transportation and power fields, will come from fossil fuels over the next few decades. But, in spite of forecasts of large reserves, we know that these natural resources are limited. We also know that there is a limit to nature's ability, and to our own human tolerance, to absorb all the pollution that would result should we try to burn up all these fuels over the next century or so. I am not going to document the pollution loads that would accrue from the combustion of that massive amount of fuel. I think the members of this committee have many times been made aware of these amounts and their consequences. Fortunately, we have for the generation of electric power an alternate fuel—nuclear energy.

As I have said on other occasions, I believe that nuclear energy has arrived on the scene, historically speaking, in the nick of time. I base this belief on several factors:

1. The projected demand for power based on population growth and increasing per capita consumption of electricity.
2. The need for a cleaner and more manageable source of energy to reduce the degradation of the environment.

**Excerpts from testimony before the Joint Committee on Atomic Energy, Oct. 29, 1969.*

3. The need also for abundant and very economic energy in a world of diminishing natural resources where such energy may well determine how many people can be supported and at what living standard.

Let me expand briefly on each of these.

The current electric generating capacity of the United States is about 325 million kilowatts. If we look ahead a mere 30 years to the year 2000, our projected capacity is about 1.5 billion kilowatts. What is required in the way of generating facilities and fuel to keep such a capacity operating? As a hypothetical illustration of the magnitude of this requirement, consider a power economy derived solely from coal. Fifteen hundred generating plants, each with a capacity of one million kilowatts, operating at an assumed three-quarters load factor, would burn about ten million tons of coal per day. Such a requirement, by the way, would involve the daily movement of 100,000 railroad cars and the dumping of coal into billions of cubic feet of storage space. Should we go the nuclear route to generate the same amount of electricity, roughly the same number of nuclear plants would consume all of three tons of fissionable material per day, and, I might add, the nuclear plants using such fuel would require reloading only once every two or three years.

What I have just pointed out, let me remind you, involves only *one day's* generation of electricity only 30 years from today. I do not think, therefore, that anyone can seriously believe we could rely on coal as our major source of power as we enter the twenty-first century or that we should not develop with all due urgency the best systems for producing nuclear power.

Even if our projected coal reserves should be sufficient to fill our furnaces for a few centuries, long before we dig for that last lump of coal we will have far better uses for this valuable resource than to burn it. Here I have reference to its use as a unique source of material for the chemical industry. From this standpoint alone I think the advent of nuclear energy will prove to be a historical necessity for man.

The same thing, I think, will hold true from an environmental standpoint. The pollution load that would result from the burning of all the fossil fuels in massive amounts and as rapidly as we would need them going into the next century would pose a disastrous environmental hazard. I am thinking here, as I believe we must when we speak of long-range future energy requirements, on an international scale. In considering such requirements we must recognize that there is a world of two billion people—rapidly growing—outside of the developed world and that these people are striving for a life that will demand an energy consumption on a scale with ours.

This thought becomes staggering when one considers that at present two billion people in the world still have no electricity. Asia, with half the world's population produces only one-tenth of the world's total electric power. In raising their standard of living, these people cannot and will not relive our Industrial Revolution—the Coal Age. They obviously are going to enter the Nuclear Age as they work to emulate the developed nations.

Let me state at this point that my remarks related to coal do not mean that I think we can get along without it. Coal will continue to be essential to our lives for decades. I believe we would be wise to consider fossil-fuel resources and the atom as energy partners, not as competitors. But the day has passed when we can look ahead only a few decades and complacently wait for the depletion of each of our resources before we move ahead to compensate for them.

Now, since we are eventually going to live in a world that will have to depend on the energy of the atom, we must learn to live with the atom wisely. This means we must recognize, anticipate, and deal with all the environmental aspects and prospects of nuclear energy. I believe we are doing this, and doing it well. This type of technological development is something that has never before been attempted in the history of man. No technology has been born and developed with the regard for human safety and well-being that is inherent in the development of nuclear energy.

In fact, you might say that the extent of our knowledge about the biological aspects of nuclear energy has been a problem to us—or at least to those in the nuclear field who are impatient. The tremendous amount of knowledge we have accumulated over some twenty-odd years has made us almost overly conservative in the development of nuclear power. I have often thought that if the potential health and safety implications of so many aspects of our lives—our chemical products, our foods, our transportation systems, our athletic activities, even our sleeping habits, to name a few—were so well known and documented, we would have a very apprehensive public, one literally afraid to eat or drink anything or go anywhere or do anything.

Fortunately, because of our knowledge of nuclear energy and the way we have developed it in accordance with that knowledge, we have at hand a unique opportunity to advance an abundant source of power with minimum environmental impact. We are following such a course, fulfilling such an opportunity.

My total experience in the nuclear energy field for more than a quarter of a century and my association with others who have devoted their lives to this field have given me the firm conviction that the environmental problems associated with nuclear energy are manageable. With good planning and continued dedicated work on the part of those in the nuclear field, our electric utilities, and those government agencies that regulate our nation's power systems, we can have safe, clean, and reliable nuclear power—as much of it as we will need.

The suggestions I have made earlier of vast benefits that can be derived for mankind from nuclear energy were not made without full awareness that there are inherent in this technology certain risks and potential hazards to health and safety, just as there are risks in many other activities. Recognition of the fact of these risks is the basic reason for the comprehensive system of safety review and regulatory controls set up by the Congress for the protection of people and the safety of reactor facilities and for the extensive programs of safety research in both the physical and biological aspects of nuclear power plants and radiation.

In spite of the current wave of misunderstanding and fear registered by a certain segment of the public, I think we are going to prove the important point that the benefits related to nuclear power will outweigh the risks involved by a factor far greater than most of our modern technologies can boast.

There will be continuous agitation, there will be adjustment and compromise, but, more important, there will be more understanding and a better working relationship between reasonable and rational environmentalists and technologists who will see that they are not as far apart as they had believed. As a result, we will see in the long run more nuclear power and a healthier environment.

When we have got past this point, I believe we will see some remarkable things happening with nuclear power. We will find, with good site planning and the aesthetic designing of nuclear plants, that nature and technology are not incompatible. We may well see the advent of "Nuclear Parks" advocated by members of this committee. We could see the use of abundant and very economic nuclear energy having a widespread beneficial effect on many other environmental problems—helping us to supplement and control our water resources and helping us to recycle much of our solid waste, thus preserving our diminishing mineral resources and eliminating many eyesores and environmental blights on our landscape. We will ultimately see this kind of nuclear energy having a remarkable effect on world development, helping to lift billions of energy-starved individuals into the mainstream of the twentieth century.

Perhaps the most disturbing thing about the current reaction to environmental problems is the attitude it is engendering—a fear that is making many look backwards. There are some people whose only reaction to the possibility of future power shortages—and "blackouts" and "brownouts"—should we fail to plan and build now to meet our future needs is that we should reduce our use of electricity, we should turn out our lights. There are others who are so irrational in their fear of nuclear power and so desperate for alternatives that they have seriously advocated harnessing the Gulf Stream, or icebergs, or volcanoes, or hot air balloons. Fortunately, most people are not willing to sit in the dark or to search in the dark for a better life for themselves and their children.

We who are involved in developing nuclear power to provide for future electricity needs are naturally disturbed by public resistance that seeks to halt or slow down such development. However, along with our obligation to safeguard the natural environment, we also have a responsibility to help supply our people with the power to run a technologically sustained society. In the years ahead, today's outcries about the environment will be nothing compared to cries of angry citizens who find that power failures due to a lack of sufficient generating capacity to meet peak loads have plunged them into prolonged blackouts—not mere minutes of inconvenience, but hours, perhaps days, when their health and well-being and that of their families may be seriously endangered. The environment of a city whose life's energy has been cut, whose transportation and communications are dead, in which medical and police help cannot be had, and where food spoils and people stifle or shiver while imprisoned in stalled subways or darkened skyscrapers—all this also represents a dangerous environment that we must anticipate and work to avoid.

Among those who oppose nuclear power on the grounds that we are too affluent in our use of energy and could afford to cut back are many whose motives are sincere but who have not thought things through.

More often than not, these are the very same people who, rightfully, want to lift their less fortunate fellow humans from poverty; who want to build new cities, new schools, and new homes; who want to produce more food for the hungry; and who want to achieve other social and human goals for more people. Such accomplishments invariably will call for the use of much more energy than we have at hand today. The self-sacrifice of turning out some lights or unplugging some appliances is not the way to bring a better life to those growing millions who need and want the benefits brought through more energy.

In conclusion, let me go back to a little bit of light that was shed by a wise man who wrote long before this nuclear age, at another time when men struggled with their thoughts and actions about the future. Almost two centuries ago Edmund Burke wrote: "The public interest requires doing today those things that men of intelligence and good will would wish, five or ten years hence, had been done."

I believe that the judicial development of nuclear power as a major source of energy for the future is in the public interest and that five, ten, and a hundred years hence men will look back with favor on the course we are taking today.

*Nuclear power—status and outlook**

When I spoke at the American Power Conference five years ago on the theme "Nuclear Power—New Member of the Energy Team," I said that nuclear energy was no longer "on the bench" and that it had moved onto the field to take its place among the other members of the team. We are all aware that many people doubted then that nuclear power had in fact left the bench to join the game since there were relatively few commercial nuclear plants operating or on order by the utilities. Actually, I was quite confident at that time that nuclear power had come of age and would grow to something like 75,000 MW(e) of installed capacity by 1980 in the United States.

You all know what has been happening over the course of the five intervening years. The nuclear plants now in operation, under construction, or on order by the utilities in the United States already exceed 75,000 MW(e) in combined capacity. We and others in the energy field have admitted to having been on the low side in previous predictions; accordingly, we have increased our estimate to something more like 150,000 MW(e) by 1980 [actually, we have hedged a bit by estimating a range of 120,000 to 170,000 MW(e)]. Underestimating energy growth patterns in the U.S. seems to be typical in these unprecedented times; so we need not be apologetic for our previous, and possible current, predictive failings.

At the time of this American Power Conference, there is wide recognition that nuclear power has become an important and rapidly growing member of the energy team both here and abroad. And there is greatly increased awareness of the benefits of nuclear power, such as providing competition for other energy sources, reducing air pollution, and essentially eliminating the problems of transporting massive quantities of fuel.

**Remarks at a luncheon sponsored by the Institute of Electrical and Electronic Engineers, American Power Conference, Chicago, Ill., Apr. 22, 1970.*

We anticipate that 30 years from now nuclear power plants will generate over one-half of the nation's total electric power. Of course, this growth may not be achieved if we are counting on doing the job exclusively with today's types of commercial light-water reactor plants. These plants must be the workhorses of the nuclear power industry in the years ahead, but they must be coupled with other more-advanced types to fulfill our longer-term energy needs while at the same time satisfying environmental and social concerns about large-scale energy production. Although current light-water reactors have many advantageous characteristics, we know that they do not achieve thermal efficiencies comparable to the more-advanced reactors now under development. Furthermore, they extract only between 1 and 2% of the potential energy from their uranium fuel. They are dependent on the availability of large amounts of low-price uranium ores to keep their power costs economically competitive with those of fossil-fuel plants.

Fortunately, nature has arranged things so that we can obtain a large fraction of the vast amounts of energy locked up in uranium and thorium minerals through the breeder-reactor principle, and we can expect that breeder-reactor power costs will be relatively insensitive to the cost of the uranium and thorium; this opens up the economic use of low-grade as well as high-grade ores. Through our breeder-reactor development program, those of us in the energy community—the utilities, manufacturers, universities, and the government—are now well under way toward taking advantage of this gift of nature, an abundance of low-cost nuclear energy that can serve our needs for thousands of years to come.

I believe we are only beginning to recognize the implications of this promised abundance. We simply have not had time to develop the long-term perspective necessary to envision the full possibilities. But, as we achieve our goals in the breeder development, I believe we will witness a transition to the massive use of nuclear energy in a new economic and technological framework. This transition may be slow, and it will require the introduction of a series of innovations in industrial, agricultural, and transportation technology. The innovations will include such advances as large-scale dual-purpose desalting plants, electromechanization of the farm and of transportation, electrification of the metal and chemical industries, more effective means for utilizing wastes, and devices for converting nuclear energy directly to electricity. It seems to me that these innovations, and others, are going to be necessary to keep this planet liveable for the increased number of people we will see on it, even with a reduced population growth, and to effect needed improvements in standards of living. Vast new possibilities will be opened up by abundant low-cost electric energy. Low-cost energy will make it economically possible to use low-grade ores of many metals. As needs mount, low-cost nuclear generated electricity will also become a basic ingredient that can be used instead of some of the less abundant fossil resources that are now being used for energy production.

These are attractive promises that will challenge the very best efforts we can summon to the task. But we must plan and prepare for them today.

With emphasis on this planning and preparation, I want to tell you something about the path we are taking in breeder-reactor development, and why, and some of our expectations along the way.

Let me begin by reminding you that breeding of fissile material can be accomplished by two different routes. One is the thermal breeder employing slow (thermal) neutrons; it works best on the ^{232}Th–^{233}U cycle, called the thorium cycle for short. The other is the fast breeder employing more-energetic (fast) neutrons; it operates best on the ^{238}U–^{239}Pu cycle, called the uranium cycle for short. Over the years, we have done enough work with these two cycles to know that breeding does happen, that we can create more fissile material than is consumed while producing power. We must, of course, go beyond this; we must assemble and apply on the large scale required the resources, the knowledge, and other capabilities in the nuclear industry.

It has long been recognized that nuclear energy's full promise for providing a virtually unlimited energy source for future generations could be realized only through the development and application of the breeder reactors. The U.S. interest in breeder reactors dates back to the Manhattan Project days when the possibility was first recognized by pioneers in the nuclear field. Much of the preliminary effort on the breeder was conducted in the AEC national laboratories. The Clementine reactor was constructed at Los Alamos and used from March 1949 to December 1952 to demonstrate the feasibility of operating with fast neutrons, plutonium fuel, and a liquid-metal coolant. The Experimental Breeder Reactor No. I (EBR-I) was built and operated by Argonne National Laboratory from August 1951 through December 1963 to prove the breeding principle in a fast-flux reactor and to establish the engineering feasibility of using liquid-metal coolant.

Research and development efforts related to operation in environments of fast flux and high-temperature liquid metal were initiated. These efforts culminated in the construction of two fast reactors in the mid-1950's, the 20-MW(e) Experimental Breeder Reactor No. II (EBR-II) and the 60-MW(e) Fermi reactor.

Several factors worked against immediate success in terms of the commercial exploitation of the breeder reactor. Breeder development was essentially confined to the national laboratories, and industrial involvement was minimal, with the exception of the Fermi development effort. The industrial groups were concentrated on the light-water reactors and the nuclear Navy, where the prospect of success was nearer at hand. The proven uranium resources appeared sufficient to meet projected requirements. Although a substantial technological base, including test facilities, was being developed in the laboratories, until the mid-1960's there appeared to be no urgent requirement to channel the major part of our effort and resources into the breeder program.

About four years ago, when we felt the time was right to embark on an intensive breeder-reactor development program aimed at making this type of reactor a commercial reality, we knew full well that it would be a difficult, complex, and costly undertaking. Given the many pressing national needs competing for funds in a finite budget, we also knew it would probably not be possible to go forward with intensive parallel development of machines for both the uranium and thorium cycles, even though each was extremely promising. A choice was needed and one was made. The route chosen was the uranium—plutonium one.

It was further decided to focus efforts on the Liquid Metal Fast Breeder Reactor, or LMFBR for short. Liquid metal (sodium) was chosen as the coolant for several reasons, among which was the fact that over the years substantially more experience had been acquired in the laboratories and industry, both here and abroad, with liquid-metal systems than with the other coolants for the breeder application. This experience included that gained from operation of a number of experimental reactors using a liquid-metal coolant. These reasons were strong enough to offset some unfavorable characteristics of sodium, such as its high chemical reactivity.

Although priority has been given to the LMFBR, investigations are continuing on other advanced reactors that have an important potential for increased fuel utilization or breeding. These include two thermal breeder concepts using the thorium cycle, namely, the Molten Salt Breeder Reactor (MSBR) under investigation at Oak Ridge National Laboratory and the Light Water Breeder Reactor (LWBR) being investigated under Admiral Rickover's direction. In addition, considerable interest exists, both here and abroad, in the development of the Gas Cooled Fast Breeder Reactor (GCFBR), which employs the uranium cycle. I might note here that some 43 U.S. utilities have joined with the reactor manufacturer, Gulf General Atomic Incorporated, in pursuing this breeder concept.

I should also mention one other concept, the High Temperature Gas Cooled Reactor (HTGR), which like the MSBR and the LWBR employs the thorium cycle. Although not a breeder, the HTGR offers substantial improvement in fuel utilization, reduced sensitivity to rising ore costs, and reduced thermal discharge because of its high thermal efficiency. A prototype plant based on this concept, Peach Bottom Atomic Power Station, Unit I, has been in operation in Pennsylvania since 1967, and a 330-MW(e) prototype, Fort St. Vrain Nuclear Generating Station, is under construction in Colorado. Gulf General Atomic Incorporated, the reactor manufacturer, is currently marketing an 1100-MW(e) HTGR plant.

Having discussed these alternative efforts, I should point out that the direction we have taken was importantly influenced by the earlier decisions to proceed with development of the light-water reactors and, later, their large-scale acceptance by the utility industry. These light-water reactors operate on the uranium cycle, and, although they are not breeders, they do produce plutonium in significant quantities. The projected operation of about 150,000 MW(e) of predominantly light-water reactor plants by 1980 will result in the production of many thousands of kilograms (literally tons) of plutonium, which can support the large-scale introduction of fast breeders beginning in the 1980's. Of course, much of this ^{239}Pu can and will be recycled to the light-water reactors as a substitute for ^{235}U, but we know that it should be economically more valuable as breeder fuel than as recycle fuel for the water reactors.

The utilities will have options as to how they will use this material—whether to use it in light-water reactors, in breeders, or in both, depending on the characteristics of the plants in their system and other considerations. In any event, this man-made plutonium fuel will be a highly valuable resource with a vast domestic and worldwide potential.

From the commercial viewpoint this technical coupling through the fuel cycle is an extremely important factor. A significant facet of this coupling is the complex of facilities that industry has provided and will continue to provide at large capital outlays for the various operations in the fuel cycle for water reactors. Because of this close coupling with respect to fuel cycles, it is possible to expand from these facility investments and the know-how related to light-water reactors to their use as breeders.

Thus we see the transition from the light-water reactors to the breeder as an orderly process in which the fuel produced by the light-water reactors will help to supply both until enough of the fast reactors are on line long enough to form a completely self-sufficient fuel system. In such a system each breeder reactor would, hopefully, in 7 to 10 years produce enough fissionable fuel to refuel itself and one other reactor. This is what we refer to as a "doubling time" of 7 to 10 years. If a fuel doubling time of less than about 10 years (the approximate doubling time of the electrical power demand in the United States) can be achieved with the breeders, these nuclear power generating systems could become self-sustaining in about 30 years after introduction, providing fuel for new and old reactors as needed.

The development of such a breeder reactor system will, of course, cost money, but the indications are that financial savings and other important benefits resulting from the decreased cost of the electric power will compensate for this expense many times over. The economic advantages that can be expected to accrue from a strong program for the development of breeder reactors were brought out by a "cost–benefit analysis of the U.S. breeder reactor program" completed last year by the AEC. According to this analysis, the breeder offers a tremendous dollar payoff. For example, in addition to large industrial expenditures, we estimate that the LMFBR research-and-development cost will be in excess of $2 billion through the year 2020 for the AEC. Assuming a 1984 introduction of the commercial fast breeder, the gross benefits to this nation from electrical energy savings in the 35-year period thereafter, to the year 2020, are estimated to be more than $200 billion in terms of 1970 dollars. I might mention also that, under the same set of assumptions, a significant savings of nuclear fuel resources and other benefits would accrue as a result of introducing the breeder. The savings over the 35-year period would amount to 1.4 million tons of U_3O_8, the energy equivalent of 400 thousand million tons of coal. To put this into perspective, I might recall for you that this nation currently consumes about 300 million tons of coal annually for electric power generation.

In addition to the economic and resource conservation benefits associated with the breeder, we believe that significant environmental advantages will accrue as a result of its development. Like the light-water reactor, the breeder will not add products of combustion to the atmosphere. Since the breeder will operate at higher thermal efficiencies, the amount of waste heat released to the environment per unit of power produced will be comparable to that from the modern fossil-fueled power plant. Finally, the LMFBR, because of its inherent characteristics, can be readily designed to even improve on the already very low releases of radioactive wastes to the environment at the nuclear plant site.

*Nuclear fusion**

The question might arise, If the energy potential of breeders is so good, why bother with trying to achieve controlled thermonuclear fusion? There are several answers to this question. The first that comes to mind has to do with the amount of energy resources controlled fusion would make available to man. Fission through breeders will supply us with energy for centuries or perhaps thousands of years. But, with the successful use of controlled fusion, man will have a virtually unlimited energy resource at hand. Even at a power consumption rate many times that of today, he will have an energy reserve that will last for millions of years. Furthermore, he will be able to use this energy with a minimum of manageable radioactive wastes and, as I will point out in a moment, to use it in many remarkable new ways.

The fusion processes employ deuterium as their fuel. Deuterium is a stable heavy isotope of hydrogen present in all water in low concentration. In many of my talks to general audiences, I have tried to point out the abundance of this energy source in nature by saying that controlled fusion would give us an energy equivalent of 500 Pacific Oceans filled with high-grade fuel oil. But in every audience there is someone who seems to misinterpret this. As a result I have heard it said that the Chairman of the AEC plans, through some atomic magic, to make 500 Pacific Oceans full of oil. In view of the incident off the coast of Santa Barbara this year, that creates a rather frightening image to many people. Therefore, I may not use that particular energy analogy again.

In all seriousness though, the potential of controlled fusion is so impressive that the attainment of a power system based on fusion reactors must be one of our long-term energy goals. I stress "long-term" here. If we call to mind that the first practical demonstration of a sustained fission reaction occurred on Dec. 2, 1942, and that over 25 years then passed before an economically competitive nuclear

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**Remarks at the Council for the Advancement of Science Writing, Seventh Annual Briefing on "New Horizons in Science," Berkeley, Calif., Nov. 20, 1969.*

power plant was in operation in the United States, bringing nuclear fusion to economic fruition may well take an even longer period of time. The fusion technology is much more complex, and, as I will demonstrate, we have yet to show that the fusion reaction can be sustained; i.e., we have yet to reach the point with nuclear fusion that we reached with nuclear fission on Dec. 2, 1942. Of course, our scientists involved in fusion research are quite optimistic about their program because of recent developments in the field, and they may prove that I was too conservative in my prediction of the time required to develop a commercial-scale fusion reactor. The reason for some of their enthusiasm will be evident in a moment.

What is involved in the attainment of controlled fusion? What progress are we making? What will be the ultimate payoff?

Efforts to control the release of thermonuclear energy have been going on in the United States and abroad for somewhat less than 20 years. We know that there are several possible fusion reactions using the nuclei of light elements which can be the basis for controlled fusion. Two are deuterium–deuterium (D–D) reactions. The third is a deuterium–tritium (D–T) reaction, and the last is a deuterium–helium-3 (D–^{3}He) reaction:

$$\text{Equal probabilities}\quad\begin{cases} {}^2_1\mathrm{D} + {}^2_1\mathrm{D} \longrightarrow {}^3_2\mathrm{He} + {}^1_0\mathrm{n} + 3.2\ \mathrm{MeV} \\ {}^2_1\mathrm{D} + {}^2_1\mathrm{D} \longrightarrow {}^3_1\mathrm{T} + {}^1_1\mathrm{H} + 4.0\ \mathrm{MeV} \end{cases}$$

$${}^2_1\mathrm{D} + {}^3_1\mathrm{T} \longrightarrow {}^4_2\mathrm{He} + {}^1_0\mathrm{n} + 17.6\ \mathrm{MeV}$$

$${}^2_1\mathrm{D} + {}^3_2\mathrm{He} \longrightarrow {}^4_2\mathrm{He} + {}^1_1\mathrm{H} + 18.3\ \mathrm{MeV}$$

Basically three things must be accomplished to demonstrate that the fusion reaction can be sustained: (1) The deuterium fuel must be heated to between 100 million to 5 billion degrees Kelvin, corresponding to 10,000 to 500,000 electron volts (depending on the fuel cycle). (2) The resulting ions, the plasma, must be held in a configuration where their density is of the order of 10^{15} ions per cubic centimeter. (3) The confinement time of the hot ions at these densities must be of the order of tenths of a second if the ions are to undergo fusion. It is important to note that, if the densities are higher, the confinement times can be correspondingly shorter. Alternatively, if they are lower than 10^{15} ions per cubic centimeter, then the confinement times must be longer.

I hardly need to point out to this audience that these performance criteria pose enormous physical problems. No container material can withstand temperatures of the kind cited, and the density of the plasma actually represents a vacuum. Under these fantastic conditions, means must be provided for introducing the reactants and removing the energy produced. The most promising way at the moment to achieve these objectives is to heat and confine the plasma (without any contact with the walls of the container) by means of strong magnetic fields.

Many kinds of devices have been constructed throughout the world to study plasma confinement. In the United States the AEC is sponsoring major experimental work at Lawrence Radiation Laboratory, Los Alamos Scientific Laboratory, Oak Ridge National Laboratory, Princeton Plasma Physics Laboratory, Massachusetts Institute of Technology, the University of Wisconsin, and Gulf General Atomic Incorporated. This work is currently being budgeted at about $28 million annually. On a worldwide basis, over $150 million annually is being invested in fusion research, principally in Great Britain and the USSR, with the Soviet Union having the most manpower and money devoted to this effort.

What progress have we made in reaching the criteria for controlled fusion? Figure 1 gives an idea of where we stand today as to temperature, density, and confinement time in comparison to our goals. As the figure shows, the target values for these three criteria are roughly 100 million degrees Kelvin, 10^{15} ions per cubic centimeter, and one second or so, respectively.

There is a permissible trade-off between confinement time and ion density, in that the product of these two numbers should be about 10^{14} and each number can be varied accordingly. We can see that, although individual U.S. or British fusion devices have attained at least one of the desired performance criteria, the USSR Tokomak T-3 device has the best overall performance—so good that the U.S. program is being revised radically to take advantage of the successes of the Russian work. These recent international advances have given the scientists and engineers involved in controlled fusion the feeling that at last they are off a plateau of progress and that they will now move with increased speed toward the full attainment of their goals. Obviously the difficulty that

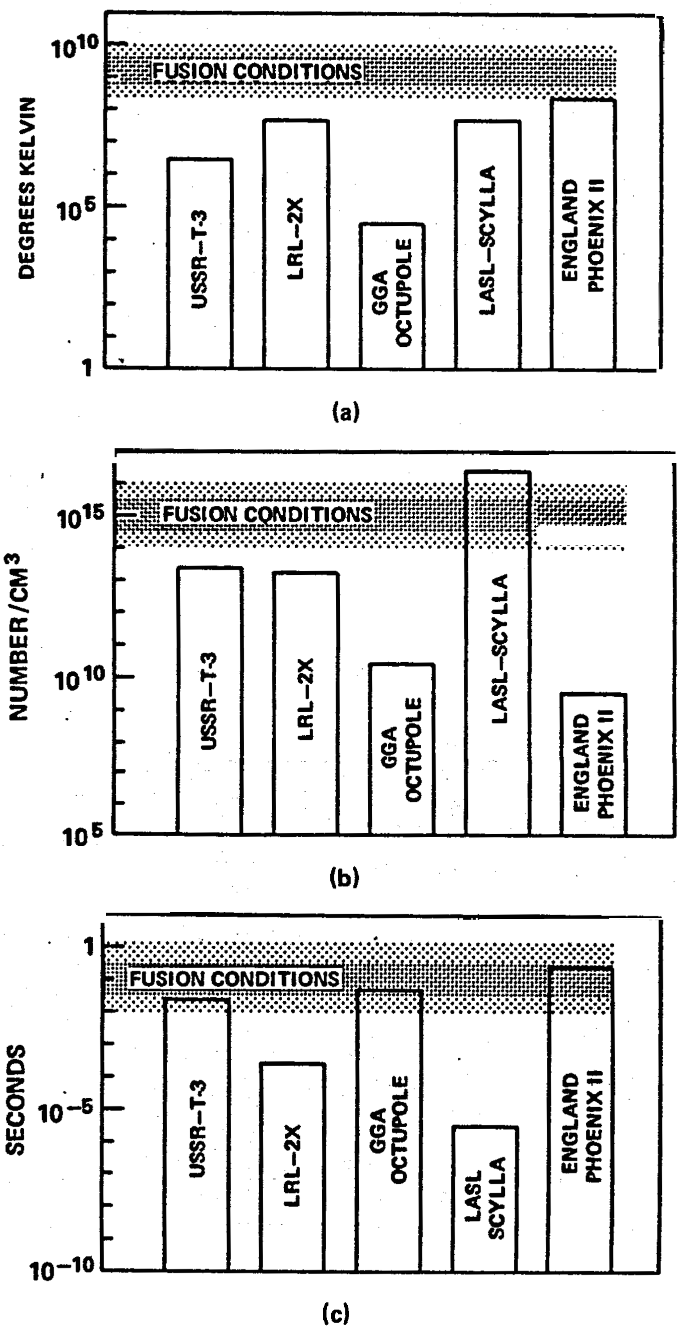


Figure 1. Conditions for controlled thermonuclear fusion. (a) Ion temperature. (b) Ion density. (c) Confinement time.

lies before them is that a combination of all criteria must be met in a single machine.

When we have arrived at that point, what do we do to transform this enormous release of energy into manageable forms of heat and electricity? In other words, what is a controlled fusion reactor and how does it operate?

Figure 2 illustrates the major components of one type of fusion power plant and the system's operation. This is a system based on a deuterium–tritium fuel cycle. In this D–T cycle plant, neutrons from the fusion reaction are absorbed in a lithium "blanket" and heat the blanket, maintaining it in a molten condition. Thus the lithium acts as a heat-transfer medium, a means of generating tritium for further use in the fuel cycle, and as a source of additional thermal energy. The molten lithium is then passed through a heat exchanger, where it gives up its energy, along with some tritium, to potassium vapor. The potassium vapor drives a turbogenerator and then exits into a combined tritium recovery system and heat exchanger. This heat exchanger transfers much of the remaining energy in the potassium to water and generates steam for a steam turbine. The overall system thermal efficiency has been estimated at 60%. Of course, part of the electrical power produced is needed to run vacuum pumps and liquid-metal circulation

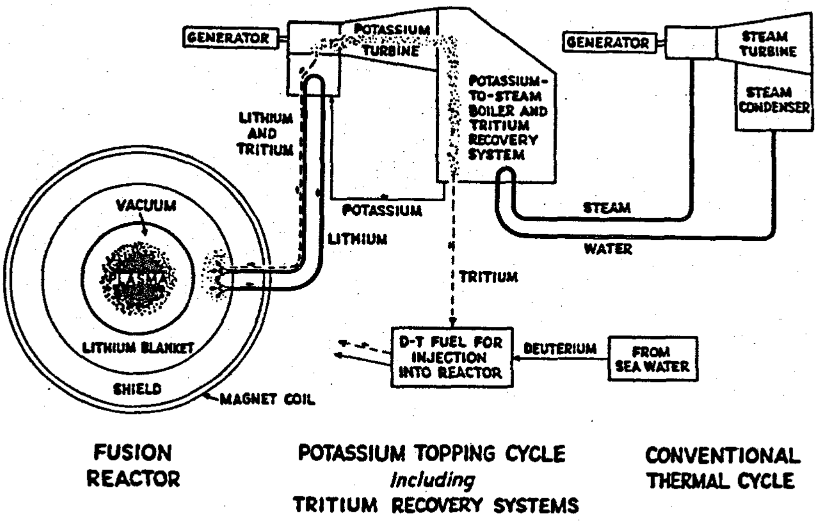


Figure 2. D–T fusion power plant.

pumps, as well as to provide the intense magnetic fields for the fusion reactor.

The following equations illustrate the reactions taking place in this system which breed additional tritium in the lithium blanket.

$$^{6}_{3}\text{Li} + ^{1}_{0}\text{n} \longrightarrow ^{3}_{1}\text{T} + ^{4}_{2}\text{He} + 4.8\ \text{MeV} \qquad (1)$$

$$^{7}_{3}\text{Li} + ^{1}_{0}\text{n} \longrightarrow ^{3}_{1}\text{T} + ^{4}_{2}\text{He} + ^{1}_{0}\text{n} - 2.5\ \text{MeV} \qquad (2)$$

This tritium becomes a fuel to feed the same or another fusion reactor. Calculations indicate that much more tritium is produced than is consumed; so a very short doubling time can be predicted for this fuel cycle.

Let me bring out at this point that the fusion reactor I have just described, as well as other types contemplated, offers some remarkable environmental benefits. Briefly they are:

1. Fusion power plants will not produce large quantities of radioactive wastes. While the internal structure of a fusion reactor will become highly radioactive, the waste products are not radioactive. (I should stress here that the tritium produced in a D–T system is *not* a waste: it is a fuel that is fed directly back into the system.)
2. Fusion power plants operate at high conversion efficiencies, of the order of 60% or higher; therefore they will greatly reduce problems associated with waste heat.
3. Fusion power plants are inherently very safe. Thus we may see the day when such plants are installed in the center of urban complexes, reducing the costs and other disadvantages associated with long-distance power transmission and perhaps making use of the waste heat for space heating and low-temperature industrial processes.
4. Fusion power plants practically eliminate the consideration of the safeguarding of weapons-grade material from diversion for subversive purposes. A plant operating on the D–^{3}He cycle would eliminate the problem altogether.
5. Fusion power plants do not present an after-heat problem in the event of a cooling failure.

Before describing the fusion plant using the D–T cycle, I mentioned the possible use also of the D–D and D–^{3}He cycles for fusion reactors.

The D–^{3}He cycle holds special interest because it does not generate excess neutrons. A balanced system is possible by small adjustments in the ratio of D to ^{3}He; this produces the ^{3}He via D–D fusion reactions occurring in the D–^{3}He fuel itself. Of course, additional ^{3}He can be obtained by the radioactive decay of tritium for mixing with deuterium to form the fuel. No inventory of additional fuel need be bred in the D–^{3}He reactor as would be the case in the breeding of tritium through the use of lithium in the D–T cycle.

Both the D–D and D–^{3}He cycles may be used for another type of fusion reactor we are considering with great interest. That reactor would employ the principle of direct conversion. Figure 3 illustrates the direct conversion of fusion power to electricity through what is called the "mirror machine." This system has been proposed and is being developed by Dr. Richard Post at Lawrence Radiation Laboratory at Livermore. Typically, the D–^{3}He reaction would be used in such a conversion system. The principal energetic products are charged helium and hydrogen ions.

As shown schematically in Figure 3, the reaction products from the fusion reactor would escape from the end of the magnetic mirror, and their already low ion density would be further reduced by expansion into a larger chamber. In this expansion the rather random motion of

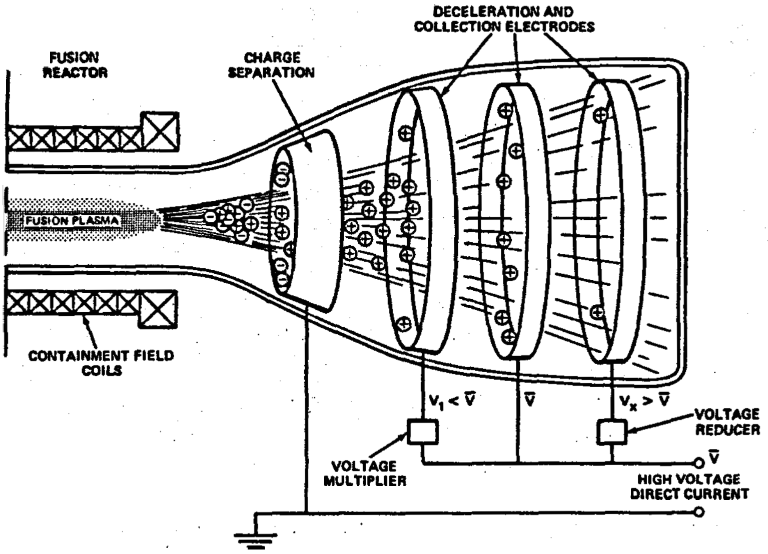


Figure 3. Fusion reactor with direct conversion.

the charged particles would be converted into a directional stream. This expansion process is similar to that occurring in the expansion of hot gases in a rocket nozzle. Electrons escaping with the ions would then be separated electromagnetically from the positive ions, and the electrons would flow to the "ground" of the electrical system. The positive-ion stream, carrying most of the energy of the fusion reaction and consisting of particles of differing energies (or voltages), would be caught by a series of electrostatic collectors. Each collector would be kept at a different potential, the first ones being at voltages less than the average of the particles and later ones at voltages equal to or higher than the average. Suitable voltage transformers would convert all these voltages to a common potential, from which useful power could be obtained in the form of high-voltage direct current. I should point out that most of the particles would be at energies near the average potential. Only about 30% of the energy would have to be subjected to voltage transformation.

No intermediate conversion to heat is required in this type of system; the kinetic energy of the positive ions is converted directly into electricity. Since there are virtually no thermodynamic limitations, the efficiency of this process could be very high, of the order of 90%. The equipment appears to be simple to construct. Very low capital costs for the direct conversion equipment, possibly as low as $10 to $15 per kilowatt, appear obtainable for 1000 MW(e) units. Please understand that this direct conversion concept is as yet untested. Although preliminary small-scale tests of the concept will begin in fiscal year 1971, we have no plans as yet to build full-scale units. In other words, direct conversion from fusion is not just around the corner. However, it could become an important element in future fusion power systems.

In conclusion let me spend a moment discussing a potential application of controlled fusion that has a special fascination and is receiving considerable attention these days even though its realization also may be many decades away. That potential application has been termed the "fusion torch" by the two young AEC scientists who conceived it: Dr. Bernard J. Eastlund and Dr. William C. Gough. Briefly the concept of the fusion torch involves using the ultrahigh-temperature plasma of a thermonuclear reactor to convert any material to its basic elements or to produce large amounts of ultraviolet radiation.

In a world in which we are rapidly depleting many of our natural resources and in which we are unable to handle our waste adequately, this concept seems like the answer to both the conservationists' and the technologists' prayer. Such a dual answer has not seemed very likely in the past.

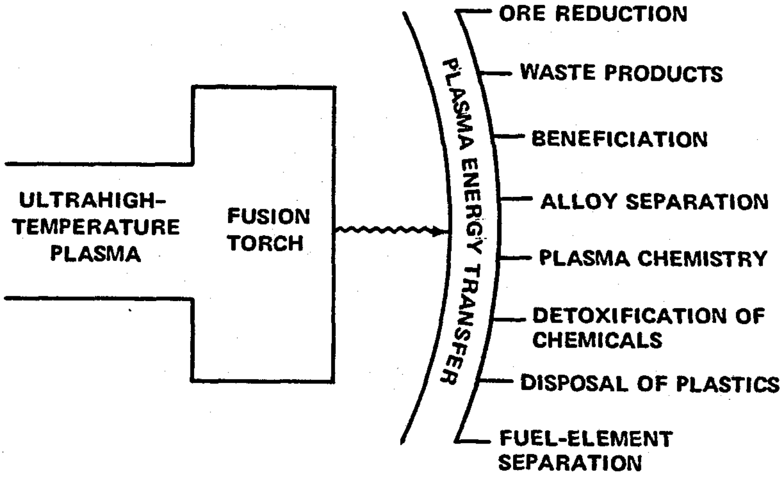


Figure 4. Fusion torch applications (Case 1).

Figure 4 shows some of the things that might be accomplished using the fusion torch. With this system the plasma energy is used to vaporize and ionize solid material, converting initially complex chemical compositions into an ionized gas consisting only of elements. The elements could then be separated by a variety of techniques. Toxic chemicals could be reduced to their basic constituents, ores reduced, and alloys separated.

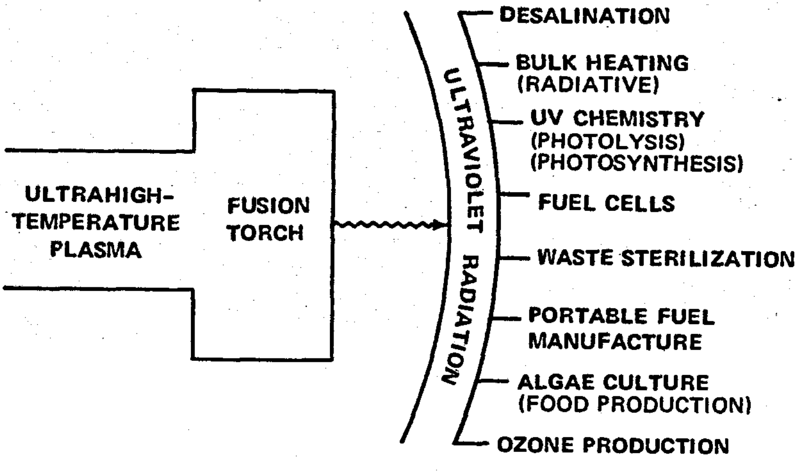


Figure 5. Fusion torch applications (Case 2).

Figure 5 indicates some of the ways in which the ultraviolet radiation from the fusion torch may be applied. Here again the potential is enormous. Among other things, it includes the large-scale desalting of seawater, bulk heating for many applications, the sterilization of sewage and other wastes, and food production through algae culture and possibly through the direct synthesis of carbohydrates from carbon dioxide and water. Through the production and use of ozone, the fusion torch has been suggested as a method of sterilizing drinking water, of reviving "dead" lakes and rivers by reducing their excessive organic matter, and of reducing industrial air pollution. Dr. Farrington Daniels of the University of Wisconsin has suggested these and many other possible uses of ozone from the fusion torch.

I do not have time to go into further detail on the fusion torch and its many ramifications, but more material is available on this subject from the AEC's Division of Research.

Much of the progress that we will make in these fields in the years ahead will depend on public understanding and support. You as interpreters to the public of our activities are a vital link between the scientific and technical community and that public. You bear a tremendous responsibility in forging that link with the utmost integrity.

All the new horizons that can be envisioned at these annual briefings will become realities only if there is the public will to pursue them. To a great extent you help shape and increase that will. We in the scientific community hope you will continue to recognize the important trust your profession bestows on you and, especially today when so much more understanding is necessary and a more positive public outlook is needed, that you will raise the standards of science journalism to an even higher level than we enjoy at this time.

Nuclear energy in space

Our rapidly advancing technology

It may not be many years before people anywhere on earth will be able to turn on their television sets and routinely view events taking place throughout the earth at that very moment. Among the programs already seen are direct coverage of Olympics contests being held on the other side of the globe and live telecasts of important political events taking place in foreign capitals. Worldwide weather forecasts might soon include as their weather map an actual color view of the continent showing cloud cover as it exists at that very time. Through such a television system, the surface of the moon might also be seen while two TV astronauts—possibly something akin to a lunar Huntley–Brinkley team—report on the scene of a new landing there or of a moon-based launch for a distant planet. All this would be made possible by the transmission of the television signal directly into the home from a system of communications satellites in orbit more than 22,000 miles above the earth. The operation of these satellites and the benefit of many more miracles of the Space Age may be realized through the use of the compact, long-lived sources of nuclear energy we are now developing in the concurrent Nuclear Age.

It is indeed of epochal significance that man has recently become spaceborne after his long earthbound existence. No longer tied to this planet, he is now probing space with instrumented and unmanned vehicles and is planning manned exploration of the nearby planets. In this extraterrestrial environment man's capabilities and his hopes for the future are being rapidly extended because of his successful exploitation of a rapidly advancing technology.

I believe it is providential that our advancing development of the atom and our entrance into space are currently taking place side by side in what might be called the Nuclear Space Age. I would like to tell you why I believe this is so and what we in the AEC are doing, in cooperation with the National Aeronautics and Space Administration and the Department of Defense, to further the exploration and beneficial uses of space. I would also like to give you some of my personal thoughts on nuclear energy in space and to suggest a number of future uses which, of course, do not yet represent in any sense our country's planned programs in this area.

Nuclear rocket propulsion

If we are to review all the aspects of the many space challenges that are brought about by our interest in space, or even just of those we will deal with in the next few decades, one fact would immediately become apparent: our success in space will depend to a major extent on energy—energy to conquer time and distance, energy to gain and communicate knowledge, and energy to protect and sustain life. I believe that nuclear energy in its many forms, working through the highly sophisticated engineering being developed today, holds one key to our ultimate success in space.

When we speak of nuclear energy for space, it is most important to emphasize at the outset its compact form. Its compactness means high energy and low mass, a combination essential for getting far into space and accomplishing many things there.

Our nuclear space programs take both these factors into account. We are developing, under our Rover program, systems for nuclear rocket propulsion and, under our SNAP program, systems for generating electric power in space. The letters S-N-A-P stand for Systems for Nuclear Auxiliary Power. Let me review these programs for you briefly—what we have accomplished to date and what might be done in the near and more-distant future.

First, look at nuclear rocket propulsion.

In earthly travel, some say "getting there is half the fun." In space travel, "getting there" is quite an effort. This is so simply because of a stubborn force called gravity. Gravity seems to insist that we earthbound creatures remain earthbound. That is why it takes a two-stage chemical rocket 90 feet high and with about one-half million pounds of thrust to put two men packaged with some relatively light equipment into an orbit about 200 miles above the earth. Incidentally, such a launching requires more than 30,000 gallons of chemical propellant—enough to keep the average family car running for over 40 years.

Chemical rockets require these large amounts of fuel and oxidizer to produce the thrust necessary to lift and accelerate the rocket vehicle. In a nuclear rocket, however, the energy of combustion is replaced by the energy of nuclear fission. A nuclear reactor is used to heat a single propellant, hydrogen. Hydrogen is chosen because it is the most efficient propellant known.

Rocket-engine designers attempt to produce engines that will achieve the highest possible fuel efficiency. We measure this efficiency in terms of specific impulse, which is defined as pounds of thrust per pound of propellant flow per second through the rocket's exhaust nozzle. Thus the higher the specific impulse, the lower the weight of propellant required. Specific impulse values twice those of the best chemically powered rockets are possible with nuclear rockets using the reactor concepts currently being developed, and certain advanced nuclear concepts promise even greater efficiency.

In the AEC's cooperative program with NASA, we are working toward the development of a single nuclear rocket engine that will satisfy a variety of upper-stage and spacecraft applications. That standard system will be a 1500-megawatt NERVA engine which will produce 75,000 pounds of thrust. NERVA, by the way, stands for Nuclear Engine for Rocket Vehicle Application. At this point I should make it clear that upper-stage nuclear rockets are planned to take over after the vehicle has been launched from earth by chemically powered rockets.

NERVA engines are shown in the schematic drawing in Figure 1 as part of a basic NERVA propulsion module that can be applied singly or in clusters. Note the three different mission configurations and the NERVA engine by itself in Figure 2. Compare the small size of the engine with the vehicle it pushes. NERVA would be about 30 feet long, the reactor in its center about 4 feet in outside diameter.

The NERVA engine could extend the capabilities of the Saturn V Apollo earth launch vehicle for landing payloads on the moon and for sending unmanned payloads about the solar system. Applied singly or in clusters of modules to spacecraft assembled in earth orbit, the NERVA engine could also be used for manned missions to the planets.

Nuclear Energy's Explor
in Space

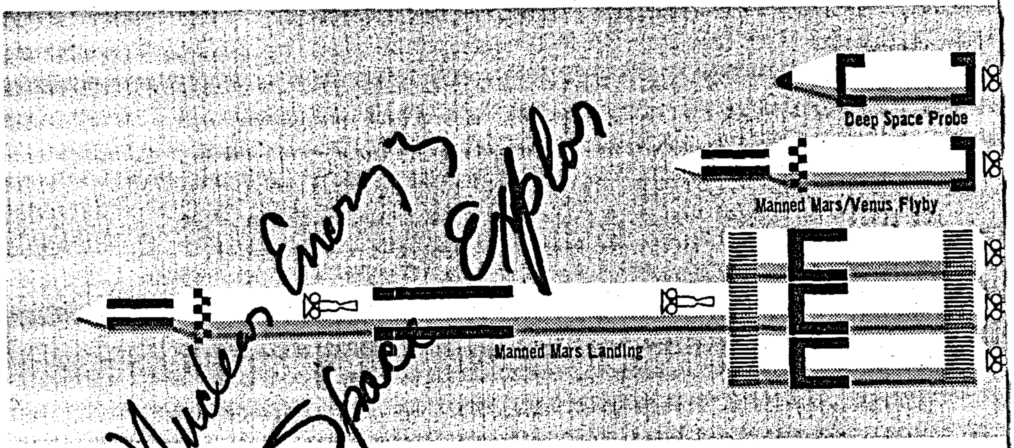


Figure 1. Missions using NERVA engines.

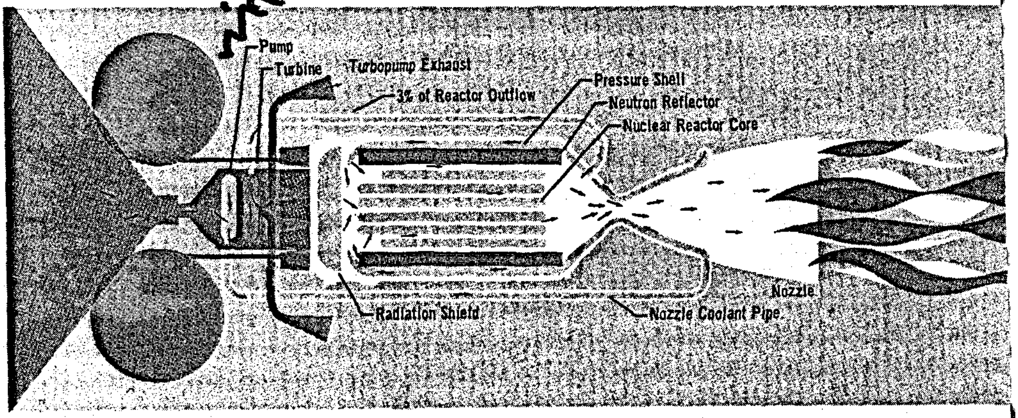


Figure 2. NERVA engine.

A single nuclear rocket propulsion module could perform a manned flyby mission of Mars or Venus with a return to and rendezvous in earth orbit.

Just what is involved in the development of a nuclear rocket system? A nuclear rocket is a flyable compact reactor, little larger than a medium-sized office desk, that will produce more power than Hoover Dam and will achieve this power from a cold start in a matter of minutes. To accomplish this, the system must raise the temperature of liquid hydrogen stored at a temperature approaching absolute zero (−420°F) to above 4000°F. There are few, if any, heat-exchanger systems that operate at such ranges of temperature.

Many problems are involved here. But I must add that the scientists and engineers at Los Alamos Scientific Laboratory who pioneered the concept and those at Westinghouse Electric Corp. and Aerojet-General Corporation, all of whom have been taking part in various phases of our Rover Program, have been doing an outstanding job in overcoming these problems.

Since the beginning of the Rover Program, we have conducted a string of important tests at the AEC's Nuclear Rocket Development Station located at the Nevada Test Site near Las Vegas.

During the course of these tests, nuclear rocket reactors in the 1000-megawatt range were operated successfully at full power and high temperatures; specific impulse values approaching twice that of advanced chemical propulsion were reached; reactors were restarted and operated at full power through multiple cycles; and all these reactors were started rapidly and brought to full power under automatic program control.

In addition to these accomplishments, we have already completed a series of tests of the entire NERVA engine that saw that system operated for about 3½ hours at various power levels. A round trip to the moon would be on the order of 50 minutes.

In addition to the nuclear rocket, we are also developing the nuclear power technology required for an electric propulsion system. Such a system, in contrast to the relatively high thrust of the conventional nuclear rocket, would be a highly efficient low-thrust system producing a higher specific impulse. It would use electrical energy to accelerate the propellant by first ionizing the propellant gas and then accelerating it to higher velocity by electrical and magnetic means and ejecting it from the vehicle.

The thrust of the nuclear electric rocket is small compared to that of the chemical or nuclear rocket. For example, whereas the upper-stage engines of the Saturn V moon rocket, the J-2 engine, has a thrust of 200,000 pounds, the thrust of a large electric propulsion stage engine might be about 20 pounds. However, this thrust, applied over a very long period, including the time when the conventional rocket would be "coasting," can eventually build up a velocity greatly exceeding that of the chemical or nuclear rocket. For many desirable missions this can result in greatly reduced mission times and increased payload weights. Such a propulsion system therefore becomes invaluable in cutting down the travel time to distant planets or during voyages far out of the solar system. While NASA and the Air Force are developing the thrust components of these nuclear electric propulsion systems, the development of their power sources, of course, comes under our SNAP Program.

On earth we human beings feel we are a pretty hardy breed, but, in terms of the other environments of the solar system, we are indeed fragile creatures. In terms of temperature, atmosphere, and our total chemical needs, we are bound to the surface of this planet. If we leave it, we must take a portion of our world with us, or we perish. Food, water, light, a certain range of temperature, protection from radiation, and communication with our fellow humans—all these are essential to our survival, and all these require an auxiliary supply of energy in addition to that needed for space propulsion. Therefore how far we stray from this planet, how long we stay away, and what we accomplish wherever we go will depend to a large degree on the amount of energy we can take with us and the ways in which we can put that energy to use.

Space nuclear auxiliary power (SNAP)

A primary aim of our SNAP program is to provide long-lived reliable electric power systems for those manned and unmanned spacecraft that will be entering the strange and hostile environment of space and remaining there for long periods of time—weeks, months, possibly years.

In addition to the need for these special sources of energy to support our deep-space scientific probes and manned missions, there is still another area of our space program with substantial energy requirements. I refer mainly to communications satellites, navigational satellites, and weather satellites, all of which have much to do with our future global comfort and progress. In all these areas—manned and unmanned space exploration and earth satellites—our SNAP program will solve many of our energy problems in space for some time to come.

At present we have two general categories of SNAP systems. The first is based on generating electricity from the heat naturally created by decaying radioisotopes. The second uses the heat from fission reactors to produce electricity. Currently both systems use thermocouples to convert heat directly to electricity. Also under development are the more-efficient turbomachinery and advanced thermionic conversion systems. The isotopic SNAP devices are generally of lower power than our SNAP reactors; however, they, like the reactors, can be developed to operate for extremely long periods of time. In some cases their radioisotope heat sources can emit energy for many years. Plutonium-238, for example, which may prove to be our most useful radioisotope in space, has a half-life of almost 90 years; that is, it takes that long for its power output to be reduced by one-half.

Our first isotopic power system to go into space was aboard a Navy navigational satellite. It was the grapefruit-sized SNAP-3 (Figure 3) developed by the Martin Company, a 2.7-watt device powered by plutonium-238 which went into orbit in 1961. It is still up there,

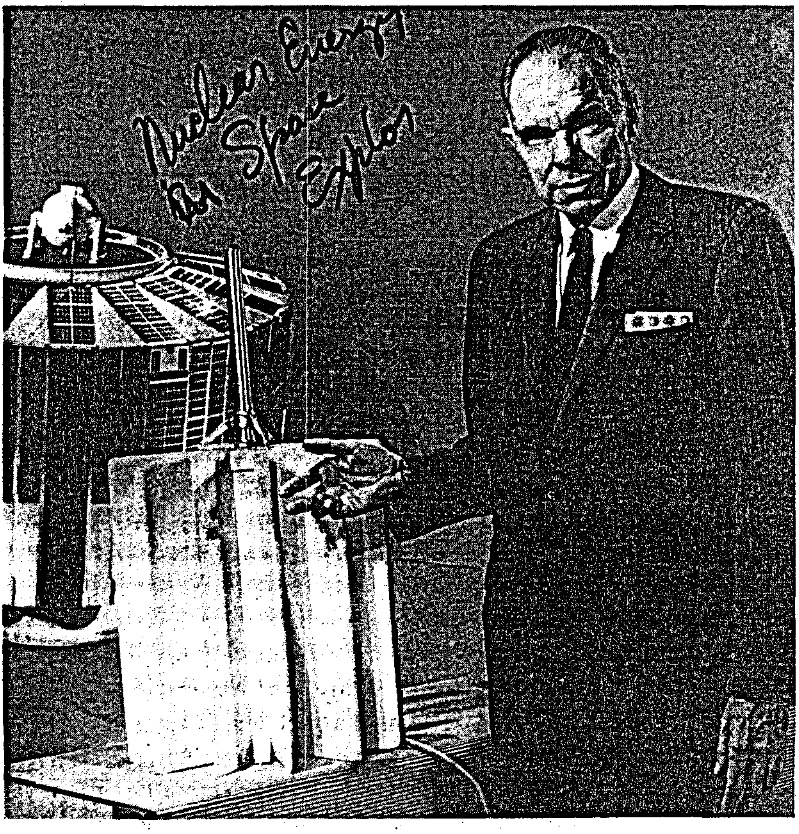


Figure 3. SNAP-27, at Dr. Seaborg's right hand, and SNAP-3, the grapefruit-sized object at the upper left.

after more than 900 million miles of continuous travel. On June 29, 1969, SNAP-3's sixth anniversary in space, it had orbited the earth over 42,000 times. It also holds the record as the oldest operating U.S. satellite.

We have already developed several additional successful SNAP devices and have more under development, including the SNAP-27 (Figure 3), which powers the Apollo Lunar Surface Experiments Package left on the moon by the Apollo 12 astronauts. One of the advantages of SNAP isotopic power becomes clear if we note that the SNAP-27 unit in this experimental package weighs about 45 pounds, whereas batteries to supply the same 50 watts day and night for one year would weigh 4,000 pounds.

In the field of SNAP reactors, which provide more power than the isotopic devices, our first orbital system was the SNAP-10A developed by Atomics International. This 500-watt system was launched from Vandenberg Air Force Base in April 1965. In orbit it operated at full power for 43 days before a failure in the satellite's automatic control system—not the reactor system—caused a shutdown of the whole satellite. Had this failure not occurred, the chances are that SNAP-10A would still be operating today. An exact copy of this orbital unit completed over one year of uninterrupted operation on the ground at the Santa Susana, Calif., test site. This, incidentally, is the longest uninterrupted operation of any nuclear reactor in the world to date.

Nuclear energy fits space needs

Let us turn to some of the projected uses of nuclear systems in space and see why they will be so important to our total space effort. Let us take another look into the future. Consider the further exploration of the moon.

Two men have spent several hours exploring a limited area on the lunar surface. They were restricted in their ability to move around, to excavate, and to bring back specimens. Their choice of landing site was limited to a small band along the moon's equator. There is a strong desire to have scientific specialists there to do the exploration; this will require larger parties of astronauts in which specialization can be accommodated and therefore larger lunar vehicles for transportation there and back.

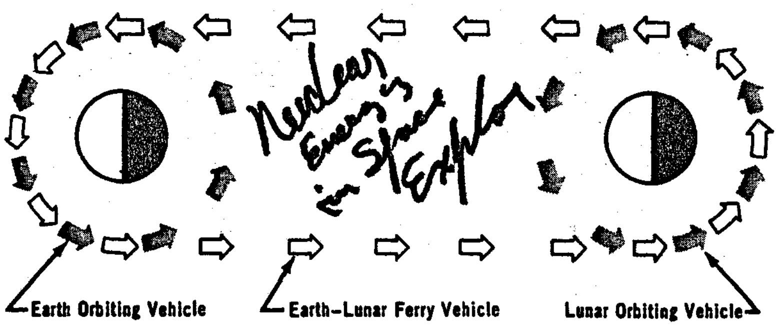
To learn more about the moon, which will help us to learn more about the earth and the solar system, scientists will need more equipment, including vehicles for moving about and machinery for doing heavy work. The extra people and equipment will require corresponding increases of food, water, oxygen, and fuels. In other words some kind of base or camp will have to be established, and the more interested we get in exploring the moon and using it, perhaps as a better vantage point for further study of the universe, the more traffic will build up in lunar logistics. Large payloads of engineering equipment and supplies will have to be shipped to our lunar bases.

The efficiency of nuclear rockets could be the answer to the increased cost of such operations. At an early phase the use of nuclear rocket upper stages could so increase the load-carrying capability of the Apollo booster, the Saturn V, that more men and supplies could be landed per launch and the landing site restriction could be eliminated. Stay times on the surface could be lengthened to months, and roving vehicles could be made available for more meaningful exploration.

The next logical step to reduce operational costs might be to introduce reusable rocket vehicles for transporting material to earth orbit. Chemically fueled boosters used to carry payloads from earth surface to earth orbit would be designed to reenter the earth's atmosphere and be reused to reduce the cost per pound in orbit, a major factor in the cost of space travel.

At the other end, a reusable chemically fueled shuttle could carry personnel and cargo from lunar orbit to lunar surface. But the intermediate transportation system from earth orbit to lunar orbit is a natural application for nuclear rockets. The economy with which nuclear rockets use propellant would greatly reduce the amount of propellant that would have to be supplied to the lunar ferry. This kind of space-flight operation represents a reusable approach, in contrast to the expendable approach we must use now. Eventually we visualize, as a result of this approach, the equivalent of a lunar ferry service with extensive docking service at earth-orbiting and lunar-orbiting stations (Figure 4).

Another type of space vehicle that requires many uses over an extended service lifetime is one designed for shuttling about between various earth orbits for resupply, inspection, maintenance, and, perhaps, rescue action. Rapid movement in orbit, especially where the plane of the orbit must be changed, requires a great amount of



Nuclear Energy in Space Explor

Figure 4. A lunar ferry system.

propellant energy. Thus nuclear rockets offer significant advantages in such an application because of their propellant economy. Although requirements for such an orbital taxi service have not been defined, it seems inevitable that it would be a vital link in a space program that includes manned orbital research laboratories and operational satellite systems for communications, navigation, meteorology, ground observation, and astronomy.

There is a mounting interest in the near planets Mars and Venus and, to a lesser extent, in the other bodies of the solar system. The amount of scientific interest stems from the good prospects of getting there with instruments and, ultimately, with men and also from the great importance of these planets in the search for knowledge of the solar system and of life.

We have recognized for a long time that nuclear rockets are vital to a manned exploration of Mars. The early objective of manned planetary flight will be similar to that of Apollo in relation to lunar exploration: to transport a few men to the surface of the planet with the capability of doing limited exploration and sample collection and to return them to earth. Even with nuclear rockets this will require that several million pounds of spacecraft and propulsion stages be boosted into earth orbit and assembled there into an interplanetary vehicle. With chemically powered rockets the initial weight would be two to four times greater.

Under one mission approach the Mars-bound vehicle would be propelled out of earth orbit into a transfer trajectory to Mars with the thrust furnished by two to four standard nuclear rocket engines. After a 200-day coasting trip, the next nuclear rocket stage would slow the vehicle until it entered an orbit about Mars. During a three- to four-week stopover at Mars, a portion of the crew would descend to the surface—probably using a chemically powered rocket—perform their exploration, and return to the mother craft. Then a third nuclear rocket stage would send the spacecraft back to earth, where the speed of the approaching spacecraft would be reduced using a chemically powered rocket, and the landing technique would be similar to that employed in the Apollo missions. The crew would use the earth's atmosphere to help brake their descent.

To accommodate the trend toward heavier payloads and shorter trip times, which would ultimately come about in our advanced exploration of the planets, we may require new nuclear propulsion systems and flight stages. A capability might be established that would either increase the payload or shorten the trip time to Mars and Venus and make possible Voyager-type flights to Jupiter, Saturn, Mercury, and selected asteroids and comets. The low-thrust nuclear electric propulsion system might provide an ideal way of accomplishing such a task. Each such member of the solar system offers unique opportunities to contribute to our knowledge of the universe. It has even been suggested that we capture an asteroid, which may be a fragment of a shattered planet, and by nuclear propulsion bring it into orbit about the earth where it can be analyzed thoroughly.

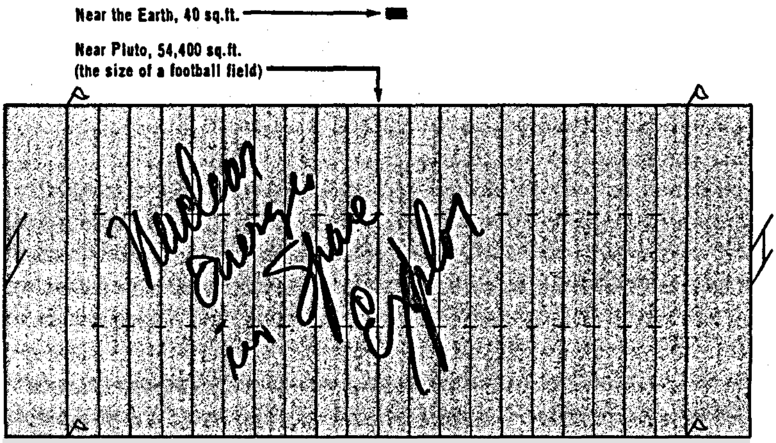
Summarizing the role of nuclear propulsion in space, we see that both nuclear rockets and nuclear electric propulsion systems offer substantial advantages in the exploration of the solar system. The combination of high-thrust nuclear rockets for escape from planetary gravity fields and low-thrust low-weight nuclear electric systems for interplanetary propulsion promises to do great things for solar system exploration.

But, as I indicated earlier, we are not going to accomplish much in space, no matter how far or with how much versatility we can propel ourselves, unless we take with us enough energy to power our scientific, communication, and life-support equipment. To this end our SNAP systems will play a primary role in future space programs. How will they accomplish this, and what are their advantages over other systems?

First, let me point out that such nuclear energy sources are for missions of longer duration than a few hours to a few days. For those short-lived missions, batteries or fuel cells are usually the lightest, smallest power sources. For the long-lived missions, the main competitor of nuclear systems is the solar-powered system. The choice among solar, isotope, and reactor systems for long missions depends on many factors, such as weight, size, required power level, cost and adequacy of supply, reliability, convenience of use, and the peculiar requirements of the mission. There are missions having special requirements for which nuclear systems offer important advantages over solar and other competitors.

One such mission is the exploration of places that receive little or no sunlight—as in the shadow of a planet or a moon. Consider that the density of solar energy incidence drops as the square of the distance from the sun. Mars, being about 1½ times as far out as earth, receives less than half the solar energy per square foot that earth does. This means that a solar energy collector on Mars will have to be over twice as large as one producing the same amount of power on earth. Even this might not be prohibitively large, but the comparable size for Jupiter, the next planet after Mars, would be 27 times as large and for Pluto, over 1500 times as large.

Therefore at Pluto it would take solar cells covering an area about as large as an entire football field (Figure 5) to produce as much power as our 500-watt SNAP-10A system—and this is assuming that such a football field of solar cells could be constantly oriented directly toward the sun. At the vicinity of earth, for the same solar power, only about 40 sq ft of solar cells would be needed. Of course, within the dense atmospheres of some of these planets or on their dark sides, practi-



Nuclear Energy in Space

Figure 5. Comparison of size of solar energy collector required.

cally no sun at all will shine. On the moon, for example, the night is 14 earth days long. For this reason permanent lunar bases probably will have to use nuclear power, which is independent of the location of the sun.

Another mission where nuclear systems offer advantage is the manned orbiting stations. It is desirable to operate these stations at the relatively low altitudes of between 100 and 200 nautical miles to reduce the logistics costs of operating at higher altitudes and to minimize the natural radiation to which the stations at higher altitudes would be exposed. For these low orbits the smaller exposed area of nuclear power systems results in great reductions in the atmospheric drag and in the pounds of propellant required to keep the station in its assigned orbit. An unmanned scientific or defense system that has to operate close to the earth will similarly have the advantage of low atmospheric drag if nuclear power systems are used. A third important mission is the kind that requires large quantities of electric power. Because of its extreme compactness, the nuclear reactor heat source is the lightest and most convenient concept for electric power levels above a few tens of kilowatts.

Manned missions, of course, require more electric power than unmanned missions. To survive in the hostile environment of space, man must take along or generate within his spacecraft food to eat, water to drink, and oxygen to breathe. He needs electric power to preserve, prepare, and purify these; to light his cabin and to maintain it at a temperature and pressure he can tolerate; and to provide the energy needed for communication and for the hundreds of other mechanical operations required during the mission. A listing of electric power requirements for the long-lived manned space station now being studied by NASA indicates that at least 1 to 1½ kilowatts per man will be required in orbit.

The Gemini missions, being of only a few days duration, have used fuel cells and batteries for their primary electric power plants, but these become less attractive as primary power sources when mission times of several weeks are required. This is indicated in Figure 6. Mission power requirements from 30 watts to 100 kilowatts are plotted here vs. the length of time for these missions from 6 minutes to several years. Observe that the nuclear and solar power systems are better for long missions.

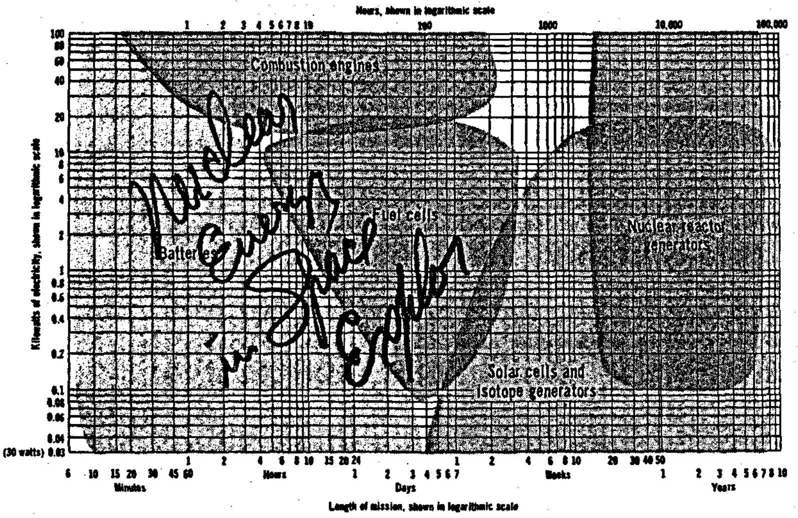


Figure 6. Power required for various mission lengths.

In the area of manned exploration, let us project some possible future energy requirements of bases on the surface of the moon and planets. Here we may well meet the greatest energy challenges of the next decade.

Manned bases on the surface of the moon may be the first users of large nuclear power plants in space. A semipermanent station on the moon probably would require between 150 and 250 kilowatts, which could be supplied only by nuclear reactor power. Smaller shorter-duration stations would require between a few hundred watts and a few kilowatts for life support and for charging the batteries of lunar exploration vehicles. For the smaller stations we are considering the use of isotope as well as reactor power plants.

If we choose to develop larger stations or even colonies on the moon, we will probably have to transport and assemble there even larger nuclear power systems. In addition to providing heat or cooling as required and all electric power, such reactors could possibly be used to extract water from the rock, to help produce synthetic food, and to extract minerals and other materials from the surface.

Perhaps some time in the most distant future, if enough nuclear power can be made available on a planet, it might be possible to convert, to a limited degree, some of the materials on the planet's surface into a contained atmosphere. This would be going quite a bit further than air conditioning. Such "planet conditioning" would make life away from earth a little more comfortable. Here, as on the moon, nuclear power would be necessary to provide local surface transportation, probably by means of electric battery-operated vehicles charged by nuclear power systems.

I believe the deeper into space we go, the more vital communication will become to us. Unfortunately communication also becomes far more difficult at great distances and requires much greater levels of energy. The Mariner IV radio near Mars, using about 10 watts of transmitted power, was able to send 20 fairly low-resolution photographs in about a week. At the orbit of Pluto, the transmission of even this small amount of information would require about 7 kilowatts, and a single voice channel would require over a hundred times this much power. For this reason alone, we must plan on the need for large amounts of energy as we move away from earth.

Back to earth again

For a few final thoughts, let us come back to earth—or at least somewhat closer to earth than the moon and the distant planets we have been thinking about. As suggested earlier, our space activities are going to bestow many direct benefits on those of us who decide not to become astronauts for a while. We have already seen some of these benefits—for example, the Tiros and Early Bird satellites—and we will be seeing more in the future. The remarkable picture in Figure 7 indicates the benefit that can be gained in weather prediction using the vantage point of space for weather photographs. Among other exciting benefits will probably be a system of communications satellites that will make possible not only the transmission of television from any place in the world directly into the home but also such communications marvels as have been suggested by the highly imaginative science writer Arthur C. Clarke. For example, Clarke foresees the orbital post office providing the delivery of copies of letters anywhere in the world only minutes after original letters are posted, the orbital newspaper bringing us detailed news in any language from anywhere in the world at any time of the day or night, and global conference facilities making international business meetings as common in the future as local telephone calls are today.

Figure 7. The earth from 22,000 miles in space. This weather picture of the Western Hemisphere was transmitted by NASA's ATS-III satellite from its on-station position over the Brazilian equator.

We have covered much ground—actually, much space—in surveying part of the role that nuclear energy might play in space. Why do we embark upon such a huge and expensive venture? What will it mean to us as individuals, as a nation, and to mankind? These are large questions, but each of us, I am sure, ponders them from time to time. There are no answers in detail, but I believe we can arrive at some general conclusions.

There are, of course, the important needs of national defense, national prestige, and widespread technological benefits that inevitably would flow from such a magnificent venture. For example, consider the moon, only one space body of the many that we shall undoubtedly explore one day. The near-vacuum condition that is found naturally upon the moon's airless surface would be very useful to us. Such a condition is difficult to achieve and even more difficult to maintain on a large scale at the bottom of this sea of air upon our earth. A number of industrial processes, however, depend upon and operate more efficiently at a near-vacuum condition. We can therefore imagine that the moon might at some future time become a center for vacuum research and processes. This and other natural advantages of the moon to industry are fascinatingly detailed in an imaginative and ingenious book, *The Case for Going to the Moon* by Neil P. Ruzic (G. P. Putnam's Sons, New York, 1965).

Apart from this we voyage to space for intangible reasons that in the long run could be even more important, indirectly, than the most immediate ones. The Age of Space is perhaps the most exciting time in human history since the Age of Discovery that followed Columbus' voyage. What intuitive inspiration was Queen Isabella's when she offered to pawn the crown jewels to finance the poor mariner's voyage! We have no visions of gold and the riches of the Indies before us, but we have long since learned that there are things more valuable than gold.

We have a pioneering heritage. Our forebears were adventurous people who broke with old ties to come to the New World and to conquer a new continent, and we have continued these traditions in science, industry, and technology. When it was possible to explore the atom, we did not hesitate. It has now become feasible to explore space. We dare not shirk the adventure. We cannot draw a curtain over a New World that is within our grasp. We cannot sit at home, so to speak, and hear secondhand of new wonders that men have pondered through the ages. Our enthusiastic participation on the frontier, wherever the frontier exists, is necessary for our continuation as a dynamic and creative people. If there were no other reason for space exploration—and there are a great many more—this one would be good enough for me.

We have entered what is truly a new age of discovery. We who are living in it and are privileged to take an active part in it can look forward to exciting and rewarding days ahead.

The atom's expanding role in medicine*

I would like to take this opportunity to tell you something of the work in the nuclear field related to medicine and to health in general. This is an area of the peaceful uses of nuclear energy that, even though it affects the lives of many millions of people in this country and throughout the world, is not as well known and appreciated as it should be.

To put my story in perspective, let me begin with some brief historical background. Generally speaking, radiation has been a valuable tool of medicine for quite some time. When the Rev. Hugh A. Cooper started the Southwestern Presbyterian Sanatorium, the forerunner of your hospital center, here in Albuquerque in October of 1908, the X ray had already become an important and internationally used tool of medical diagnosis even though it had been discovered by Roentgen only in December of 1895. In fact, it is somewhat amazing that within two years of that discovery crude but effective X-ray equipment was being used very successfully by the military to diagnose battle injuries. During the Tirah Campaign, the 1897 tribal uprising in India that closed off the Khyber Pass to the British, X-ray apparatus was carried on the backs of native bearers and pack animals over some of the worst terrain in the world. Quickly unpacked and used whenever necessary, it proved invaluable in locating bullets and splinters of lead, as well as in determining the extent of injury to the bone. In that campaign three fragile X-ray tubes were used in more than 200 cases, and, in spite of their rough transport, were brought home in perfect working condition.

About the same time similar equipment was being used on the sunbaked shores of the Nile where Lord Kitchener was trying to subdue the savage Dervish tribesmen—with the help of a young cavalry officer

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**Remarks upon receiving the Presbyterian Hospital Center Foundation Award at the Founders' Day Dinner, Presbyterian Hospital Center Foundation, Albuquerque, N. M., Oct. 13, 1969.*

named Winston Churchill. There in the Sudan, at an advance-base surgical hospital, portable X-ray equipment was used in some 60 cases. In this area, where the temperature rose to 122°F in the shade, the X-ray apparatus had to be packed in felt saturated with water every two hours to keep it operative. The batteries were charged by two soldiers generating electricity on a tandem bicycle. (I want you to know that I rarely tell this story as I do not want to give certain people the impression that large amounts of electricity can be generated by bicycles. This would give the nuclear power field still another source of competition.)

Although machine-generated X-ray radiation was quickly adapted to medical uses after its discovery, the use of radiation from radioisotopes, natural and later man-made, was a little longer in coming. But, as I hope to point out, it was well worth waiting for.

I will not review for you the whole story of the discovery of natural radioactivity by Bequerel or the Curies' discovery and subsequent work with radium. I think this is all well known to most of you. For more than 30 years, X rays and radium continued to be the only sources of radiation used in medical diagnosis and therapy. During this period an understanding of radiation and radioisotopes was built up by the work of many great scientists—Thompson, Rutherford, Soddy, Hahn, Cockcroft and Walton, the Joliot-Curies, and others. Significant as all their work was in understanding the atom and laying the foundation for the Nuclear Age, it did not have any direct application in medicine. The great step in this direction—and it was a giant one indeed—followed Ernest O. Lawrence's invention of the cyclotron in 1929. The cyclotron, rapidly developed in the 1930's, allowed us to create a number of new radioisotopes, many of which were to be useful in biological and medical work. I said "us" in mentioning the production of these new isotopes because I had the extreme good fortune to be one of a group of young scientists at the University of California at Berkeley at the time of Lawrence's work and was able to use his cyclotron in my work in nuclear chemistry. Artificial radioactivity was new then, and in those days we were able to produce a new radioisotope every month or so. I was personally most concerned with learning more about the nucleus of the atom, but we were kept aware of the utilitarian aspect of our work by the requests from our biological and medical colleagues for new radioisotopes.

As early as 1935 the radioisotopes produced in the cyclotron were being used as tracers to make new biological explorations. On one occasion during this period, the late Dr. Joseph G. Hamilton, one of the outstanding nuclear medical pioneers, mentioned to me the limitations on his studies of thyroid metabolism imposed by the short lifetime of the radioactive iodine tracer that was available. He was working with iodine-128, which has a half-life of only 25 minutes. When he inquired about the possibility of finding another iodine isotope with a longer half-life, I asked him what value would be best for his work. He replied, "Oh, about a week." Soon after that J. J. Livingood and I synthesized and identified iodine-131, which, luckily enough, has a half-life of eight days.

There was another occasion when we young physical scientists pulled a nuclear rabbit out of the hat. Dr. George H. Whipple, the Nobel pathologist now at the University of Rochester and formerly at the University of California Medical Center, wanted a radioisotope of iron for his studies of hemoglobin formation in the blood. His experiments were of several weeks duration, and he needed a radioisotope with a suitable half-life. He was delighted when we discovered and provided for him iron-59 with a 45-day half-life. This isotope has played a major role in revolutionizing our knowledge of the blood.

I should not like to leave the impression that we young physical scientists were modern Merlins capable of producing any kind of magic requested of us—far from it. As you know, Nature is characterized by order, and she allows atoms, for example, to exist only in certain orderly arrangements and not in others. It was simply fortunate that, within the order Nature prescribed, there were many elements of which we could produce radioactive isotopes of great use to biological and medical scientists.

But, as successful as we were in those days, cyclotron bombardment made only small quantities of radioisotopes available. So this was only the beginning of a medical revolution the full impact of which was yet to come.

With the successful development of nuclear reactors, it was possible after World War II to begin to realize the great potential of radioisotopes. Instead of minute amounts created in cyclotron bombardment, large quantities of hundreds of radioisotopes were produced in reactors, and powerful new sources of radiation could be developed to extend the range of radiation therapy. The Atomic Energy Commission, established shortly after World War II, was fortunate in that many of the physicians who had been associated with the wartime Manhattan

Project and thereby had seen at firsthand the great medical potential of nuclear energy joined the Commission to help develop the new tools. It is noteworthy that the first shipment of a radioisotope from the atomic energy project, in August 1946, went to a cancer clinic in St. Louis, Mo., for private medical research.

Since that time the Atomic Energy Commission has carried on major efforts on four fronts to advance the cause of nuclear medicine. First, it produces and distributes radioactive isotopes useful in medical research, diagnosis, and therapy. Second, it provides opportunities for medical personnel to receive training in the techniques of using radioisotopes safely and efficiently. Third, it operates major research facilities in the medical field that require specialized equipment and staff not ordinarily found in existing medical centers. Finally, it supports promising research projects through contracts with medical schools, universities, hospitals, and other research organizations.

Although the AEC continues to play an important role in the medical field, I should point out that within recent years it has turned over much of its activity involving the production and distribution of medical radioisotopes and radiopharmaceuticals to private enterprise and nongovernment institutions.

With all this as general background, let me review for you some of the accomplishments of this big and diverse field today. I know that a number of you in this audience are men and women of the business world who fortunately have taken a great interest in your community medical care and the administration of your fine hospital center, so I will begin by relating a few businesslike statistics concerning the growth of nuclear medicine.

The entire field of nuclear medicine—the use of radioisotopes and sophisticated scanners, cameras, and counters for diagnosis, treatment, and medical research; the application of teletherapy and brachytherapy—all this is growing at a remarkable rate. When we consider that nuclear medicine was in its infancy in the 1950's, its growth rate is all the more remarkable.

Reports of recent years offer some interesting information related to this growth. For example, under AEC and AEC-agreement state licenses, there are more than 4,300 U.S. hospitals using nuclear medicine, and an average of 100 new nuclear facilities are being added each year. In addition, more than 2,200 physicians in private practice are licensed by the AEC or by their states to use radioisotopes in their work. The annual market for nuclear medicine equipment in hospitals, clinics, and physicians' offices will exceed $40 million this year. To this we can add $25 million in annual sales figures for nuclear medicine for a total in excess of $65 million. (These figures, by the way, do not include radiochemicals and sealed sources, for which total figures are not available, nor do they include the very large radiological use of machine X-ray sources, the cost of which today is considerably more than those Roentgen tubes and tandem bicycles I mentioned before.)

Now let us break down some of these items, not in terms of cost but as to what they are and what they are accomplishing for medicine. I should begin by pointing out that over the past 20 years, since the days when we produced those first medical isotopes with Lawrence's cyclotron, 100 different radioisotopes have been used in medical research. Today some 30 different radioisotopes, available in quantity, are used around the world in the diagnosis and treatment of many diseases and disorders and in continuing research on them. In the United States alone radioisotopes are employed annually in approximately eight million individual therapeutic treatments or in vivo or in vitro diagnostic procedures.

Let me take a minute here to explain for those of you not familiar with it the major principles upon which radioisotopes work in medical diagnosis and treatment. The radioisotope, being a radioactive counterpart of a regular isotope of an element, behaves chemically like its nonradioactive relative; that is, if ingested or injected into a living system, it goes to that part of the system or functions in the system in the same manner as the nonradioactive substance. The radioisotope can be used to "tag" a compound, which becomes a radiopharmaceutical that also behaves within the body as its nonradioactive counterpart might. As the radioisotope or the radiopharmaceutical moves within the system or locates at a certain point, it continually sends out "signals" as to where it is and how it is concentrated. When these "signals" are detected by the physician's scanners, cameras, or counters, they give a picture or an analysis of the functioning of the system or of a certain organ. This is used by the physician as a diagnostic tool to determine the system's or organ's health. In a similar way, injection or ingestion of a prescribed amount of a radioisotope may be given to travel to a selected part of the body to destroy cancerous material there. As I will point out later, radiation from radioisotopes or machines also can be applied from external sources to attack tumorous tissue.

What are some of these radioisotopes, and how are they used? In terms of both the variety of applications and total doses administered, iodine-131, the isotope first synthesized back in 1938, seems to be the most useful by far. Iodine-131 is used to diagnose various thyroid disorders, treat hyperthyroidism and functional metastatic thyroid cancer, diagnose kidney and liver disorders and make function tests of these organs, screen for pulmonary emboli by lung scans, locate brain tumors, and make blood volume and cardiac output studies. Reciting such a list makes iodine-131 sound like the radioactive equivalent of one of those old-fashioned all-purpose remedies. In some respects it is just as easy to administer. For the thyroid function test, iodine-131 is simply given in a glass of water in the form of a clear, odorless, tasteless drink. More than a million such "atomic cocktails"—which produce no "hangover," by the way—are served annually in the United States.

Another very useful isotope—which I had the good fortune to co-discover with my colleague and friend of many years, Emilio Segre—is technetium-99*m*. As developed at Brookhaven National Laboratory and Argonne Cancer Research Hospital, this radioisotope has in recent years proved to be such a versatile tool that I feel it is worth some special attention as an example of recent progress in nuclear medicine.

Technetium-99*m*, used in different physical and chemical states in the diagnosis of thyroid, liver, brain, and kidney disease, is obtained from a radioisotope generator or "cow." This cow is a laboratory device in which technetium-99*m* is formed by the decay of molybdenum-99 and can be readily "milked off" by the appropriate chemical process whenever there is need for it (Figure 1). At least 2,000 diagnostic procedures are being carried out daily in the United States with this radioisotope, and it is now being used on a worldwide basis because of its nearly ideal properties as a diagnostic tracer.

The list of other radioisotopes used extensively in medicine includes carbon-14, gallium-68, strontium-85, fluorine-18, calcium-47, arsenic-74, mercury-197, gold-198, sodium-22, zinc-65, iron-59, phosphorus-32, cesium-137, and cobalt-60. This is only a partial list at best. Reciting all of them and explaining their many applications is another talk in itself, one I have given recently.

Most of the radioisotopes I have just mentioned are produced today in reactors in large quantities even though, as you may recall, some of them were created initially with the cyclotron. In recent years we have been returning to the cyclotron for certain radioisotopes for medicine.

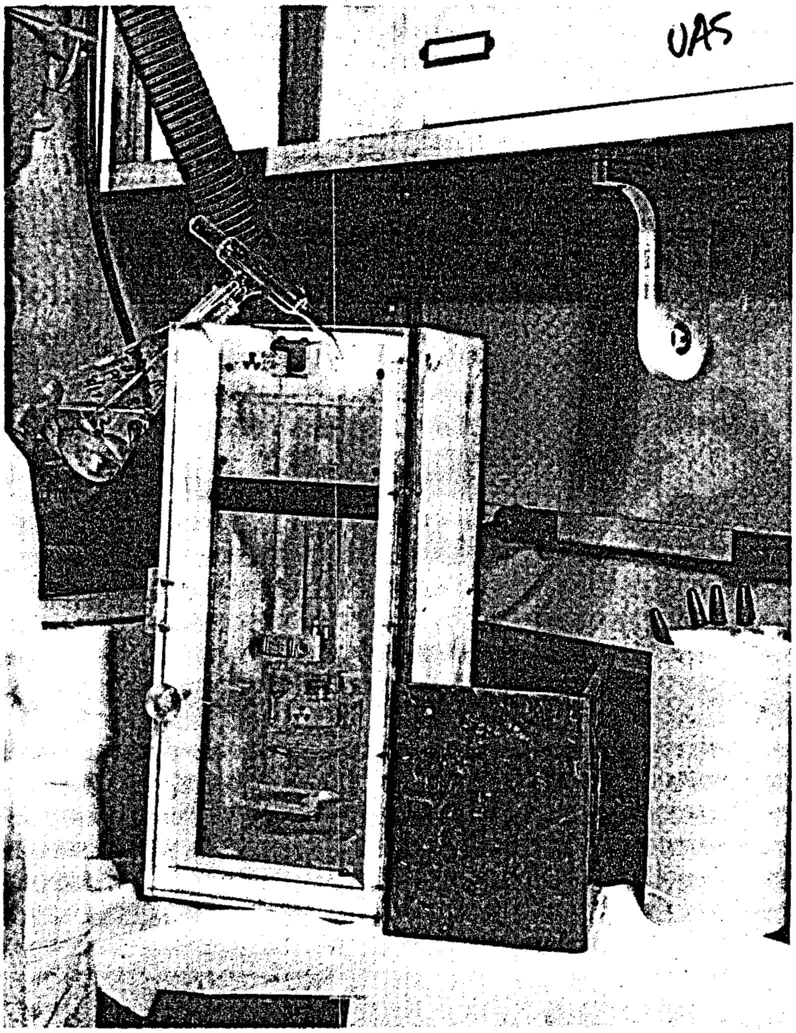

*Figure 1. Using a "nuclear cow" to get technetium from its parent isotope. The cow is being fed saltwater through a tube. The saltwater drains through a high-radiation (hot) isotope. The resultant drip-off is a daughter such as technetium-99*m. *This new, mild isotope can be mixed with other elements, and these become the day's supply of radioisotopes for other scans. Technetium-99*m *decays in 6 hours. Thus greater amounts, with less possibility of injury, can be administered and a better picture results.*

These are the short-lived isotopes such as carbon-11, nitrogen-13, oxygen-15, fluorine-18, and others that are of immediate interest for metabolic studies. They permit the use of larger initial amounts of activity; this gives good counting statistics without an increase in the overall radiation exposure. Because compact and relatively inexpensive cyclotrons are being made available now, more hospitals and research centers will be able to obtain them to produce these isotopes and carry on expanded research and treatment.

As I pointed out in describing how these medical isotopes are used, their radioactivity is detected by nuclear instruments of great sensitivity. Very significant progress has been made over the years in the improvement and sophistication of such equipment. Due recognition should be given to those scientists and engineers who have developed and improved these valuable tools of nuclear medicine. Foremost among them has been Hal Anger, who pioneered in this work at the Lawrence Radiation Laboratory's Donner Laboratory at the University of California, Berkeley. His scintillation camera, commonly known as the "Anger Camera," was a major contribution that is still finding new applications. (Figure 2.)

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Figure 2. Time-lapse motion pictures of the liver of a 3-year-old girl were made with the scintillation camera 1 hour after injection of 50 microcuries of iodine-131-labeled rose bengal dye. This child was born without a bile-duct system, and an artificial bile duct had been created surgically. She developed symptoms that caused concern that the duct had closed. These scans show the mass of material containing the radioactive iodine (small light area) moving downward and to the right, indicating that the duct was still open.

One new use of the Anger Camera involves a technique for the diagnosis of lung diseases. In this innovation the patient receives an injection, or inhales, a small amount of radioactive xenon. As he breathes in front of the scintillation camera, it records the distribution and rate of the xenon entering and leaving his lungs and transmits this information to a computer. From the computer readout the physician can analyze the functioning of 64 regions of the lung. This technique holds great promise for early detection of emphysema and a certain type of lung cancer difficult to diagnose by X-ray, fluoroscope, or lung scanning.

Recently a new investigative technique has been developed for producing images of the thyroid gland and other organs through the use of X-ray fluorescence. This technique incorporates the basic scheme of an X-ray fluorescence spectrophotometer, and therefore no radioisotope is introduced into the patient. Americium-241 is used as a gamma radiation source, and its gamma rays penetrate to the thyroid gland, where they excite atoms of stable iodine present there, causing them to emit characteristic X rays. The information obtained from this device, developed at the Argonne Cancer Research Hospital, is unique. It describes the distribution and relative concentration of stable iodine within the thyroid gland and will serve as a valuable addition to conventional thyroid scans and studies.

Radioisotopic studies can also be carried on with probes inside living systems. The probe is used to measure the location of the radioisotope serving as a label for the part of the anatomy that is to be studied. This technique usually requires measurements that are restricted to a small volume and are best performed with miniaturized semiconductor detectors. Such detectors are now being used experimentally to measure regional blood flow in the brain.

Since a number of important neurological diseases are caused by subsurface disturbances, more refined probe methods for quantitative measurements in the depths of the brain are being developed. In one such program miniaturized probes are implanted within the brain. Blood volume and flow rate are determined following the inhalation of either xenon-133 or krypton-85 by the patient. By the use of this technique, it has been possible to pinpoint areas suffering from reduced blood flow.

Going from the miniaturized probes to much larger equipment, I want to say a few words about the whole body counters that have been developed to measure and identify radioactivity in the body. In their first applications their high sensitivity made it possible to measure natural body levels of radioactivity as well as levels encountered in radiological health work where the activity acquired accidentally, as from radioactive fallout or nuclear accidents, was to be measured. Now their additional potential in medical diagnosis and research is beginning to be realized. Whole body counters offer the physician a more sensitive alternative to the classical balance-type study for turnover of such materials as calcium in normal and diseased states. They afford information on tissue distribution, kinetics, and body content of labeled materials.

Two important treatment techniques in nuclear medicine are teletherapy and brachytherapy. Teletherapy is the treatment of a disease with radiation (usually gamma radiation) from a source located at a distance from the patient. Oak Ridge Associated Universities had a major role in developing the use of cobalt-60 and cesium-137 teletherapy devices as a substitute for or supplement to high-voltage X-ray machines. Those who use these teletherapy machines claim excellent therapeutic results in the treatment of cancer. Today over 150,000 patients receive a total of almost two million teletherapy administrations during the course of a year.

Several unique radiation sources are under investigation as teletherapy tools. For example, at Lawrence Radiation Laboratory the 184-inch cyclotron has been used to produce high-energy particles (both alpha particles and protons) to destroy selectively pituitary tissue of patients with diabetic retinopathy or acromegaly, leading to marked improvements in the cases where the condition is related to pituitary function. At the Argonne Cancer Research Hospital, very high-energy electrons (40 Mev) from a linear accelerator are being used to treat deep-seated tumors.

In contrast to teletherapy, brachytherapy is the treatment of disease with sealed radioactive sources placed near or inserted directly into the diseased area.

An exciting new possibility for use in brachytherapy is californium-252, which has the useful property of emitting neutrons as part of its decay process. Neutrons may be more efficient in destroying oxygen-deficient cancer cells than are X rays and gamma rays. Needles containing californium-252 have been prepared at Savannah River Laboratory and are being evaluated in radiation experiments at Brookhaven National

Laboratory and the M. D. Anderson Hospital in Houston. Such experiments may lead to the use of an internal isotopic source in cancer therapy, and this could prove to be a major advancement in the treatment of this disease.

Among the persistent and unsolved problems confronting physicians today are those concerning management of leukemia. At the Brookhaven National Laboratory solutions are being sought by a new and unorthodox technique of intermittent irradiation of blood in an exteriorized shunt (extracorporeal irradiation). Results so far indicate that certain forms of leukemia may be favorably influenced by this treatment. By means of surgical connections to a plastic tube, blood is made to flow in a temporary external circuit from an artery to a vein. The external circuit is made sufficiently long to include passage through a high-intensity field of beta or gamma radiation. Thus only exteriorized blood and plastic tubing is irradiated, and the rest of the body remains untreated. The results obtained from this procedure are similar to those seen when certain drugs are used to treat leukemia, with one significant exception. The drugs have potential and actual toxic side effects on other tissues of the body, whereas in the irradiation of exteriorized blood only the cells in the blood are affected. A commercial extracorporeal blood irradiator using strontium-90 as a source of beta radiation is now being marketed.

In addition to its application in the treatment of certain leukemias, extracorporeal irradiation of blood for suppression of the immune response is being used to prepare recipient patients for kidney transplants and to help patients in whom the rejection of a transplanted kidney is threatened. One of the latest innovations in this type of irradiation is the use by an ambulatory patient of a bracelet containing a radiation source. This bracelet, under investigation at the Medical College of Virginia, is a plastic coil containing a radioisotope of phosphorus with a half-life of 14 days. As the patient's blood is shunted through this bracelet, from an artery to a vein, it is irradiated to selectively destroy white blood cells responsible for rejection of the organ transplant.

An entirely different method of irradiation therapy being investigated is that employed in the Low Dose Rate Facility. The Medical Division of Oak Ridge Associated Universities has constructed such a facility to allow prolonged total body irradiation treatment of patients. The new facility will make possible a reevaluation of the effectiveness of chronic total body exposure to cobalt-60 gamma irradiation in selected patients having chronic leukemias or other blood diseases characterized by an overproduction of blood cells. The exposure room is constructed and furnished so that these long exposures are automatically controlled by sensing switches for uniformity of dose rate. The environment is that of a modern motel room to minimize the understandable anxiety inherent with confinement.

This new radiation facility will be useful not only in studying therapy of chronic leukemia but also will provide opportunity to test whether total body radiation delivered at low dose rates produces undesired effects. This information is of significant interest to the National Aeronautics and Space Administration, since astronauts could conceivably receive similar low-level exposures during space travel.

Let me turn now for a moment to a completely different use of the atom in medicine. This is the possibility of using the energy emitted by radioisotopes as a power source. At the AEC we are particularly interested in the development of such a power source for a heart pacemaker and also for a blood pump for a completely artificial heart.

In a healthy heart the rate of beating is controlled by a small node of specialized tissue called a pacemaker. In certain disease conditions an artificial pacemaker is required to deliver small electrical impulses to the ventricle at a preset rate. Up to the present time surgically implanted pacemakers of this sort have been powered by batteries with an average life of two years, so that repetitive surgery is required at approximately two-year intervals. The AEC in collaboration with the National Heart Institute has been supporting the development of an isotope-powered pacemaker system with a lifetime of 10 years or more, which would reduce greatly the need for repeated surgery.

Interest in artificial organs goes back a number of years; however, recent efforts at human heart transplantation have focused public attention on the problem of organ replacement. The AEC has joined the National Heart Institute in exploring the feasibility of using radioisotopes to power pumps that could assist or replace the functions of a diseased or damaged heart.

In such a radioisotope-powered artificial heart, the heat from the decay of the radioisotope would be used by a thermodynamic converter to provide hydraulic or pneumatic power for the blood pump.

By way of concluding my remarks this evening, I would like briefly to touch on two areas that, although they do not directly involve nuclear medicine, are related to the AEC's role in promoting and safeguarding human health. The first area relates to the broad function of our AEC national laboratories in the field of health and safety and the fact that their work in this direction has led to many advances in medicine not tied directly to nuclear activities. For example, our broad biological investigations having to do with the effects of radiation have brought forth invaluable new knowledge on such subjects as aging, genetics, and heredity. There has been considerable spin-off to the medical field from our laboratory work with computers and other highly sophisticated equipment and technologies. One device, the zonal centrifuge, which grew out of a program at Oak Ridge for isotope separation, has given us the ability to produce ultrapure vaccines and possibly to isolate viruses responsible for hepatitis, polio, rabies, the common cold, animal tumors, and other diseases.

A nuclear chemistry technique known as neutron activation analysis has led to discovery of a drug at Brookhaven National Laboratory which is being used with favorable results in the treatment of Parkinson's disease.

The first successful treatment for Parkinson's and related diseases using this drug, L-Dopa, was developed by a team headed by Dr. George C. Cotzias at Brookhaven Laboratory. Significantly, a great many of those receiving L-Dopa have become self-sufficient in their daily needs, and some have even gone back to full-time work. Out of approximately 50 patients treated at Brookhaven's Medical Center, a hospital administrator has returned to his job; a trial lawyer has returned to the courtroom; a carpenter has returned to using his tools; a retired journalist has returned to writing, traveling, and other activities, including water skiing; and more than half a dozen women have returned to their homes where they have assumed full responsibilities.

Many hospitals are now using the Brookhaven L-Dopa treatment on a large clinical scale in the treatment of Parkinson's disease. In the Albuquerque area it is being used at the Bernalillo County Medical Center of the University of New Mexico School of Medicine.

In a collaborative program with Dr. Ismael Mena of Catholic University in Santiago, Chile, the Brookhaven treatment with L-Dopa is being used on miners afflicted with manganese poisoning. Out of eight miners treated, five have gone back to work in occupations other than mining.

One of these, who had extreme difficulty in walking and whose arms and hands were virtually useless, is now actively playing soccer.

In another use of L-Dopa, several youngsters with the crippling disease dystonia muscularum deformans have been treated at Brookhaven and at Children's Hospital in Washington, D. C. One of the two treated at Brookhaven has returned home and is currently attending a regular school with normal children. Previously this child had been disqualified even from a school for crippled children.

Let us look at another spin-off innovation of great value to medicine today.

One of the adjunctive problems in treating certain forms of cancer and in controlling rejection of organ transplants is the need for sterile surroundings to reduce chances of secondary infection. That brings me to a dramatic example of how nuclear technology has benefited medicine in unexpected ways. It is a story which, by the way, is set here in Albuquerque.

Sandia Laboratory needed an exceptionally clean room for assembly of nuclear weapons components and systems. Willis J. Whitfield, a Sandia physicist, designed and led engineering development of a revolutionary type of clean room, called the laminar-air-flow room, in which a continuous, uniform flow of filtered air from ceiling to floor or wall to wall gently but inescapably sweeps bacteria and particulates down to the floor and out of the room.

With Dr. John G. Whitcomb of Bataan Memorial Hospital here in Albuquerque and the late Dr. W. R. Lovelace II, Whitfield helped adapt his design to medical use, and the first laminar-air-flow operating room was put into use at Bataan Memorial Hospital on Jan. 6, 1966. In just over three years the use of laminar-air-flow rooms was so widely adopted that Willis Whitfield tells us he can no longer keep track of it.

Laminar-air-flow rooms are being used to protect patients undergoing chemotherapy for leukemia and to provide germ-free conditions for long and serious operations where the risk of infection is high. Dr. Whitcomb also has used portable laminar-air-flow equipment with great success in treating burn patients. We understand that the military is experimenting with portable equipment to isolate patients with highly infectious diseases. The AEC has installed a laminar-air-flow operating room in the Oak Ridge Hospital, looking forward to the day when germ-free environs will be needed to perform bone marrow transplants in man, among other uses.

I might add an aside to this local story which is not medical, but which shows how quickly a good idea spreads. We understand that industry had adopted the laminar-air-flow clean room in many manufacturing processes. I am told, for instance, that all color television tubes are now being assembled in laminar-air-flow rooms and that the integrated circuits for all the nation's pushbutton telephones are being made in Willis Whitfield's ultraclean rooms.

Another innovation to come out of an AEC laboratory, our Argonne National Laboratory, is a small, portable hemodialyzer—an artificial kidney—now under extensive testing. Should this device live up to expectations, it would revolutionize the treatment of kidney patients by making widely available a convenient, inexpensive replacement for what heretofore has been a costly and confining treatment of limited availability.

The National Institutes of Health, which is supporting refinement and clinical testing of the device, reports that dialysis treatments now run between $5,000 and $25,000 a year.

Finley Markley, an associate physicist in the High Energy Facilities Division of AEC's Argonne National Laboratory, was aware of the cost caused by the complexity of the procedure and thought he knew a way to improve it. Markley had put together many apparatuses for high-energy physics experiments that required bonding materials to form an airtight seal without using clamps and gaskets. He used this expertise to produce a device about 8 by 1¾ by 1¾ inches, which may be further reduced to the size of a package of cigarettes. The tubing is bound together by epoxy resins, eliminating the need for clamps and precision seals. Connected to the patient via a permanently implanted artery-to-vein shunt, the new dialyzer is pumpless, has a priming volume one-tenth that of conventional dialyzers, and is compact, lightweight, simple to use, and disposable. Its ultimate cost is expected to be no more than $15 per unit and possibly as little as $5 per unit. It should be possible to use this unit in conjunction with an inflatable vinyl tank and deionized water at home or on vacation, giving a potential for freedom that today's kidney patient does not have. Preliminary clinical tests have been very encouraging thus far. A long-term test with two patients is now under way. As I have said, if this device continues to perform up to expectations, we may have achieved a dramatic technological, and I would add, certainly humanitarian breakthrough that benefits us all.

The AEC's history of support for basic research into the causes and treatment of cancers is relatively well known within medical circles. There is another area, however, where nuclear energy's contributions have been quite as significant but are not so visible. That is in immunology and transplantations. It would not be an exaggeration to say that the basic push for research on the immune system was made by the AEC as part of its search for a successful treatment for severe radiation injury, which may destroy the body's natural immune mechanism. Little by little, beginning in the days of the Manhattan District, research into immunology, supported by the AEC, has provided a massive amount of new knowledge on how man's immune system works. From that understanding we are reaching now toward control of the immune system and treatment of diseases and injuries for which there is now a poor prognosis. Among those—and here lies the Atomic Energy Commission's focus—is serious radiation injury. The best potential treatment for severe radiation injury is to replace the damaged bone marrow, the primary source of the body's disease-fighting agents. A few bone marrow transplants have been made successfully in man, but most experience has been with animals. We believe that the time is quickly approaching when we can expect considerably more success. Just this summer the AEC cosponsored an international conference of the Transplantation Society to develop a clinical protocol for bone marrow transplants in man. An immediate and significant result of that meeting was establishment of an international registry of human bone marrow transplant cases—a major step toward a standard clinical protocol and the day when bone marrow transplants will be an accepted and valuable treatment for leukemia and some 20 other diseases of the blood.

The AEC is involved in still another field of work that may have significant bearing on the future of medicine. This has to do with clinical chemistry. The number of clinical tests done per year in the United States has been increasing at a rate in excess of 15% per year, and it is estimated that more than one billion tests were performed in the U.S. during 1968. As the demand for clinical chemistry services expands at this explosive rate and as research provides new and more complex tests for detecting disease, it is evident that new automated analytical systems will be required. As a joint effort between the AEC and the National Institute of General Medical Sciences, basic studies have been undertaken at the Oak Ridge National Laboratory and the

Oak Ridge Gaseous Diffusion Plant as part of the molecular anatomy or "MAN" program to provide new approaches to this problem.

The first concrete result is the GeMSAEC Fast Analyzer, the first analytical system that provides data at a high rate of speed in a computer-compatible form. Although this system is hardly a year old, four commercial firms have announced the availability of operational systems.

Briefly, the fast analyzer uses centrifugal force to transport and mix up to 40 samples with reagents simultaneously and, in addition, moves the mixture past a light beam at a high rate of speed. In the simplest instance all measurements may be made during one turn of the cuvette rotor, which takes 50 milliseconds.

The adaptation of clinical tests to this device is in progress, and an evaluation of it in cost—benefit terms will effectively measure its impact on human health.

The final area of concern in which I believe the AEC plays a vital role related to national health is that of the environment. We do this from two standpoints, the first in terms of using the highly advanced methods of nuclear science to gain a better understanding of the environment and, second, through our function as a regulatory agency charged with the responsibility of seeing that the health and safety of the public is a foremost consideration where and when nuclear energy is at work. This is a responsibility that I can assure you the staff of the AEC carries out with great dedication and integrity. I think it is important that the public know this, and therefore I make this point at every opportunity.

Concerning the nuclear investigations of the environment, there have been very significant studies in marine biology and physical oceanography. These studies also yield valuable knowledge of the atmosphere and of the world's water, its chemistry and its movement from rainfall, through our waterways and underground systems. They help us analyze air pollution. They give us important information on the ecology of animal and plant life. In fact, one of the reasons for our alarm over environmental conditions today is that studies like these have given us better understanding of the environment and the ability to project future dangers to it. I believe these studies and projections, as frightening as they may be today, are going to have a positive effect in the long run. They should give us both the knowledge and the will to face and solve these problems.

I have tried to give you a broad picture of the atom's contribution to medicine and health. I am gratified by the honor you have given me this evening for my own small contribution to this field and for the pleasure of visiting you here in New Mexico where so many citizens contribute so much to the health and well-being of their neighbors, their country, and the world.

*The atom's expanding role in industry**

The history of industrial applications of radioisotopes is, in microcosm, the story of how government-supported science can be applied to increase the productivity of industry and thus expand our nation's economy. Fifty percent of the 500 largest manufacturing concerns in the United States use radioisotopes. About 4,500 other firms also are licensed to use radioisotopes. Innumerable other companies use exempt quantities of radioisotopes under AEC general licenses. These thousands of firms benefiting from radioisotopes come from virtually every type of industry, including the metals, electrical, transportation, chemicals, plastics, pharmaceuticals, petroleum refining, paper, rubber, stone, clay, glass, food, tobacco, textiles, crude petroleum, natural gas, and mining industries and the utilities.

Even the production and distribution of radioisotopes themselves have followed a similar government-to-industry course. Under its policy of not competing with private industry, the AEC has routinely discontinued supplying products and services as industry becomes equipped to supply them. In 1965, when industry had substantial capability for producing radioisotopes, the AEC began significant transfer of its commercial radioisotope production and distribution activities to private industry. So far we have withdrawn from the production and distribution of 37 radioisotopes—about one-third of our product line—because of private capability to produce and market them. As a result, about 100 private firms produce radioisotopes and convert them into products for medicine, science, and industry. Total sales of these companies are estimated at $53 million annually; this consists of about $8 million in basic radioisotope materials, $16 million in radiochemicals, $25 million in radiopharmaceuticals, and $4 million in radiation sources. In addition, sales of devices in which radioisotopes are employed total about $40 million a year. Of course, these figures do not include sales of products produced by radiation processing nor of auxiliary materials

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**Remarks at the dedication ceremony for Radiation Machinery Corporation's Headquarters and Development Center, Hanover, N. J., July 31, 1969.*

and services related to radioisotope and radiation use, such as detection and measurement instrumentation, shielding material, handling equipment, etc. From this overall viewpoint, it can be seen that radioisotopes are generating commercial activity in the United States at a level of several hundred million dollars annually. Thus in both nature and magnitude a new industry has been created.

As an indication of the breadth and depth of the influence that radioisotopes have had on industry, I would now like to take a close look at such typical radioisotope applications as tracing, gauging, radiography, and radiation processing.

Tracer studies

The use of radioisotope tracers is one of the most common applications of isotopes in industry. The majority of tracer studies are performed in laboratory research programs, but many large-scale investigations of the movement of objects or the flow of fluids are carried out in pilot-plant or production facilities. In addition to studies of the physical movement of matter, tracers are used in the chemical analysis of complex mixtures. Some examples of tracer uses should illustrate their importance.

The use of radioisotope tracers for wear studies is especially valuable to manufacturers of machine tools. One such firm used tracers to develop improved cutting fluids for milling and turning operations, and its studies also provided information on the optimum combination of tool material, preparation and geometry, cutting speed, feed rate, vibration, and rigidity effects on various metals and alloys. As a result, the manufacturer was able to recommend to his customers the most efficient methods of using the machine tools. Moreover, some of the tracer studies of the effect of vibration on tool wear led to improvements in machine-tool design.

A manufacturer of earth-moving machinery used neutron-irradiated steel rollers to simulate the conditions of gear wear and studied the amount of radioactivity removed from the steel surface by the lubricating oil. In a study of the performance of engine gaskets, a tracer was added to the cooling system, and the gasket leakage was measured by monitoring the build-up of radioactivity in the engine lubricating oil. Afterwards the gaskets were autoradiographed to locate the imperfections causing the seal's failure. A manufacturer of large diesel engines has studied cylinder wear by irradiating areas of the cylinder liner in a nuclear reactor and measuring the radioactivity of debris in the lubricating oil and that emitted by the exhaust of the engine.

Tracers have been used in quality-control procedures by a manufacturer of printed circuit boards. Tracers were incorporated into masking agents and etch solutions to detect any minute quantities of these compounds after the boards were cleaned. The presence of these impurities was correlated with defects in solder joints after accelerated aging tests. The advantages of tracers are that they are nondestructive and yield results in a shorter time than the aging tests.

Radioisotope tracers are particularly useful in detection of problems. One aircraft manufacturer has eliminated the problem of "bucking bars" being left in the aircraft by placing microcurie quantities of cesium-137 in the bars. A radiation detector can then reveal the presence of any of the bucking bars. Otherwise these heavy metal pads, which are placed behind rivets as they are driven into place, might be left in the aircraft and become a potential hazard in flight if they remained undetected.

Tracers are valuable as detectors of obstructions in underground pipe lines. In one case a pipe line extending 25 miles from a compressor station to a polymer processing plant had been installed 30 years ago and had not been used for about the last 25 years. A new use for the line was proposed, and a cleaning tool was propelled down it by air pressure to remove debris. A sealed source containing 300 millicuries of radioactive gold was attached to the tool. As expected, the tool stuck at an obstruction somewhere in the middle of the line. A crew was sent out with a Geiger counter to find the plugged section. The obstruction was located within 25 feet and removed. Without this technique the line would have been abandoned, according to plant engineers, and a new pipe would have been installed at considerable cost.

Tracer studies also have important applications in the pharmaceutical industry. They can detect and measure radioactive atoms from the original tagged sample regardless of the nature of the chemical structure in which they are incorporated. Thus drug researchers can detect, isolate, and measure not only the original labeled compound but also its many derivatives.

Most of the tracer work in drug research uses carbon-14 or tritium because the drugs are complex organic molecules. To a smaller extent phosphorus-32 and sulfur-35 are used, and in special cases, such as in vitamin B-12, cobalt-60 or cobalt-58 is the tracer atom. Tracers are also used for production and process development in the pharmaceutical industry. In process design, for example, tracers are used to study mixing efficiency, residence time in reactors, flow rates and patterns in columns, and towers for chromatography, absorption, racemization, etc. One firm reported that its process for a vitamin B-12 product could not have been properly designed without the engineering information obtained from tracer studies with the cobalt-60 labeled vitamin.

In the petroleum industry one of the most useful tracer applications of radioisotopes has been in the study of catalytic cracking operations (Figure 1). Catalyst beads are tagged with some suitable gamma emitter, such as cobalt-60 or zirconium—niobium-90, and inserted into the fluidized bed. It is possible with this technique to determine the distribution of particles within the chamber, the residence time, and the effects of chamber geometry on the results of the cracking operation. Corresponding information can be obtained for the gas stream through insertion of radioxenon. The importance of this work in controlling cracking operations cannot be overestimated since the process involves the production of billions of dollars worth of petroleum products.

Tracer techniques have proved valuable in connection with consumer as well as industrial products. For example, one study using carbon-14-labeled acetic acid investigated the penetration of vinegar into polyvinyl chloride bottles. It was found that 0.5% of the acetic acid in the vinegar diffused into the wall of the container bottle in a month; this would have been nearly impossible to measure by any other method. These results were useful in developing and evaluating the process for fabricating the bottles.

Another analytical technique involving radioisotope tracers is neutron activation analysis. The sample to be analyzed is exposed to a flux of neutrons produced by a nuclear reactor, isotope source, or particle accelerator, and certain elements in the sample are radioactivated. The gamma radiation emitted by the neutron-activated sample is analyzed to determine the energy of the gamma rays and the intensity and rate of decay of the radiation. (Figure 2.) Since each radioisotope has a characteristic half-life and set of gamma-ray energies, the identity and amount of the neutron-activated radioisotopes can be determined by

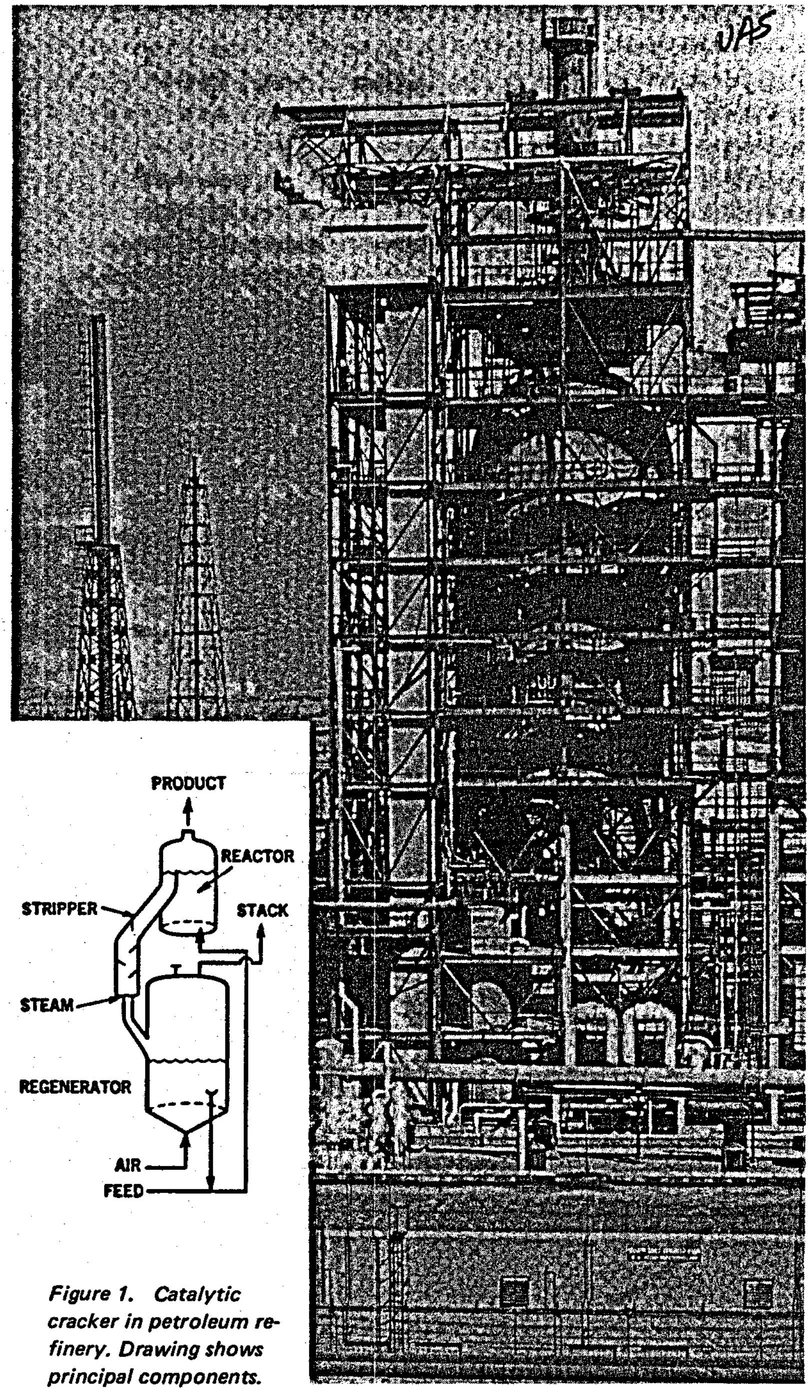

Figure 1. Catalytic cracker in petroleum refinery. Drawing shows principal components.

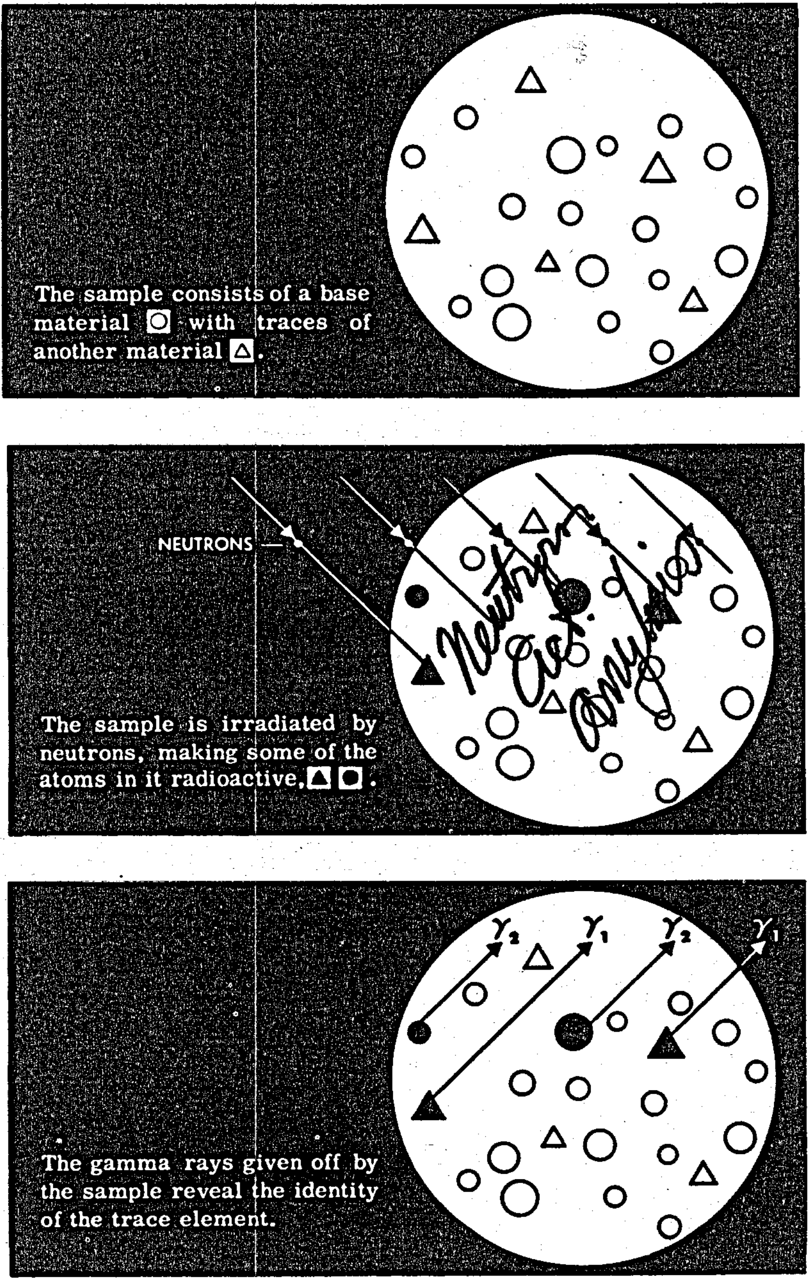

Figure 2. In activation analysis traces of various elements can be identified and measured by analyzing the gamma rays they give off after being irradiated with neutrons or other nuclear particles.

comparison with known radioisotope energies and half-lives or by comparison with standards that have been activated under identical conditions. The advantages of this technique arise mainly from its extreme sensitivity; in favorable cases it can detect concentrations as minute as a few parts per billion. As an example of the industrial uses of neutron activation analysis, it can detect traces of vanadium in the feedstock to oil refinery catalytic crackers; small amounts of this element can poison the catalyst with disastrous effects.

A potential industrial use of neutron activation analysis can be found in the manufacture of detergents. Materials used in the production of detergents include monosodium phosphate and disodium phosphate. In the production of suitable detergents, the ratio of sodium to phosphorus should be 1.67, within a few tenths of one percent. Current production methods require that a batch be held up until a chemical analysis can indicate that the mixture is within limits. A technique that could yield a reliable on-line measurement would eliminate substantial time in manufacture, as well as the need for mixing tanks and holdup of batches. Neutron activation analysis appears to be a solution to this problem since both sodium and phosphorus can be activated to yield radioisotopes that decay with the emission of rather short-lived gamma rays. Measurement in a matter of a few minutes or less should be possible to provide the desired process-control information.

These are only a few of the many tracer applications in industry. The following list of additional tracer uses should provide an indication of the great variety of industrial applications.

- Mixing of ingredients and additives in production.
- Location of leaks in storage tanks and pipelines.
- Determination of the degree of impregnation of wood with fungicides.
- Activation analysis of metals in pulp.
- Tracing of the diffusion of sulfur in cable rubber.
- Application of radioactive tracer techniques to fabric-washing efficiency studies.
- Study of detergents in sewage.
- Measurement of traffic paint abrasion.
- Location of gas leaks in underground gas pipes.
- Study of the rate of penetration of sulfate ions into cement mortars.
- Determination of the uniformity of mixing of Portland cement.
- Studies of intermetallic diffusion.
- Studies of diffusion in semiconductors.
- Detection of leaks in telephone cables.
- Leak testing of hermetically sealed components.

Gauging

Gauges containing radioisotopes are widely used in industry to measure thickness, density, level, and other properties of a variety of materials. The importance of radioisotope gauges in industry is evident in the fact that approximately 20,000 of these devices are currently in use.

Basically, a radioisotope gauge consists of a radioisotope source and a radiation detector. The radioisotope is encapsulated into sealed sources emitting beta or gamma radiation, which interacts with the materials being gauged and is detected by the ionization chamber or other type of radiation detector. In most gauges the radioisotope sealed source is located on one side of the material being measured, and the detector is placed on the opposite side. (Figure 3.)

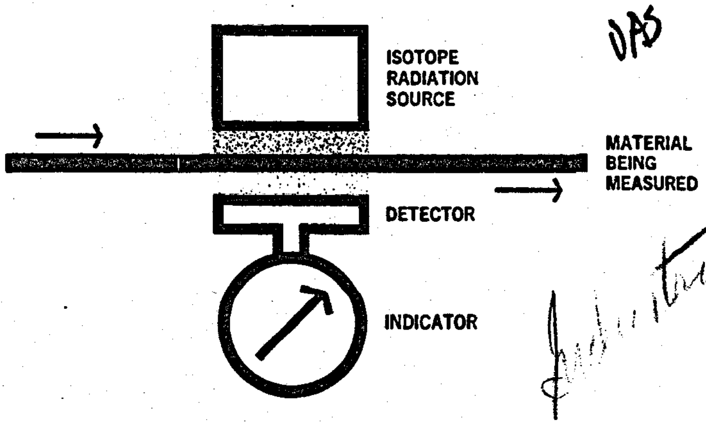

Figure 3. Principle of the thickness gauge.

OPS

Industry

The intensity of radiation penetrating a sheet of plastic, metal, paper, or rubber can be accurately correlated with the thickness or density of the sheet. Gauges of this transmission type are widely used by the industries producing such materials. The radiation source and detector traverse synchronously across the moving sheet on rigid parallel tracks to measure the variation of thickness across sheet material as it is continuously produced. The output of the radiation detector is amplified and used to drive a chart recorder, which produces a graph of the thickness profile. The signal can also signal automatic control mechanisms to keep the thickness as close as possible to specifications. Radioisotope thickness gauges of the transmission type usually employ a beta emitter as the radiation source; two of the most common isotopes used in this application are krypton-85 and strontium-90.

The chief advantages of radioisotope thickness gauges are their ability to monitor thickness continuously and the fact that they do not touch the material being measured. In some applications, such as in paper manufacture, radioisotope gauges have replaced the traditional technique of hand sampling and weighing. The sampling procedure formerly used does not cover enough of the sheet to be statistically reliable, and the results are determined when it is too late to correct deviations from specifications. In this instance it is impractical to measure the thickness continuously with a mechanical caliper because the paper would be marred or torn by a contacting instrument. Continuous measurement with a radioisotope gauge permits adjustment of the machine variables to compensate for deviations from the target.

In other applications, such as measurement of the thickness of cold-rolled steel, caliper gauges can be used without damaging the product, but variations in the surface roughness or vertical movement of the rapidly moving metal can cause chattering of the mechanical contacts, which leads to inaccuracy.

Density gauges are another important type of process-control instrumentation using radioisotopes. These units are widely used to measure the density of a variety of liquids, slurries, powders, and granular solids. As in the transmission-type thickness gauges, the radioisotope source and detector are mounted on opposite sides of the material being measured, which is contained in a fixed geometry, usually by a pipe or small vessel. Since the thickness of material between the source and the detector is constant, variations in density cause changes in the intensity of radiation reaching the detector.

A third major type of radioisotope gauge is the level gauge (Figure 4). These instruments consist of a gamma source and radiation detector

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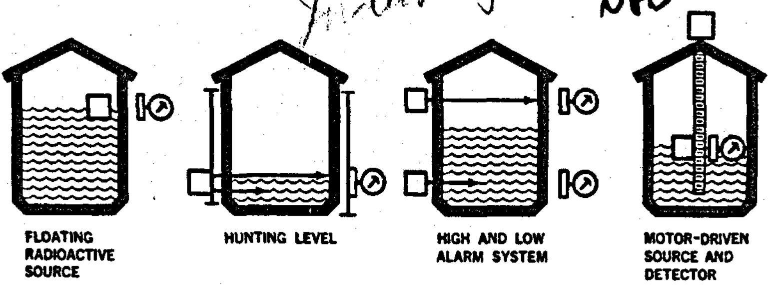

Figure 4. Principle of various types of level gauges.

placed on opposite sides of a tank or other vessel. Overfilling causes a sharp attenuation of the radiation reaching the detector, and underfilling gives an intensified radiation signal. The input and output of the vessel can be controlled to maintain the detector signal at an intermediate value, which causes the liquid to be maintained at a predetermined level.

Some examples of gauging applications may be of interest.

In the steel industry, for example, as specifications for dimensional tolerances have become more rigid, radiation gauges have become generally accepted for monitoring the thickness of steel sheets. Virtually all steel rolling mills are now equipped with this type of instrumentation. A major related application for gauges which has received almost uniform acceptance and which uses isotopic sources of radiation is in the manufacture of galvanized sheet. Beta-ray-reflectance gauges are used to monitor the thickness of the zinc coating on each side of the steel. The industry reports a much greater degree of product uniformity since installing this equipment, and tangible dollar savings result from the smaller quantities of zinc used per unit area of the product. These reductions in quantity are reported to average approximately 10% of the total metal used when compared with previous practice.

The production of coke is an integral part of the operation of any iron and steel complex, and isotope gauging is finding some important applications in this area. Gamma-ray gauges have been effectively used to determine the bulk density of coal, thus permitting coking ovens to be loaded with coal to optimum capacity. One steel company found that the capacity of a coke oven complex could be increased by over 5%, or 24,000 tons per year, by using gamma-ray gauges.

The use of density and level gauges by major chemicals and plastics companies for process control has been growing at a rate of about 25% per year, and it is significant that instrumentation engineers in the larger chemical companies now regard these techniques as conventional.

The payout period on isotope density and level gauges ranges from four months to three years in most chemical companies, the average being about six to nine months. For example, in a polymer synthesis process, it was found that an appreciable fraction of the product was spilling over into the raw material recovery unit because of faulty operation of capacitance level gauges. It was decided to automate the process with 10 isotope level gauges, which were installed at a total cost of $40,000, including $15,000 for the hardware. The new equipment virtually eliminated downtime and increased the chemical yield from the process, saving an estimated $80,000 annually.

Another widespread use of isotope gauging equipment is in the automatic control of extruders for plastic film manufacture. The larger companies producing film for both consumer and industrial packaging use have completely automated their operations with the use of scanning beta thickness gauges. The close control achieved by these gauges results in a more uniform product and in lower consumption of polymer than without the instrumentation. According to one of the largest producers of food-wrapping film, the greatest saving is associated with reduced labor requirements. At one plant operated by this company the reduction in manpower following the installation of the gauges resulted in a saving in labor costs of about $160,000 annually.

Beta gauges, usually containing sealed sources of krypton-85 or strontium-90, are used extensively to measure thickness or "basis weight" of paper, usually expressed in pounds per 500-sheet ream. The economic advantages of using beta gauges in paper production can be illustrated by the example of a Midwestern company producing fine writing and printing papers. Examination of the records for two years of operation with the beta gauges compared with experience before their installation showed a saving in scrap material of 40 tons annually per machine, or 200 tons per year for the entire operation. Additional benefits were realized through a decrease in the time required for weight changes. This wasted time was reduced from 240 to 90 hours per year per machine by the use of the beta-gauge system. The increased productivity is equivalent to 1100 tons of paper per year for the whole mill.

Finally, deviations from uniformity, as measured by the sum of the variances above and below nominal basis weight, declined from 1.405 to 1.052%.

Radioisotope gauging is also of major importance to the rubber industry. Very precise quality control is essential in the manufacturing process to achieve the close tolerances required in the fabrication of tires capable of long service under high-speed driving conditions. A most important step is the regulation of the thickness of the rubber coating on the nylon or rayon ply used in the tires. All five of the largest tire manufacturers have installed radioisotope gauges on their rubber calenders for this purpose.

One of the most successful and widespread uses of isotope thickness gauges has been in the manufacture of coated abrasive materials, such as sandpaper and emery cloth, where it is difficult to control the weight of adhesive and abrasive uniformly by other means. Gauges are located immediately before and after each coating operation, and the signal representing difference in weight is used to adjust the calenders. (Figure 5.) One manufacturer producing over 500 different types and grit sizes of products reports annual savings of at least $12,000 through this use of beta gauges. The savings are mainly attributed to reduced material waste and lower scrap production. Other users of this technique emphasize that increased uniformity of the product is the greatest advantage of this gauging system, which allows their product to command a premium price.

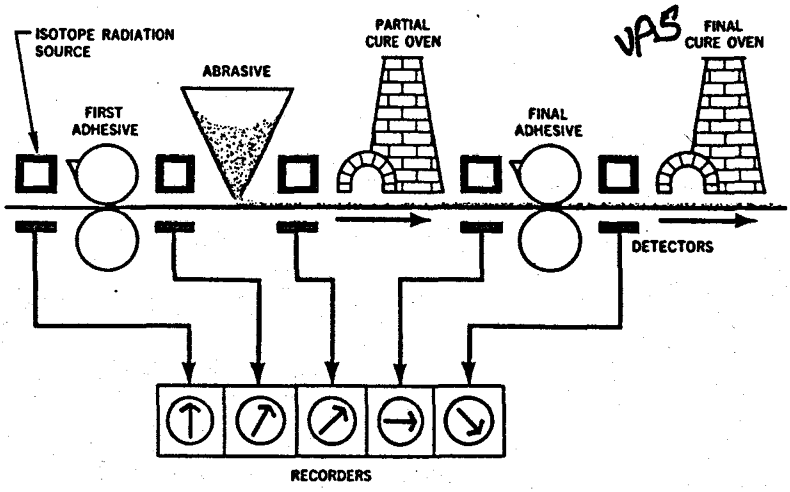

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Figure 5. Use of multiple radioisotope gauges with remote controls.

An important and typical application of gamma density gauges is in ore processing for the measurement and control of pulp density in the underflow thickeners. At a large copper mine the need for such process control arose because of water conservation problems. When the capacity of the mine and reduction plant was increased from 15,000 to 22,500 tons of ore per day, it was found that the process required an additional 3,000 gallons of water per minute. The plant was legally restricted to the use of 10,000 gallons of water per minute from the local river supply, and the full quota was being withdrawn before the expansion of capacity. Consequently, the additional water had to be recovered from mill operations. Successful water conservation was based on the use of two gamma density gauges containing sealed sources of cesium-137. The measurement and control system based on these gamma gauges aided in the saving of the needed 3,000 gallons per minute.

Another illustration of the economic advantages of gamma density gauges is the case of a uranium-ore processing mill. This plant processes 1,000 tons per day of uranium ore containing about 2,500 parts per million of U_3O_8. The underflow from each of eight thickeners in the wash circuit is pumped to the succeeding stage at a rate that determines the ratio of solids to liquid. It is highly desirable to maintain an optimum wash ratio to minimize losses from the ore. Nine gamma density gauges, each containing 50 millicuries of cesium-137, were installed so that the output of each controlled the slurry pump at that stage or at the system input to maintain a constant wash ratio and a preset feed rate to the leaching circuit. Without automatic control by the gamma gauges, it is estimated that at least 50 pounds of uranium values would be lost in the tailings from the leach circuit each day; the prevention of this loss represented an annual savings of $90,000. Furthermore, the close automatic control of the liquid-phase flow rate allows an additional annual savings of about $12,000 in reduced flocculent use and $18,000 in decreased uranium in the waste tailings from the subsequent ion-exchange concentration step. This gives a total savings of about $120,000 per year.

Physical inventory of coal piles has become increasingly important as generating stations and annual coal consumption rates grow larger. Typical annual consumption at a large plant is in the neighborhood of four million tons; so a small percentage error in coal weighing can represent a large quantity of coal. The procedure for taking physical inventory involves measuring the total volume, density, and moisture content of a coal pile. Methods for determining total volume are quite accurate, but density and moisture measurements have been restricted to areas near the surface of the pile, which are not representative of conditions many feet below. One solution to this problem is a combination "density-moisture gauge" based on sealed isotope sources. Moisture content is derived from the total hydrogen concentration of the coal, which, in turn, is determined by the output of a slow-neutron detector in conjunction with an isotopic source of fast neutrons. Hydrogen is the principal neutron moderator in coal; so neutron thermalization is nearly directly related to hydrogen content and can be correlated with moisture. Density is determined by back-scattered gamma radiation. The combination unit is lowered into a steel tube driven into the coal pile, and a series of readings is made at various depths in a sampling grid over the pile. Variations in both moisture and density with position are rapidly and accurately observed in situ, and the results lead to a more precise and rapid measurement of coal inventory than was previously possible.

Density-moisture gauges also have proved themselves in the national highway construction program. A critical factor in building roads is the compaction of the road bed, which can be determined from a wet and dry density measurement of the soil. These measurements involved taking a sample, measuring its volume by backfilling with sand, and then weighing the sample before and after baking it in an oven to obtain the wet and dry density data. These data, used in an appropriate equation, give the percent of soil compaction. Not only was this time consuming, but also the act of taking the sample disturbed the soil and hence the validity of the data. Portable isotope density-moisture gauges are now routinely employed in many state highway programs to obtain on-the-spot, quick, accurate measurements of soil compaction.

The following list should indicate the many diverse isotope gauging applications now routinely employed in industry.

- Determination of saline water in oil fields.
- Detection of empty and underfilled packages.
- Determination of moisture in wood chips.
- Control of roofing paper thickness.
- Retention of resin by paper and migration of resins during drying.
- Control of the amount of tobacco in cigarettes, and, an application now being developed, control of the thickness of cigarette paper.
- Measurement of bulk density of heterogeneous mixtures.
- Measurement or control of thickness in metallic capsule manufacturing.
- Testing of auto-wax thickness and durability.
- Measurement of the level of liquid chlorine.
- Measurement of concrete density.
- Level measurement in glass furnaces.
- Neutron moisture gauge for concrete.
- Accurate weighing of sand and gravel during loading at pit site.
- Weighing of iron ore on a large belt conveyor at ore-processing plant.

- Density measurements to distinguish between different grades of oil.
- Control of level in coal pulverizing.
- Measurement of metal thickness and deposits.
- Control of slurry density in reclaiming lime in paper mills.
- Measurement of coverage and film thickness of printing ink and paint.
- Measurement of thickness of raw leather.

Radiography

Radiography is a process of visualizing the internal structure of solid materials by exposing them to a source of penetrating radiation and recording the shadow image on film. An internal void decreases the amount of material through which the radiation penetrates and thus increases the intensity of radiation reaching the film at a position corresponding to the location of the void. The resulting darkened area of the film indicates the outline of the defect and its thickness, according to the degree of darkening. (Figure 6.)

Both X-ray generators and radioisotopes are commonly used as radiation sources for industrial radiography. X-ray machines are usually used in fixed installations in which workpieces can be conveniently moved to the inspection station. Radioisotopes are commonly used to inspect large fixed structures or complex shapes when the source can be easily positioned to achieve the optimum exposure geometry. In maintenance work or in such applications as pipeline construction, where inspection must be done in the field, radioisotope sources have the advantages of being portable and free from the need for an external power supply. The major users of radioisotope radiography are the metal products industries and the commercial testing laboratories that serve the producers and users of castings and weldments. Although a variety of gamma-emitting isotopes have been used as radiographic sources in research programs and specialized applications, the great majority of industrial radiographers employ either cobalt-60 for thick sections or iridium-192 for thin sections. Well over 1,000 companies and more than 7,000 individuals are engaged in industrial radiography.

A typical large company using radiography is a manufacturer of boilers for both nuclear and conventional steam generators and of large, high-pressure chemical reactors. A typical unit is 15 feet in diameter and 75 feet long, with more than 500 feet of welded seams up to 8 inches thick. Every inch of the welds is radiographed because

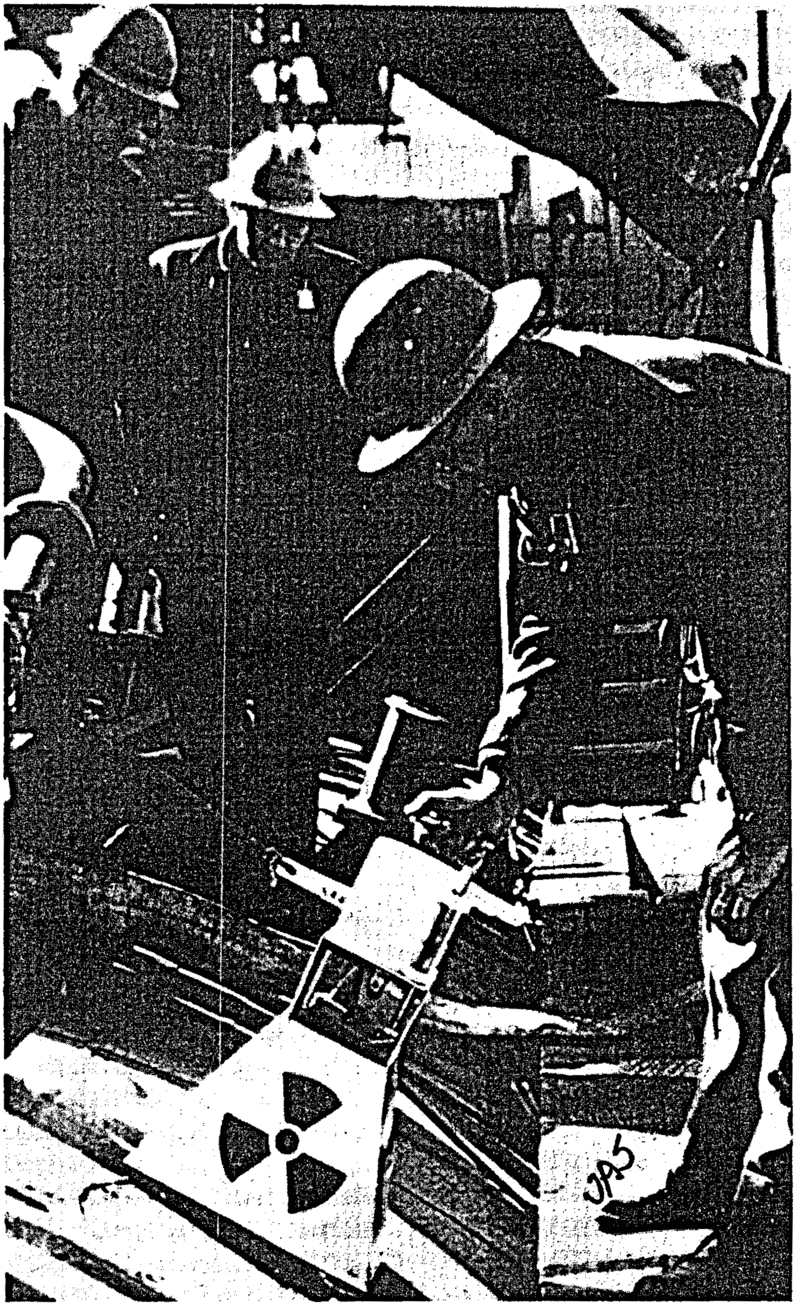


Figure 6. Using a portable radiation source for radiographic inspection of a submarine hull.

of the high stresses expected in service. This firm has invested about $2 million in equipment and employs 90 people for inspection services, mainly radiography, to carry out its extensive program of nondestructive testing. Both X-ray machines and radioisotopes are used.

The large cobalt-60 camera is considerably less expensive than the supervoltage X-ray units; the former costs about $55,000 installed, and each of the latter costs $225,000. Moreover, it takes six times longer to radiograph a 6-inch-thick weld with a 1-Mev X-ray machine than it would take with a 2,500-curie cobalt source. However, a 2-Mev X ray is necessary for inspecting sections greater than 6 inches because the energy of cobalt gamma rays is too low for this purpose.

As an example of savings resulting from isotope radiography, a small company that previously lacked nondestructive testing facilities spent about $13,000 a year on destructively testing 1,000 castings annually. The firm has now installed a radioisotope radiography unit, and its savings are estimated at $8,000 a year. Another firm, which manufactures railroad car wheels, estimates a saving in reduced scrap of $18,000 annually.

Other specific applications of radiography include:

- Study of nonmetallic inclusions in steel.
- Measurement of the thickness of walls.
- Inspection of welded joints in ship structure.
- Detection of flaws in metal castings.
- Inspection of penstock segment weldments.
- Inspection of welds in continuous pipelines.

A new and promising type of radiography uses neutrons as the penetrating radiation. Neutron radiography complements the other types because of its ability to examine materials impervious or insensitive to X rays and gamma rays. X rays and gamma rays interact with an atom's electrons, and their attenuation is proportional to material density and atomic number. Neutrons, however, interact with the nucleus, and their attenuation is proportional not only to the thickness of a material but also to its neutron absorption coefficient. Neutrons, therefore, can examine materials that are rich in hydrogen, such as plastics and rubber, even when encased in heavy elements like lead.

Neutron radiography was investigated before World War II in both Germany and England, but it was not until the early 1960's that it began to receive the considerable attention that has led to its present stage of development. Investigations have been limited by the lack of intense neutron sources and good imaging devices. Today improvements in imaging systems and the development of more versatile neutron sources, such as californium-252 and antimony–beryllium, are helping to expand the use of neutron radiography in industrial applications as well as in basic research. That process is used, for example, to inspect more than 200 devices in the Apollo program, ranging from explosive charges that separate the booster stages to charges that trigger the reentry parachutes. Neutron radiography is also used to inspect fuel elements and control rods to assure their proper performance in nuclear reactors. Undoubtedly many more industrial uses for this unique tool will develop in the near future.

Radiation processing

The commercial use of ionizing radiation to improve the properties of existing products and catalyze the synthesis of new materials has been studied for nearly 20 years, but only in recent years has this potential become a reality. The interaction of gamma rays and high-energy electrons with matter can catalyze chemical reactions, change the molecular or lattice structure of solids, and destroy microorganisms. Each of these types of radiation effects has been used by industrial firms to manufacture or process a number of products, and many companies are conducting experimental programs to apply the beneficial effects of radiation to other production operations.

Commercial radiation processing has grown rapidly from virtually nothing a decade ago to an annual volume of irradiated products estimated at more than $200 million. Radiation is used by industry to improve the properties of transistors and diodes, to cross-link polyethylene and other polymers for electrical insulation and packaging film, to initiate the synthesis of ethyl bromide, and to sterilize surgical sutures and other medical supplies. These radiation applications result in products now sold commercially, and there is an even broader spectrum of AEC and industrial research and development on other irradiated products that may soon appear on the market.

Most commercial radiation processes currently use electron beam irradiation. This type of radiation, produced by machines of various kinds, is ideal when sheet or film is to be treated or when only surface treatment is required, since electrons have relatively poor penetrating power. In recent years, however, a number of radiation products and processes for which isotopic radiation sources have proved to have technical or economic advantages have been commercialized or have entered the pilot-plant stage.

Wood–plastic material, of course, is one of these, and it promises to become a major commercial product. The material is produced by impregnating wood with a chemical monomer, such as methyl methacrylate, and then irradiating it with gamma rays from cobalt-60 or cesium-137. The radiation polymerizes the plastic molecules and yields a solid wood–plastic combination that:

1. Is harder than natural wood by several hundred percent and thus is more resistant to blows, scratches, etc.
2. Has much higher compression strength and abrasion resistance.
3. Absorbs moisture more slowly and therefore has more dimensional stability (resistance to warping and swelling).
4. Has much improved shear and static bending strength.
5. Retains the natural wood grain and color, or can be artificially colored throughout.
6. Can be sawed, drilled, turned, and sanded with conventional equipment, giving a hard, beautiful, satin-smooth finish.

The distinct advantage of this new process is that many of the properties of natural wood are improved without sacrificing any of the wood's important characteristics, including aesthetic appeal.

This new material has promise for such applications as floors, furniture, window frames, sills and doors, tool handles, decorative trim, sporting goods, boat decks and fittings, and dies and jigs.

The plant we are dedicating today has a design capacity of 15 million square feet of wood–plastic flooring per year. The total industry design capacity is on the order of 25 million square feet per year. A market demand within a few years has been estimated in the range of 100 million square feet annually. Certainly other significant uses of this unique material also will be forthcoming.

Wood–plastics are only the most recent of a number of radiation-produced products that began to appear on the industrial scene about a decade ago. The earliest of these was cross-linked polyethylene. The bridging or linking together of polyethylene molecules was easily accomplished with ionizing radiation. The effect of cross-linking the material is to significantly increase its heat resistance and thereby expand its usefulness. Cross-linked polyethylene wire insulation, for example, became standard in the space program and now seems promising for underground electric cables.

Cross-linking technology has been extended to other polymers and copolymers, including polymers for shrinkable tubing. The polymer tubing is cross-linked with radiation, then heated and expanded. After the sleeve thus produced is slipped over the cable or "bunch" of cables, it is heated again, causing it to shrink tightly around the cable. The same principle is employed in the commercial manufacture of heat-shrinkable polymer widely used for food packaging. A number of specialty copolymers, such as battery separators, also are commercially produced using radiation.

One radiation application that is benefiting virtually everyone is the manufacture of soil-release fabrics. Radiation is used to graft a soil-resistant polymer to a fiber substrate. The desirable properties of the basic fabric are retained, but the grafted polymer makes the material soil resistant. One manufacturer produces 10 million square yards of such fabric annually.

Another radiation-produced product of widespread use is surface-coated panels. By means of radiation, special lacquers and paints can be polymerized on virtually any flat surface, including wood, glass, plastic, ceramics, and metal sheets. These materials can be used in a variety of applications, including outdoor siding, indoor paneling, furniture, and even ping-pong tables. The unique advantage of radiation in this process is that it accomplishes the required polymerization of the paint or lacquer in seconds, whereas conventional heat techniques require hours. At present upwards of 30 million square feet of radiation-produced surface-coated panels are being marketed annually.

These radiation applications, except for wood plastics, employ electron machine radiation. It is gratifying that the basic technology underlying many of the current commercial applications of machines comes from the early AEC-sponsored radiation chemistry research at the AEC's Brookhaven National Laboratory. Today there also appears to be a trend toward radiation processes using isotopic radiation sources.

The bellwether for the use of isotopic radiation is generally considered to be the radiation process for the production of ethyl bromide. This product is conventionally produced by reacting ethylene and hydrogen bromide in the presence of a catalyst. This reaction is quite difficult to control, has side reactions, and results in product impurities. Gamma radiation was found by one manufacturer to sustain the reaction between ethylene and hydrogen bromide in the absence of any chemical catalyst. The process was much easier to control and yielded a much purer product. The company has converted its entire commercial production of this chemical—about one million pounds a year—to the radiation method. With appropriate instrumentation the process has been made self-regulating and runs 24 hours a day without attendance.

Another company recently purchased 250,000 curies of cobalt-60 to be used in a commercial process for the controlled degradation of polyethylene oxide. Polymerization of ethylene oxide yields a very high molecular-weight polymer. For some uses of polyethylene oxide, however, lower molecular-weight grades of the polymer are desirable. Radiation permits controlled degradation of the polymer to selected molecular-weight ranges.

Radiation synthesis of polyethylene is of special significance. This is the most widely used polymer in the world, with several billion pounds produced annually. Some years ago AEC-sponsored work at Brookhaven National Laboratory resulted in a demonstration of the feasibility of polymerizing ethylene with radiation from the radioisotope cobalt-60. This work showed that with radiation the exothermic polymerization reaction could be much more easily controlled than with chemical catalysis. Also, because no chemical catalyst was required, the product was much purer. Finally, the radiation process appeared to be economically competitive.

As a result of this AEC laboratory-scale research and development, two companies have invested their private funds in pilot plants for radiation production of polyethylene, and a third company is considering a similar investment. I believe that during the next round of expansion of polyethylene production capacity we may well see several full-scale plants using cobalt-60 or another suitable radioisotope for polyethylene manufacture.

New applications

New industrial applications of radioisotopes now under development assure additional contributions of isotopes technology to industry and our national economy. A brief discussion of some of these may be of interest.

In the field of radiation processing, the AEC, together with the Bureau of Reclamation and the Office of Saline Water, is developing the technology for the production of concrete—polymer materials. This product is prepared similarly to wood—plastics; i.e., the preformed, set concrete is impregnated with a monomer which is then polymerized in situ with radiation. Remarkable improvements in properties have been obtained, for example:

1. Compressive strength increased nearly 300% or a factor of almost four times the compressive strength of untreated concrete.
2. Tensile strength increased nearly 300%.
3. Modulus of elasticity increased 80%.
4. Modulus of rupture increased 250%.
5. Resistance to freezing and thawing disintegration was improved by over 300%.
6. Water permeability decreased to negligible values.
7. Water absorption decreased as much as 95%.
8. Corrosion by distilled water and sulfate brines was reduced to negligible values compared with the severe attack observed on untreated concrete.

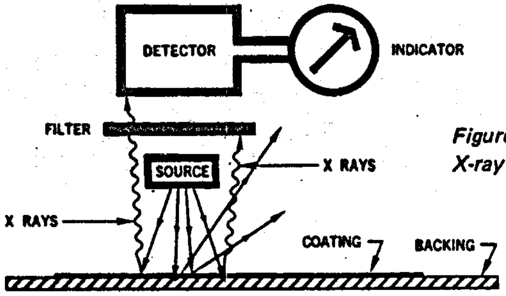
Potential applications of concrete—polymer materials include concrete pipe for transportation of irrigation water, sewage, and municipal and industrial water; construction material for low-cost housing, desalination plants, and underseas structures; and fabrication of prestressed concrete pressure vessels for nuclear reactors. In addition, there may be architectural and aesthetic applications because dyes can be incorporated into the monomer, producing a variety of colors. Although there must be additional research and development, industrial interest is already evident, and private plans are being formulated for commercial production.

In another project the technology for radiation-induced emulsion polymerization has been demonstrated, and a pilot plant is producing vinyl acetate paint latex using this technology. Although production of the latex was intended primarily to demonstrate the radiation-induced emulsion polymerization techniques, the latex product obtained has attracted commercial interest. Samples of the radiation-produced latex product have been evaluated by both commercial laboratories and potential industrial users with the following general results:

1. Each evaluator was able to formulate a satisfactory paint from the latex.
2. The paint was generally acceptable and comparable in performance to that produced from good quality commercial latexes, with the exception that in all cases tested, the paint produced from the radiation-polymerized latexes remained glossier than conventional paint.
3. The latex produced by radiation polymerization had smaller particle sizes and higher molecular weight than that of conventional latexes.

This process is being evaluated by a number of commercial concerns.

Turning to another area of isotopes technology, radioisotope X-ray fluorescence analysis is being developed for a variety of applications, including industrial uses. This technique can be used to detect the presence and measure the amount of a number of chemical elements. It is based on the selective absorption of X rays by particular elements and the reemission and detection of a characteristic X-ray photon. Both X-ray machines and radioisotopes can be employed to generate the incident X rays. Radioisotopes offer the opportunity for development and use of portable equipment. The advantages of this already have been demonstrated in tests that successfully detected such elements as gold and silver in ores. The potential applications of this technique are being further explored. (Figure 7.)



ORX5

Figure 7. Principle of X-ray fluorescence.

In another AEC study a laboratory-type Mossbauer spectrometer is being developed to determine the structural characteristics of iron and steel products. For example, analyses of specimens of bearing-type steel subject to varying heat treatments and containing varying levels of retained austenite have shown that the Mossbauer technique provides quantitative measurement of the austenitic phase in agreement with values determined by X-ray diffraction measurements. We are also exploring other potential uses of the Mossbauer scattering technique for determining the volume fractions of iron phases in multiphase mixtures. Preliminary data indicate that this technique can follow austenite transformation, cementite precipitation, and tempered martensite production in heat-treated high-alloy high-speed steels, cold-worked medium-alloy die steels, and aged maraging steels. In addition, the scattering method provides a convenient nondestructive method for detection and identification of surface compound formation in iron corrosion studies. The Mossbauer technique should prove applicable to a variety of industrial problems.

In still another project we are investigating isotopic methods for measuring the cement content of concrete. An important problem in civil engineering is the quality control of concrete. Quality is based on the strength of the concrete, which can be directly measured only after setting and curing. The strength of concrete is related to the cement and water content and to the bulk density and air entrainment factor of the wet mix. Although methods are available to determine water and air content and bulk density, no satisfactory method for measuring cement content has been found. Preliminary tests using low-energy gamma-ray backscatter techniques, however, have indicated that this method can measure cement content within 1% in only 10 seconds. These results were obtained using a 1-millicurie americium-241 source.

Environmental protection

As our world becomes more crowded, industrialized, and polluted, industry is finding itself more and more concerned with matters involving environment and conservation. Radioisotopes and radioisotope technology offer unique contributions to our understanding of these increasingly vital areas.

Before legal and technical aspects of air-pollution-control efforts can be effective, there must be a way to measure the gas pollutants, particularly the sulfur dioxide, emitted from the stacks of industrial plants. One promising solution to this problem is a radioisotope substitution method. In the mercury substitution—nucleonic detection method, sulfur dioxide reacts stoichiometrically with insoluble mercurous chloride to produce soluble bisulfito-mercurate ions. The concentration of mercury can be determined by X-ray absorption spectroscopy, perhaps using low-energy X rays emitted by cadmium-109 or molybdenum X rays excited by americium-241. This process will indicate the concentration of sulfur dioxide.

Systems studies and working-design concepts have indicated that an instrument for stack-gas monitoring would be capable of stable, reliable measurement of sulfur dioxide to about 10% accuracy in the 100 to 4000 parts per million range with a response time of about 10 minutes. Field testing of a working model is being conducted this year, and, if the results are favorable, prototype units will be developed for extended testing.

Sulfur compounds emitted from industrial facilities are among the most damaging of atmospheric pollutants. In many metropolitan areas there are so many sources of sulfur pollutants that there is no way to determine which among them are the chief contributors. The AEC is now working with the National Air Pollution Control Administration to adapt radioisotope techniques to trace atmospheric sulfur compounds from their origin to their ultimate fate in the environment. The "isotope ratio tracer" uses nonradioactive isotopes to chart the origin of specific pollutants in an industrialized area. It should make possible new experiments on some of the major meteorological problems of sulfur oxides released into the air over large metropolitan areas.

This method is based on the marked variation from one fossil fuel to another in the ratio of sulfur-32 to sulfur-34. Measured ratios are expressed in "per mil" units, or parts per thousand, as either higher or lower in sulfur-34 than the standard of meteoritic sulfur. An isotope-ratio mass spectrometer now in use can achieve a precision of measurement such that about 1 part of fuel sulfur in the atmosphere can be detected in 50 parts of background sulfur.

This process is undergoing extensive testing in New Haven, Conn., with the cooperation of the local power company. The tests are being conducted over 24-hour periods at different times of the year to establish seasonal and diurnal variations in the background. For a similar program in New York City, a "tall-stack" power plant on

Staten Island has been selected as most nearly meeting the meteorological requirements. The first study there will be of the effectiveness of tall stacks under typical inversion conditions.

Radioisotope technology may also assist in the solution of the pollution problems associated with the pulp and paper industry. If pulp fibers could be traced throughout paper-mill processes and on to their ultimate fate as finished products or as stream pollutants, the industry could learn much more about the sources and types of its effluents and, perhaps, about their control. Radioisotopic tracing was considered, but instead a similar method has been developed to trace the fibers through the mill and into effluent streams without introducing any radioactive material to the system. A small amount of fibers or chips is treated with metallic salts in such a way that the metal component becomes bonded to the cellulose or is precipitated within the fiber lumen. The treated fibers are released into the process stream, and samples are collected at various points downstream and in the effluent and are returned to the laboratory for neutron activation analysis.

This labeling technique has been used successfully in a number of paper mills in Montana and Washington. It has allowed the plants to determine the retention time of chips in continuous digesters, the clarifier pipeline flow, clarifier system operational characteristics, and the sawdust digester flow patterns.

Some observations

These applications are only a few of the many industrial uses of radioisotopes that have resulted from research by the AEC and development by industry in a relatively short time. They should indicate the great range of uses that radioisotopes and radioisotope techniques will have in the industrial processes of tomorrow.

As we have seen, the industrial applications of radioisotopes are benefiting not only private industry but the entire nation in at least three major ways. First, they are the sources of new products, like the wood–plastic that will be manufactured in this plant, which are not only opening new ventures for industry but also enriching the lives of us all. Second, their tracing, gauging, and radiographic applications are significantly increasing the productivity of private industry and bolstering our national economy. Third, radioisotope technology promises to increase our knowledge about the critical subject of environmental pollution, which is of increasing national concern. The cumulative effect of these applications has been so significant that C. P. Snow has dated the beginning of the "Scientific Revolution" from the time that nuclear particles were first used by industry.

I wish I could have had time today to mention the equally revolutionary effects radioisotopes are having in such areas as medicine, agriculture, research, the humanities, and even crime detection. But these examples I have discussed should indicate that, although the radioisotope may not be as dramatic or as widely publicized as nuclear powered rockets, power reactors, or peaceful nuclear explosives, it may nevertheless prove to be the most beneficial—and most industrious—form of nuclear energy.

The atom's expanding role in agriculture

With the world's population expected to double by the end of the century, the farmer's burden will double also. By the year 2000 he will be expected to furnish food for approximately seven billion people. To reach this goal he has to be a soil scientist, horticulturist, agronomist, and plant physiologist, as well as a businessman. Assisting him has been the research scientist, who has provided important advances in plant breeding, soil study, irrigation, livestock production, and food preservation. As a result, food production is rising, and losses from insects, plant diseases, and spoilage, which total billions of dollars annually, are being substantially reduced.

Neither the agricultural expert nor any other scientist has so far solved the primary problem of the age—population control. What agriculture has done, with an important assist from nuclear energy, is to buy time by keeping the rapidly expanding population fed while other sciences pursue methods to check a population that is growing faster than the world's resources.

In any attempt to develop new and better crop varieties, the basic problem narrows down to a manipulation of genetic material, a kind of genetic engineering.

New crops through mutations

Ever since the pioneering work of H. J. Muller in 1927, radiation has been known to significantly increase variability in living things by inducing mutation. Although most induced mutations are deleterious, a number can offer advantages. An important application of this is plant breeding for better crop strains. The plant breeder, in addition to using the more conventional techniques of selection and crossing, can now expand the available genetic inventory for his work by using radiation to enhance variability in the crop.

Nearly 100 new and improved plant strains, including many basic food crops, developed here and abroad through mutation by radiation have been released for commercial use. Included are high-yield disease-resistant varieties. Development of still other new strains continues.

A good example of the new strains is Reimei, the highest yielding rice variety in Japan. This mutant contains twice as much protein as conventional varieties. Other important new rice varieties offer high yields, shorter growing periods, or both. One new mutant, discovered in Hungary, shortens the growing period by three weeks, a development that could expand the cultivation of rice in Europe.

Sonora wheat was developed in work supported by the Rockefeller Foundation. This new variety is high in protein, matures early, and produces short straw. However, it was not well accepted in some Indian communities until the strain was further altered to produce grain in the amber color to which the people were accustomed. Radiation treatment was used to gain this final refinement.

Closer home, at the University of Georgia in Tifton, a strain of pearl millet has been selected from radiation-treated materials which produces seed heads in 43 days instead of the usual 60. Breeding this characteristic into lines with other desirable features could result in an exceptionally useful crop plant, particularly in Africa and India. The AEC is supporting this joint project of the university and the U. S. Department of Agriculture. Although this millet is not yet in use commercially, it is expected to offer farmers hope for a crop where adverse weather conditions restrict the growing season.

Another example of a radiation-induced mutant is a castor bean with a drastically shortened maturity period. Farmers in India may now use a mutant seed that matures in 120 days instead of the usual 270; this gives a 150-day growing season, which would allow rice to be grown as a second crop.

An additional illustration of the usefulness of radiation-induced mutations is to be found in the peppermint crop in the United States. For 14 years growers fought a plant disease, Fusarium wilt, which threatened to wipe out the peppermint crop in this country. Recently a new strain was developed using neutron radiation treatment which is resistant to the disease and which retains the important flavor quality. No other plant-breeding method has been successful in producing a disease-resistant variety.

The Rockefeller wheat and the new peppermint illustrate the value of radiation to obtain mutations more quickly than conventional methods—sometimes as the only feasible method. It is important to note, however, that radiation cannot induce each and every desirable mutation.

Researchers induce favorable agronomic characters by irradiating seeds or by exposing the growing plants or tissues to radiation. Mutants are usually isolated from the progenies of the second or subsequent generations. Those of agricultural interest are selected and subjected to further evaluation.

Improved crop qualities developed through radiation mutation include bread wheat resistant to rust diseases, barley with increased winter hardiness, and a peanut strain featuring damage-resistant hulls, good taste, and higher yield. In the horticulture area, many disease-resistant flower mutants have been produced; these include redder roses, more colorful chrysanthemums, and larger dahlias.

Under development at the Agriculture Research Laboratory of the University of Tennessee is a thornless blackberry bush that is also resistant to diseases and rigors of climate. Thornless berry bushes are not new. A limited number have been developed through normal breeding, but that process requires several years, and the resultant strains have been susceptible to diseases and weakened by weather. Cuttings of thornless plants have been developed in a few months with radiation-induced mutations; this enables the researcher to speed efforts to stabilize the strain as consistently thornless.

The superhighway traveler in the South has likely admired a hardy and handsome green ground cover along many banks and rights-of-way. It is a mutant strain of lespedeza called, appropriately enough, "hi-way." The leafy plant, which requires little maintenance, was developed by researchers at Auburn University in cooperation with University of Tennessee facilities at the AEC's Oak Ridge installation.

The work is worldwide and continuing. New mutant plant strains have been developed in Argentina, Austria, China, Czechoslovakia, India, Indonesia, Italy, Japan, the Netherlands, Sweden, the Soviet Union, and the United Kingdom, as well as in the United States. Next June scientists from around the world will meet in Vienna to discuss ways in which the protein content of food crops may be elevated by using nuclear radiation. The emphasis will be on staple crops which provide the basic food of most of the world's population but which are sometimes low in natural protein.

Isotopes as tracers

Photosynthesis, an important aspect of agriculture, is unquestionably the most crucial process in sustaining life on earth. While nuclear processes are a most important source of energy for the future, it is photosynthesis, the conversion of the light energy of the sun into chemical energy, which has sustained man and upon which he remains dependent for food, fiber, and also much of his fuel.

The use of radioisotopes has enabled plant scientists to make good progress in unraveling the photosynthetic process. Significant new discoveries are being made each year which ultimately will lead to an understanding of the process and possibly to the design of an effective synthetic light-energy conversion process. Such recent discoveries as the existence of a second major photosynthetic carbon fixation pathway in tropical and other grasses can be attributed to the use of the radioisotope carbon-14. This kind of basic information may eventually be utilized by the more practical scientist in such tasks as genetic engineering of new crop plants in developing high-yield varieties closely adapted to particular growth conditions.

The use of isotopes as tracers has become singularly important in agricultural research in the study of plant metabolism and plant physiology as well as photosynthesis. The use of fertilizer nutrients tagged with isotopes has been refined in the past 30 years of application to a point where the scientist can determine the availability of elements in soils, the best methods and timing of fertilizer applications, the residual value of fertilizers, and also the interaction between different fertilizer nutrients.

For example, a program carried out in several Latin American countries on maize fertilization showed that plowing down the fertilizers in some locations resulted in reduced uptake of the nitrogen in the fertilizer but that side-dressing generally resulted in an increase in uptake of nitrogen, especially when the fertilizer was applied a few weeks before tasseling.

Fertilizers labeled with radioactive isotopes are prepared by the Tennessee Valley Authority at Muscle Shoals, Ala., for licensed researchers. The user pays for the material and the shipping but is not charged for its preparation. In return, the user reports research findings to TVA on a proprietary basis. TVA is a major fertilizer producer and conducts extensive research into fertilizer uses and effects.

Roots of plants were once considered the sole organ for uptake of nutrients and water. Experiments using radioactive isotopes proved the aboveground plant parts, such as flowers, fruit, foliage, and stems, could absorb and use nutrients from sprays. Now spray applications are widely used where root adsorption of fertilizer is limited or where precise control of nutrition is required. Tracer tests show they are often more effective than root applications. Bean and tomato plants are good examples.

Radioisotope techniques are providing a research tool in animal physiology previously unavailable for the study of nutrition and metabolism of trace minerals. This work has established that more effective—and less expensive—food supplies for farm animals, such as previously discarded high-cellulose materials, are now possible. Such discoveries are possible because scientists can measure extremely minute levels of radioactive isotopes.

Isotopes are also used to measure the moisture content of the soil, information important to determine irrigation needs and also to find out how heavy a crop a certain piece of land will support. A portable neutron soil moisture meter has been developed which can give virtually instantaneous readings. A pipe is driven five feet or more into the ground, and a radioactive neutron source and a detector are lowered into the pipe to the desired depth. The neutrons pass through the pipe into the soil. Only hydrogen atoms will markedly slow up this neutron movement. The slower the flow, the higher the water content of the soil because practically all hydrogen in the soil is contained in water in the soil. The neutron soil moisture meter is probably the most widely used nuclear energy device in water studies in agriculture.

Pest control

With the current concern with environmental problems, it is significant to note that nuclear techniques have been in use for some time to help counter pollution problems in agricultural areas. The pesticides farmers use to control diseases and insect pests are a boon to the production of food, fiber, and forage, but some pesticides are toxic and leave a long-lived residue.

The traditional method of pest control, which gave way to insecticides, depended on natural factors like weather changes, insect-eating birds, and insect parasites. The use of man-made insecticides, although effective, has caused a disturbance of natural balance and the loss of many natural predators.

An important breakthrough in efforts to reduce drastically or to eliminate insecticide use—and thereby reduce environmental pollution—came with the radiation-sterilized-insect-release method. In this "sterile-male technique," the pest is mass produced in the laboratory, exposed to just enough radiation to render it sterile, and then released in infested areas. The sterile pest competes effectively with its wild counterpart and mates but produces no offspring, thus the population dwindles. In the Southeast applications of the technique have virtually eliminated the screwworm that infests livestock.

A similar campaign directed by the U. S. Department of Agriculture is under way in the Southwest. A so-called "factory" at Mission, Tex., produces and sterilizes screwworm flies in an around-the-clock operation. These flies are released in areas where the pest has been identified. The technique has drastically reduced the livestock damage by the screwworm, which used to total many millions of dollars each year. Although success is not so complete as in the Southeast, eventual eradication of the screwworm in the Southwest is expected.

The sterile-insect-release technique—or as it is frequently called, the sterile-male technique—is now being used in efforts to eliminate or control other insects that threaten livestock and crops. Particularly promising are the preliminary results in control of certain fruit flies.

The Department of Agriculture is working hard with these methods to knock out the codling moth apple pest in the Northwest; the pink bollworm, which attacks cotton in the Southwest and in California; and, the most destructive of all agricultural pests, the earworm, which affects both corn and cotton. If we could avoid using insecticides on cotton alone, we would reduce by one-third the total amount of insecticides used in this country.

Overseas hundreds of millions of dollars damage is done each year to citrus and other fruit by the Mediterranean fruit fly, which lays its eggs in the fruit. The sterile-insect-release technique has achieved drastic reductions in the fruit fly population in test areas. In experiments in Nicaragua the release of sterile flies in infested areas showed a 90.5% drop in infestation, and in areas of Spain where fly ravages have prevented profitable apricot and peach harvests the use of the sterile fruit fly has shown that commercial crop prospects can be reversed.

The sterile-male technique, supported by both the United Nations and the International Atomic Energy Agency, is also being used in efforts against the tsetse fly, olive fly, pine moth, rice stem borer, cherry fruit fly, and others. Preliminary work has been done by the AEC and Louisiana State University in using this technique to eliminate the sweet potato weevil.

Methods of rearing and sterilizing quantities of tsetse flies in captivity have not yet been perfected, but the IAEA laboratory near Vienna is making progress in this direction. The tsetse, which carries the dread sleeping sickness that infects both animals and humans, has made normal livestock production impossible in some areas of Africa. However, researchers are confident that if millions of vigorous radiation-sterilized flies could be released weekly over a long period of time, the fly population could be halved annually, and present cattle herds could be increased and crossed with dairy and beef breeds to increase the per capita protein diet of Africa.

Another area of pest control where isotopes have been helpful is in the use of herbicides to kill weeds. Organic chemicals have been developed which, when taken up through the soil by germinating seedlings, practice selective toxicity by killing off all but the desired plant.

Like the insecticides, the herbicides cause concern regarding environmental effects caused by residue. What happens when these chemicals are used in our food crops? Is there a chance of a buildup and concentration of the chemical in food chains which could be harmful to humans or wildlife? Tagging or labeling the pesticide or herbicide with a radioisotope helps researchers answer these questions by following the pattern of plant take-up, metabolism, and localization. Tagging also helps collect information on weather effects, soil moisture conditions, and the rate of disappearance of the chemical in the soil. Radiotracers enable the researcher to follow the insecticide throughout the environment. Since labeled insecticides have been available, much progress has been made in designing effective but less hazardous insecticides.

Animal diseases

For years immunologists have worked unsuccessfully to develop vaccines that might be effective against parasitic diseases in livestock. The need is urgent. These diseases alone account for a major portion of all animal losses from disease. In developing countries in particular, only preventive medicine through vaccines is considered economically feasible and effective. Chemical treatment may eliminate the infection, but it will not prevent reinfestation. Conventional methods of producing parasite vaccines have failed, but radiation techniques are now showing real signs of success and indicate an important medical breakthrough in the making.

For inoculations against parasite bronchitis, caused by a lung worm, larvae from infected cattle and sheep are incubated, irradiated, and become a vaccine that is administered orally to young calves. Irradiation suppresses the pathogenicity and reproductive capacity of the parasite. Because the parasite is still living and is mobile enough to reach the lungs as normal larvae do, the host animal can build up an immunity. This vaccine, also effective for sheep, is available commercially in the United Kingdom, Continental Europe, and Yugoslavia.

A U. S. firm is now working on a vaccine against hookworm in dogs, which showed promise in studies at Glasgow University. Scientists foresee human applications. Vaccines against still other animal parasites, including the poultry tapeworm, are being developed as are systems to tag parasites with radioisotopes to trace their migrations through the host tissue and to study the fundamental mechanisms of immunity.

The announcement that AEC and Department of Agriculture scientists achieved preliminary success in controlling foot-and-mouth disease in mice caused considerable excitement a few months ago. This highly infectious disease causes the death or destruction of millions of dollars worth of cattle each year.

The success in mice was achieved by stimulating the animal's natural virus-fighting defense— a substance called interferon—by injecting synthetic double-stranded RNA (ribonucleic acid). The interferon response literally stops the spread of virus by interfering with the transfer of infection from one cell to another. The RNA–interferon experiments came as a spin-off from nuclear energy research at the AEC's Brookhaven National Laboratory. The developers, Dr. Leonard Hamilton of Brookhaven and Dr. Jonathan Richmond of the U. S.

Department of Agriculture, report the potential for use on larger animals, including cattle, is excellent.

Radionuclides have been instrumental in revealing various physiological conditions in livestock. An example is the study of milk fever. High-producing cattle stricken with this disease often become permanently paralyzed or die because of a decrease in the calcium level in the blood when they calve and milk production begins. The outpouring of calcium into the milk and the inability of the cow to replenish the blood level is now better understood through radioactive-calcium experiments carried out by the University of Pennsylvania and the University of Illinois. A rational basis for treatment and prevention of this condition is now possible.

The application of nuclear medicine to the diagnosis and treatment of animal diseases is now becoming feasible. For example, a nuclear in vitro test has been developed to study the thyroid function of farm animals. These tests require only a sample of blood serum from the animal. When a tiny amount of radioactivity is added to the serum, the researcher can determine if the animal is normal or hyperthyroid without injecting any radioactivity into the animal. Early tests were conducted at Cornell University with dogs. Success has now been achieved with cattle, and the tests will likely be applied to sheep, pigs, and horses.

Food preservation

International food experts estimate that one-fifth of the world's food crops are destroyed by insects, microorganisms, and other pests; losses are as high as 30 to 50% in some areas. This includes spoilage in transit and storage. Food preservation by irradiation is emerging—slowly but surely—as at least a partial answer to the problem.

This technology, the first basically new food-preservation process since the invention of canning, has important implications for the world in alleviating food shortages and losses and in meeting food needs of the population growth, particularly in developing countries.

Meats exposed to high, or sterilization, doses of gamma rays remain edible without refrigeration almost indefinitely—an important plus for the field soldier, who still travels on his stomach and is usually far from freezer facilities. The radiation-sterilization research program is being conducted at the U. S. Army's food laboratory at Natick, Mass. The sterilization technology, which destroys all microorganisms, is aimed at processing perishable foods for long-term storage without refrigeration. The Army has successfully demonstrated the process for beef, pork, chicken, smoked ham, frankfurters, codfish cakes, shrimp, ground beef, pork sausage, and corned beef.

Pasteurizing foodstuffs with low doses of gamma rays from cobalt-60 or cesium-137 can destroy enough of the normal spoilage bacteria in fish, fruit, fowl, and vegetables to delay rot and extend the prime fresh state. The process can extend the season of the fragile strawberry and can provide more time for transport so that ocean delicacies like fresh haddock, cod, and shrimp can be served by the Midwest housewife. Irradiation can replace the residue-depositing chemical fumigants currently used to destroy fruit flies on papayas so this tasty tropical fruit can meet Department of Agriculture quarantine requirements when shipped from Hawaii. Irradiation can also control salmonella infections in food products, an international health problem.

Radiation pasteurization can control spoilage caused by bacteria, yeasts, and molds in such foods as strawberries, fish, chicken, and citrus fruits. It can control insect and parasite infestations on wheat and wheat products and dried fruits, replacing chemical pesticides and their potential residue danger. Radiation energy can slow ripening or aging in fruits and vegetables. A delayed maturation can be achieved for bananas, mushrooms, and mangoes, extending their prime marketing period. Irradiation can also achieve sprout inhibition in stored potatoes and onions.

The technique is complicated, however. Although the product does not become radioactive, various foods react differently to radiation. Care must be taken to employ the proper dose at the desired stages of development of the food to avoid alteration in taste and appearance while deriving the hoped-for benefit of irradiation. The Food and Drug Administration of the U. S. Department of Health, Education, and Welfare has the ultimate responsibility for issuing the regulation allowing public use of irradiated foods. Decisions are arrived at after careful review of detailed research data, which must demonstrate that the food item processed with radiation is in fact wholesome and safe for unlimited human consumption. This FDA requirement, by the way, is not unique for radiation; it applies equally to all food additives.

In 1968 the FDA rejected as insufficient the research data supporting the U. S. Army's petition for approval of radiation-sterilized canned smoked ham and later withdrew its approval of bacon. The Army, which has specialized in work on sterilizing doses for meat, is continuing its research. The AEC, whose program has been slowed down by budgetary limitations, is working closely with FDA in compiling the required data.

Two foods currently hold FDA approval, and several items have been approved abroad. The U. S. items, which are not yet commercialized, are potatoes irradiated to inhibit sprouting during storage and wheat and wheat flour irradiated for insect disinfestation. However, work is moving ahead on petitions seeking approval for low-dose radiation processing of fresh strawberries to reduce and control decay and rot, of papayas for quarantine disinfestation and delayed ripening, and of haddock and cod fillets for the extension of fresh market life by reduction of spoilage flora. So far AEC-sponsored long-term animal feeding studies in progress concerning wholesomeness and safety evaluations of irradiated strawberries and papayas show no adverse effects associated with the low-dose radiation processing.

Both the required shipping and the two-year animal feeding studies for strawberries will be completed in 1970. The petition for approval of irradiated strawberries will likely be submitted to FDA in the summer of 1970. Strawberries, by the way, have already been approved for market testing in the Netherlands.

The Department of Agriculture of the State of Hawaii is conducting shipping and packing studies of irradiated and unirradiated papayas for the AEC. Current studies to determine the effectiveness of radiation as a disinfestation agent for papayas are being conducted in cooperation with the Plant Quarantine Division of the U. S. Department of Agriculture in Hawaii. AEC-sponsored two-year animal feeding studies on papayas are scheduled to be completed in mid-1971. If the papaya petition, which AEC hopes to submit late in 1971, is approved by FDA, commercial irradiation of the fruit could begin as early as 1972.

Microbiological studies are now under way on haddock and cod fillets with particular attention to *Clostridium botulinum*, the bacterium which causes botulism food poisoning. Investigators want to confirm that radiation used to inhibit the growth of the normal spoilage organisms present in fish is also effective in controlling the growth of any botulinum organism in the fish. Two-year feeding studies on the haddock will likely begin in 1971 after the microbiological studies are completed.

In further support of the food-irradiation program, a truck-mounted portable cesium irradiator recently completed a cross-country demonstration tour, stopping at about 75 private food firms in 12 states and processing some 75,000 pounds of produce. It was a practical demonstration of the technique at the food producers' own plants. The AEC has also provided pilot-plant facilities in Gloucester, Mass., in Davis, Calif., and in Honolulu, Hawaii.

This country is also supporting food-irradiation research abroad. Large, semiportable irradiators have been or will be loaned to Israel, Argentina, Iceland, India, Chile, Korea, and Pakistan.

Some 50 countries are conducting studies on food irradiation which 26 other countries are watching with interest. Russia is offering the longest list of approved irradiation items including potatoes, grain, dried fruits, dry food concentrates, fresh fruits, and vegetables. Several prepackaged meat and poultry items are also being market tested in the USSR.

Food scientists seeking an international trade agreement on the production of irradiated foods have proposed establishment of an International Food Irradiation Project under the joint auspices of the IAEA and the European Nuclear Energy Association. The United States is planning to be an active participant in this program.

Other applications of radiation

There is more to agriculture than food, of course. The farmer helps clothe and house the world as well as feed it, and the atom is important in these areas, too.

Radiation is helping to create more appealing textiles, specifically the so-called wash-and-wear or durable-press fabrics. Radiation, usually from cobalt-60, is used in the final processing of the completed garment to produce the ease-of-care or durable-press quality.

Textile people are using what they call "radiation grafting" to build into a fiber a long list of attractive properties including crease recovery, stain release, dyeability, antistatic behavior, increased comfort, rot and mildew resistance, high thermal stability, and even fireproofing qualities. Most radiation processing is done on polyester–cotton blend, but an increasing amount of work is being done with wool, rayon, and other fabrics.

In another agriculture-related area, the atom may be used to help grow superior timber by cultivating trees with the straight grain preferred by builders for lumber. By injecting radioisotopes into the roots of a tree, the direction of the grain can be traced by a Geiger counter as the radioactive material moves up the trunk. The technique, still under development, calls for identifying straight-grain trees and using these for seed for selective breeding of more trees with the stronger, more workable grain.

A nuclear gadget used to measure the water content and density of snow is expected to help the farmer. The AEC and the Forest Service of the Department of Agriculture have developed a portable gauge that uses radioactive cesium to show even small changes in water content and density of snow over long periods of time. The gauge, now being refined by its developers at the Forest Service Experiment Station at Berkeley, Calif., aids in flood and avalanche predictions, helps foresters predict the effect of timber cutting patterns on snow accumulation and melt, and helps managers of water supply reservoirs anticipate snowmelt and runoff. Spring and summer runoff is related to plant growth. Gauge readings are also useful in predicting the forest-fire potential of a particular region.

The device, which gives almost instant information, consists of two aluminum tubes 10 inches apart, one containing the cesium and the other a detector to capture and measure gamma rays that pulse through the snow.

The Nuplex

What about using nuclear power plants, long heralded as a developing source of cheap and abundant electricity, to desalt seawater to irrigate arid seacoast areas? The basic technology is already in hand. Studies show that high-value fruits and vegetables may be grown economically with desalinated seawater, which would cost about 20¢ or more for 1,000 gallons. But such a price is still too high for general farm crops.

The most practical immediate applications would be in isolated desert areas or areas where fresh water and vegetables are not available and are costly to provide. The prospects for very large nuclear power and desalting plants near the northern end of the Gulf of California are good. Large plants in this area would produce fresh water and electric power for the arid regions of Arizona and California and the Mexican states of Baja and Sonora.

Future prospects are bright for nuclear powered agro-industrial complexes, which we refer to as "Nuplexes," which might produce up to one billion gallons per day of fresh water from the sea along with 2,000 megawatts of electricity. These complexes, which could upgrade the economics of arid coastal regions around the world, could produce food for millions of persons from a scientifically managed farm, or "food factory," and the industrial segments might produce fertilizers, aluminum, phosphorus, caustic soda, chlorine, and ammonia for export as well as domestic use. Where the climate permits, the system might have a highly intensive irrigated agriculture program of crops on a year-round basis.

The coordinated food-producing enterprise could include shrimp and fish cultures, poultry, beef and milk production, beans, peanuts, rice, millet, wheat, etc., plus production of the fertilizers needed for these crops. On-the-spot food processing is also envisioned to produce flour, frozen vegetables, shrimp, fruit, and various processed foods to avoid costly storage, transportation, and waste.

Poultry production is seen as an efficient means of converting grain grown at the complex into high-value protein food. If wheat from 22,400 acres were used for chicken feed, about 59 million pounds of live broilers and 15 million dozen eggs could be produced per year.

Irrigated desert agriculture opens up new priorities for agricultural research and stresses the need for crop varieties and production techniques that combine high yield potential, short growing seasons, and low water requirements.

The atom's expanding role in the humanities*

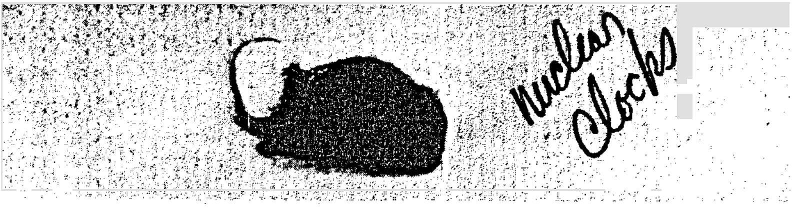
Radioactive dating

One of the earliest applications of radioisotopes in the humanities was that of radiocarbon dating, first developed and demonstrated by former Atomic Energy Commissioner Willard Libby in the late 1940's. The principle of carbon dating is based on the fact that radiocarbon (carbon-14) is produced in nature by a nuclear process involving the interaction of cosmic rays from outer space with the nitrogen in the earth's atmosphere. All living matter contains a small quantity of radiocarbon, and the proportion of this activity remains constant through the life of the organic matter. When plants, animals, and men die, the radioactivity slowly fades away. Since the half-life of carbon-14 is about 5700 years, a piece of wood of that age is only half as radioactive as it was when first formed. Using the decay rate of carbon-14 atoms as a nuclear timepiece, we can make measurements by taking a known amount of carbon from the sample, converting it to gas, and then counting the carbon-14 disintegrations in the gas.

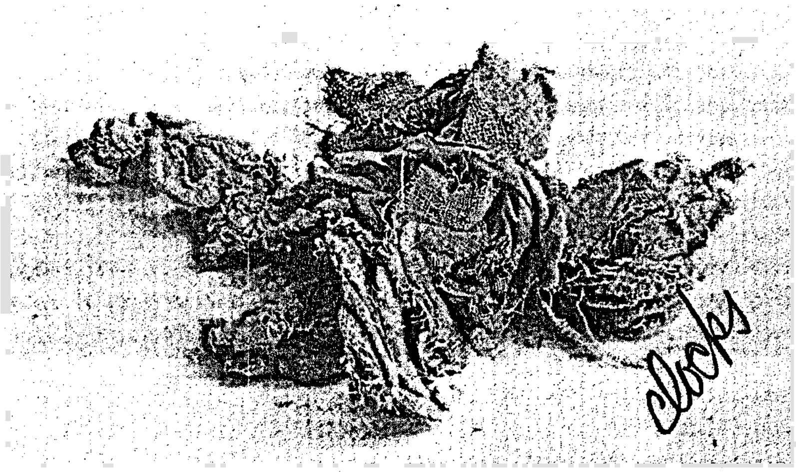
By using the most-sensitive analytical methods available today, scientists find it possible to give fairly accurate dates to the products of man's activities (Figure 1). By employing this technique, we learned that the Dead Sea Scrolls are nearly 2000 years old, not from the scrolls themselves but from the linen in which they were wrapped. The linen contained enough carbon-14 to indicate that it was alive as a flax plant about the time when Christ was born. By radiocarbon dating of charcoal materials found near the great monuments at Stonehenge in England, scientists found that they were erected about 3700 years ago. Further information about these structures was generated when geologists identified the rock of which they were made; the nearest such deposit is in Wales, 180 miles away.

**Remarks at the 1969 meeting of the American Nuclear Society, San Francisco, Calif., Dec. 2, 1969.*

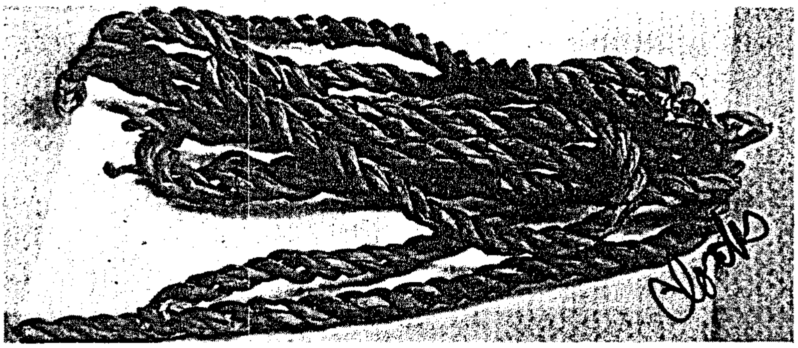
Figure 1. Some objects dated by radiocarbon.



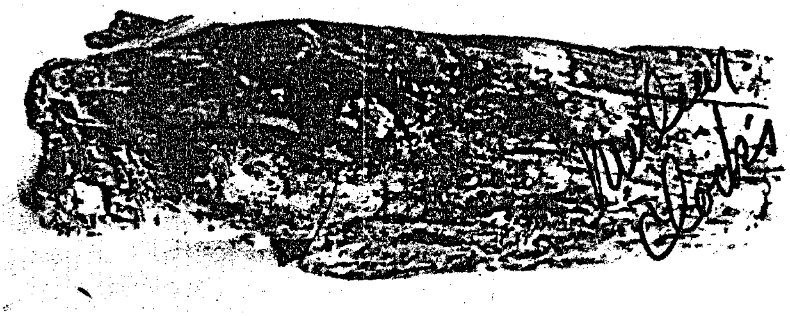
Hair of an Egyptian woman. 5020 ± 290 years old.



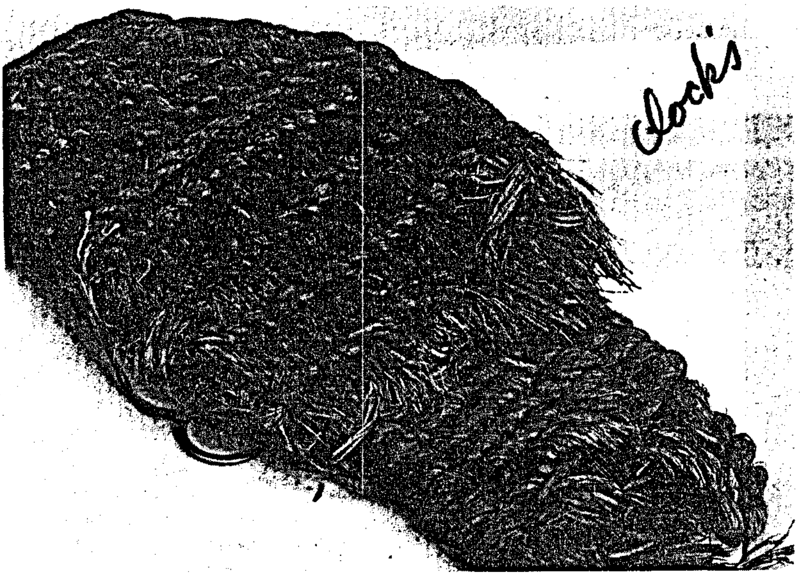
Linen wrapping from the Dead Sea Scroll containing the Book of Isaiah. 1917 ± 200 years old.



Peruvian rope. 2632 ± 200 years old.



Preglacial wood found in Ohio. More than 20,000 years old.



Rope sandal found in eastern Oregon cave. One of a pair of 300 pairs found in this cave. 9035 ± 325 years old.

One of the more-significant applications of radiocarbon dating in this country is in determining the dates connected with early inhabitants of North America. With the aid of this archeological tool, it has been possible to date the remains of ancient living sites in the Western United States, some of which have been uncovered at the AEC's Nevada Test Site. The first establishment of these sites, about 11,500 years ago, apparently coincided with the time a land bridge was open from Asia to America over what is now the Bering Strait. This was most likely the route taken by the first immigrants to America, a population of mammoth-hunters who used the Clovis arrow and spearpoint (Figure 2). Through the use of carbon-14 dating of bones of animals killed with Clovis arrows, it was possible to establish that the Clovis people preceded the bison-hunting Folsom people of the Southwest, who were long thought to be the first inhabitants of America.

Figure 2. A Clovis arrowpoint chipped from flint by the earliest men on the American continent. The photograph is actual size.

Carbon-14 is particularly useful in establishing a chronology in cultures, and this dating process is necessarily carried out in the context of known natural changes, the recorded reign of ancient kings, and other time-measuring devices, such as tree-ring dating. While radiocarbon dating is the most widely used method of measuring time covering the period of the last 50,000 years, significant advances have been made in other time-dating approaches using such long-lived, naturally occurring isotopes as thorium-230, potassium-40 to argon-40 decay, and rubidium-87 to strontium-87 decay. Thorium-230, with its half-life of 80,000 years, is best for dating materials in the range of 10,000 to 200,000 years; it also can be used for comparison purposes with the older carbon-dated materials. Because of their very long half-lives, potassium-40 and rubidium-87 are used for dating in the range of millions of years.

Basic Measurement Methods

Method	Material	Time dated	Useful time span (years)
Carbon-14	Wood, peat, charcoal	When plant died	1000 to 50,000
	Bone, shell	Slightly before animal died	2000 to 35,000
Potassium–argon	Mica, some whole rocks	When rock last cooled to about 300°C	100,000 and up
	Hornblende Sanidine	When rock last cooled to about 500°C	10,000,000 and up
Rubidium–strontium	Mica	When rock last cooled to about 300°C	5,000,000 and up
	Potash feldspar	When rock last cooled to about 500°C	50,000,000 and up
	Whole rock	Time of separation of the rock as a closed unit	100,000,000 and up
Uranium–lead	Zircon	When crystals formed	200,000,000 and up
Uranium-238 fission	Many	When rock last cooled	100 to 1,000,000,000 (Depending on material)

One of the most publicized dating efforts using the potassium–argon technique is that involving the fossil skull of Zinjanthropus, found a few years ago by the British anthropologist Dr. L. S. B. Leakey in the Olduvai Gorge in Tanzania. The measurements of radioactive decay of potassium-40, with its long half-life of 1.3 billion years, to argon-40 were made at Berkeley by Garniss Curtis and Jack Evernden. Our earliest human ancestor turned out to be almost two million years old, considerably older than anticipated. Because the amount of argon produced in two million years is extremely small and contamination by argon from the air is a serious problem, the fossils were studied a second time and the measurements repeated. Zinjanthropus was again determined to be nearly two million years old, plus the time, of course, that it took to repeat the tests.

Another check was made to confirm this time measurement using a different method called uranium fission-track dating. (Figure 3.) This process was used on uranium-bearing volcanic glass found at the site where the fossils were discovered. Based on this method, a determination was made of the ratio of the number of observed tracks (developed by etching the sample) resulting from natural fission of uranium-238 to those resulting from slow-neutron-induced fission of uranium-235 in a calibration experiment. Then, using the known ratio of uranium-235 to uranium-238 in nature, the age of the glass was computed to be essentially the same as the two-million-year-old fossils.

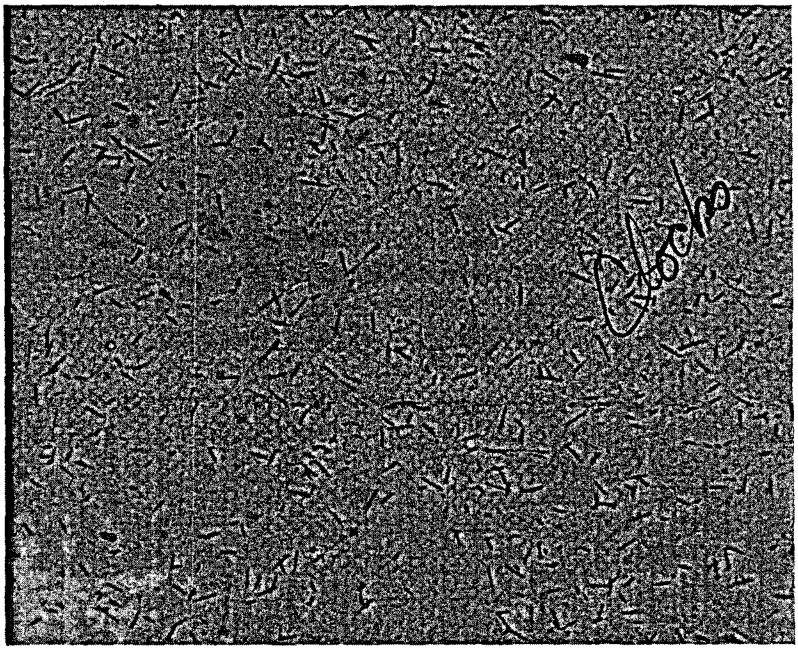


Figure 3. Tracks of uranium fission from a fossile antelope bone fragment from Hopefield, Cape Province, South Africa.

Two radioactive-dating techniques were used in combination to support the hypothesis that the continents of Africa and South America were at one time part of the same landmass and later drifted apart. Rocks of west Africa and eastern Brazil were dated, first by measuring the amount of strontium-87 formed in the radioactive decay of rubidium-87 in a total sample of rocks and then by measuring the argon-40 formed in the decay of potassium-40 in minerals separated from the rocks. The results delighted the proponents of continental drift because rocks 600 million years old found in Nigeria and rocks 2 billion years old on the coast of Ghana matched the age of rocks found in corresponding sections of Brazil if the two continents were placed together. In fact, as a result of these tests, the scientific investigators report that a small coastal fringe of northeast Brazil really belongs in a geological sense to west Africa.

More-recent applications of the radioactive-dating methods, including the potassium–argon and rubidium–strontium techniques, have been made in connection with the rock samples brought back from the moon by the Apollo 11 astronauts. The AEC provided most of the fundamental techniques for age analysis of these lunar samples, and analytical work was carried out at several of our laboratories.

When it comes to determining the age of the earth, another isotope dating method has achieved prominence. It is based on the determination of the amounts of certain stable lead isotopes—which have been formed by the decay of their long-lived uranium precursors and are called radiogenic lead isotopes—in comparison with the lead isotopes present at the time the solar system was created (called primordial lead). Because of the physical processes that occurred upon the cooling of the earth, it is not possible to obtain a good sample in the earth's crust of primordial lead essentially free of radiogenic lead; primordial lead would presumably be found in the earth's iron core, which is not accessible. Ingeniously, scientists theorized that most of the iron meteorites striking the earth are parts of the core of a disintegrated planet that was formed at the same time as the earth and that the lead isotopes present in these iron meteorites would be a very close approximation to the earth's primordial lead. Careful mass spectrometric analyses of the earth and meteorite lead samples, followed by some simple mathematics, indicate that the earth was created about 4.55 billion years ago. This figure has been confirmed in general by other procedures.

Thermoluminescence dating

Another time-measuring technique is the relatively new thermoluminescence method of dating ceramic materials. This technique dates the artifact itself rather than presumably associated materials that may or may not be closely contemporaneous. It depends largely on the uranium and thorium content in clays. Radiation from these elements bombards other substances in the clay and raises electrons to slightly unstable levels. When the clay is first fired in the kiln, each electron falls back to its stable position; this establishes the zero point on the time scale. Then much later, when a fragment of this ancient pottery is heated in the laboratory, the intensity of the photons of light (heat luminescence) emitted by the electrons as they fall back to their stable positions is representative of the accumulated radiation damage and hence of the time elapsed since the original firing of the pottery.

This technique has shown that some of the pots tested date back at least 8000 years, which is believed to be the beginning of pottery manufacture: The margin of error for pottery that old is plus or minus 300 years, but this range of uncertainty is expected to be reduced with continued development of the method.

Thermoluminescence dating has also been used on clay artifacts such as ancient Etruscan statues. Chemists at the University of Pennsylvania Museum, using this process, determined that one of their own treasures, the Etruscan Lady, was no lady in that her age was misrepresented. Tests proved that she was little more than 100 years old rather than the 2000 years claimed. A second figure tested, Diana the Huntress, owned by the St. Louis City Art Museum, was also found to be of modern origin. It is possible that both statues were made by a nineteenth-century Italian forger. The St. Louis case resulted in a lawsuit, which should be fair warning for future art dealers and collectors.

Cesium magnetometer

The more mechanical aspects of archaeology, such as excavation, also receive attention from those who develop isotopic applications. For example, a cesium magnetometer, used as a field instrument somewhat like a Geiger counter, can detect unusual archaeological remains located 20 feet underground. This highly sensitive instrument, originally designed for space research, is not strictly a nuclear device since it operates on the principle of the Zeeman effect in stable isotopes. It can measure changes in earth magnetism which would indicate the presence well below the surface of anomalous material such as tiles or bricks. If such irregularities are indicated on the magnetometer—and this instrument not only can detect but also can distinguish between stone, tile, brick, or glazed pottery—then drilling can take place in the designated area.

A cesium magnetometer was largely instrumental in finding the lost Greek city of Sybaris, buried for about 2500 years on the southern coast of what is now Italy. Sybaris, referred to many times in classical writings, was the richest and most decadent city of early Greece. First it was destroyed by war, and then, in the course of an earthquake, this ancient fun city, built literally as well as spiritually on sand, either slid into the sea or was inundated by coastal waters. Because most of the remains lie under the water level, recovery is very difficult, but the fact that the ancient city was detected under the waterline is an added technical accomplishment for this sensitive device. Use of an exploratory instrument such as this to locate ancient ruins should eliminate much of the unproductive digging that was carried out in the past. I understand that a similar instrument has been used to try to locate Camelot, the palace of King Arthur some 1400 to 1500 years ago. The search in South Sudbury, England, has not yet unearthed this legendary site.

Radioisotope X-ray fluorescence analysis

Radioisotope X-ray fluorescence analysis is being developed for a variety of industrial applications but also can be used with benefit by the archaeologist and art investigator. This technique detects the presence and measures the amount of a number of chemical elements in a specimen. It is based on the absorption of X-ray or gamma-ray photons by particular elements, followed by emission of X rays whose energies are characteristic of the elements present. Either an X-ray machine or radioisotopes can be used to generate the incident photons. Radioisotopes, however, offer the opportunity for use of portable equipment.

X-ray fluorescence has been used to analyze and identify the glazes of old ceramics and was used some years ago on the skull and jawbone of the Piltdown Man. You may recall that it contributed the final bits of information that established Piltdown as a complete fraud. This method provided proof that the brown coloration of the skull was not a result of prolonged staining by iron in the water, as originally claimed, but was the result of artificial treatment of the bones with chromic acid.

Neutron activation analysis

Another nuclear technique which has broad application in the humanities and related areas is neutron activation analysis. An important feature of this method is that the sample tested can be preserved in its original form and also that only a very minute sample need be tested. This technique involves, for example, taking a sample from an art object—it may be a pinpoint speck of paint from a painting, a tiny chip from an archaeological artifact, or an almost invisible streak from a coin or metal object—and exposing this sample to a flux of neutrons produced by a reactor, isotope source, or particle accelerator. Traces of various chemical elements can be identified and measured by analyzing the energy, intensity, and rate of decay of the radiation emitted by the radioisotopes produced by the neutron irradiation of these elements. Through use of appropriate nuclear radiation detection equipment and computer techniques, the elemental composition of the artifact is established, sometimes with interesting historical implications.

Neutron activation analysis of old coins is now carried out extensively to supplement numismatic studies of design, legends, mintmarks, dates, denominations, and weights. Some of this work is conducted through neutron irradiation in a reactor while other methods include the use of a plutonium–beryllium source of neutrons that is less intense but more portable than that available in a reactor. The isotope californium-252 may be an important source of such neutrons in the future. Knowledge of silver or gold content of ancient coins enables the historian who has no other records to go by to establish the time and extent of any debasement as well as reform of the coinage. These fluctuations in the money economy are considered one of the strongest indications of change—social, political, demographic, or environmental—in a medieval society. In other words, the economic historian expects to find that, in periods when the silver content of an early nation's coins was small, that nation was experiencing a famine or internal strife or was at war with another country.

At the University of Michigan work has been under way for several years to track down the source of the volcanic glass obsidian found in the prehistoric artifacts of the Hopewell Indians in the Great Lakes Region. Obsidian is not found geologically anywhere near that area the closest sources being 1500 miles away in Mexico, New Mexico, and the western United States. By irradiating obsidian samples from these various locations, Professor Adon Gordus found that the elemental composition of the Hopewell obsidian arrowheads was identical only to that of obsidian from a volcanic source in Yellowstone National Park. This evidence not only confirmed that contacts in prehistoric culture stretched over 1600 miles, but it also indicated a particular trade-route pattern that existed in this country more than 2000 years ago.

Most archeologists agree that the study of pottery and other ceramic objects is the most fruitful method of tracing trade routes and movements of ancient peoples. We talked briefly about pottery in connection with thermoluminescence; let me extend those remarks somewhat in connection with neutron activation analysis.

Ceramics were the major cooking utensils and containers for storage and and shipping in early civilizations. They were also a major and universal medium for artistic expression and for fashioning cult objects for religious and burial practices. It is no exaggeration to state that much of what is known about prehistory comes from the detailed study of evolutions of pottery styles unique to particular cultures. Seemingly, wherever people went, their pottery went with them so the tracing of dispersion of pottery styles has become the means for tracing migrations, conquests, trade, and other cultural contacts.

In the past archeologists have relied largely on physical characteristics to identify pottery and to deduce its place of origin. Now scientists have analyzed by neutron activation pottery fragments of the same physical appearance and have found in some cases that they have different chemical composition and therefore were produced from different clay sources. Tiny amounts of elements such as cesium, lanthanum, and cobalt can be sorted out to give pottery material its own peculiar chemical fingerprint. For example, if a potsherd found in Yucatan matched the chemical profile of pottery originating in Cuzco, Peru, it would give a more-detailed picture of ancient trade patterns than can be obtained from pottery markings and shapes. Pottery styles were not always unique to a particular location.

Professor Isadore Perlman and his staff at Lawrence Radiation Laboratory have worked out a system of analysis in which about 35 elements can be measured in neutron-irradiated pottery, most of them with very high accuarcy. Extremely sensitive radiation detection equipment is used to analyze the hundreds of gamma rays that appear when pottery is irradiated. Laboratory researchers are now engaged in the exacting task of establishing local pottery group profiles for a number of sites of archeological importance and from these of proving the origins of pottery no matter where it is excavated. One can visualize from this work a growing atlas of chemical pottery profiles that will serve as a handbook for anyone in the world applying similar methods to archeological problems.

The same systematic, analytic approach is being made in the neutron activation analysis of old paintings. The AEC is now in the midst of a three-year project with the National Gallery of Art which is being carried out by the Carnegie-Mellon University in Pittsburgh. This joint research effort is primarily concerned with analysis of various paints and materials used by particular artists or schools of artists and is aimed at resolving problems in art identification and authentication. Through neutron irradiation of paint specks from Van Gogh masterpieces, for example, it should be possible to compile a chemical profile or fingerprint of pigments that he used in his work and thereby establish a basis for authenticating or invalidating paintings represented as Van Goghs.

This research effort has become a little more complicated than originally anticipated because the early artist had a tendency to use various mixtures of whatever materials were available to achieve the color and texture he desired. Consequently, the chemical composition of certain paint materials used by the Renaissance artist is sometimes unusual enough to affect the credibility of a pigment analysis.

Neutron activation analysis is nevertheless a valuable nondestructive tool for the art investigator and is an effective method for exposing art forgeries. Since World War II there has been a growing trade in fake masterpieces, particularly of the French Impressionists. One critic has estimated that "Corot painted over 2000 pictures, and, of these, more than 5000 are in the United States."

Actually it has been quite difficult to pass off art work produced in the last 20 years as the genuine product of earlier artists. The increased amount of carbon-14 in the environment as a result of atmospheric nuclear tests has resulted in a higher concentration in linseed oil, which is produced from flax, or even in the paper or canvas on which the picture is painted. This increase in man-made radioactivity is large enough to be detected in relatively small samples taken from recent paintings and contrasts sharply with the minimal carbon-14 content in earlier paintings.

Activation analysis in crime detection

Since we are already discussing neutron activation analysis in the context of detecting art forgeries, let me branch out of the humanities just a bit to tell you how extensively this nuclear technique is used in scientific crime investigation.

Recent court decisions concerned with violations of individual rights have placed a new importance on the role of physical evidence in criminal investigations and prosecution. This emphasis has challenged the forensic scientist to obtain more information from the evidence submitted for analysis. Neutron activation analysis is now being used extensively to support evidence obtained by other means and in some cases to provide information not obtainable elsewhere. The AEC's Division of Isotopes Development works with law enforcement agencies in the Justice, Post Office, and Treasury Departments in developing evidence in criminal cases using this technique.

Physical evidence supplied by neutron activation analysis was first used in a court case by the Internal Revenue Service in 1964. Since then the IRS has employed this method in some 1500 criminal cases. The technique is being used to examine a large variety of substances including paint, soil, bullets, metal, putty, adhesive tape, paper, grease, hair, wire, and gunshot residue. Irradiation of samples is done in much the same way as if they were from art objects or pottery fragments, with the primary objective of determining elemental composition.

One great advantage of this method is the fact that samples too small to be examined by other methods can be effectively examined by neutron activation analysis. Often paint or metal samples barely visible to the naked eye can be analyzed and compared with the appropriate control sample. Another advantage is that in most cases the analysis can be carried out nondestructively, and the sample can be retained for court evidence or for examination by other techniques. The primary drawback is the need for a high-flux reactor and rather sophisiticated counting equipment.

The supersensitivity of activation analysis for measuring submicrogram quantities of barium and antimony has provided the basis for detecting gunshot residue deposited on the hand of an individual who has fired a revolver (Figure 4). This procedure is now replacing the nonspecific dermal nitrate or paraffin test, which has only limited acceptance in the courts. Activation analysis of gunshot residue also will indicate whether a hole in some material is a bullet hole and whether the hole was made from a gun fired at close or distant range. Considerable research has gone into neutron activation analysis as it applies to gun crimes, and the IRS has come up with a special field kit to be used by investigators at

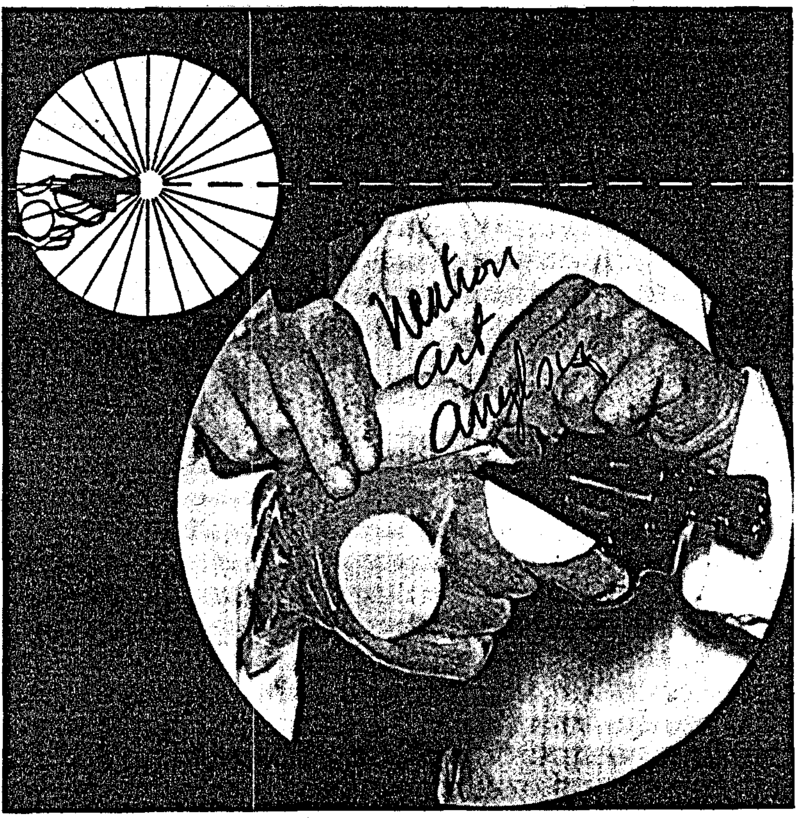


Figure 4. Activation analysis experiment to measure the distribution of gunpowder residues left on a "suspect's" hand after the firing of a revolver.

the scene of a crime. The equipment is simple and consists of a small compartmented polyethylene bag with several cotton swabs moistened with a chemical solution for collection of residue. The used swabs are returned to the original plastic bag and sealed for later analysis.

Neutron activation analysis of hair is an area of research that has grown considerably since the celebrated case a few years ago when this technique was used on a lock of hair reportedly taken from Napoleon's head immediately following his death. The hair contained 13 times as much arsenic as is normal for human hair. This, added to other symptoms of his final days, has raised an inference that the Emperor may have suffered from arsenic poisoning. Perhaps it only indicates his vanity, as some scientists have pointed out that a black hair dye used during that era also contained large amounts of arsenic.

Because of the inconclusive evidence in this case concerning Napoleon, it falls more into the category of historical speculation than ex post facto crime detection. The evidence in a recent crime case involving hair was more decisive. In this investigation hair samples were taken from the head of a man injured in a hit-and-run accident and matched with hair caught in the windshield wiper of a car owned by a primary suspect. It was a difficult case because hair taken from different parts of the same head may differ slightly in composition. Highly efficient analysis was required to remove the question of "reasonable doubt" from the jury's mind on identity of the hair in establishing the guilt of the suspect.

As you are aware, the illicit use and transport of drugs and narcotics has increased substantially in the last few years. Neutron activation analysis plays a part in the control of such traffic by determining the trace inorganic constituents of various drugs such as opiates, synthetic narcotics, marijuana, and barbituates. Marijuana samples, for example, can be successfully compared by establishing the elemental composition of the stems, seeds, leaves, and debris. From this information it can be determined where the marijuana was grown. Measurement of trace elements in heroin usually provides the identifying characteristics that can be used to determine whether heroin units seized at different times and locations are the products of the same illicit operation. This has been an important factor in a number of court cases.

Activation analysis has also been used to curb the distribution of illegally distilled spirits. Sometimes this is done by comparing chemical composition of bottled samples, but not always. In one case a man was convicted of operating an illegal distillery in Georgia, and the crucial evidence was based on the fact that mud samples from the defendant's truck, picked up in Brooklyn, N. Y., exactly matched other mud samples from a Georgia road leading to the still. Just as activation analysis can be used to identify ancient trade routes through comparison of pottery fragments and clay sources, it also can be used to identify modern trade routes in illicit goods.

Although activation analysis is a valuable tool in scientific crime detection, it should not be regarded as a forensic panacea. It is only one of several analytic techniques used to combat crime. Actual case work has shown that it works well in support of chemical analysis and microscopic examination and in that way can add points of identification and strengthen the overall evaluation of evidence. And, of course, the results of this precise analysis have frequently shown the innocence rather than guilt of the defendant.

Conclusion

In conclusion, of all the unusual circumstances where neutron activation analysis has been applied, I think identification of a so-called unidentified flying object ranks among the rarest. This involved the report of a flying disk that approached a beach in south Brazil at unbelievable speed. It was alleged then to have turned sharply and exploded, disintegrating into thousands of burning fragments, some of which were salvaged and sent to the Brazilian Agriculture Ministry. Analysis there reportedly showed the fragments to have magnesium of greater purity than human technology could produce, a report that could not help but stimulate unearthly speculation.

It was impossible to verify any relation between the magnesium fragments and a UFO sighting, but the claim of a high degree of purity could be checked by activation analysis. The work was carried out at the Internal Revenue Service Laboratory in Washington. Careful analysis showed that the fragments were really not as pure as claimed and that they did not differ significantly in magnesium content from other magnesium samples. The fragments did have a very high strontium content, and, although this was considered unusual, it was not sufficient basis for claiming unearthly composition. Analysis showed, therefore, that the fragments could not be used as valid evidence of the extraterrestrial origin of a vehicle. The project report concluded with the carefully worded statement: "Belief in the existence of such vehicles, if such belief is held, must rely on other arguments."

This was the case of the flying saucer shot down by neutron activation analysis. By its very nature, the case illustrates the idea that there seems to be no limit to the range of radioisotope and radiation techniques as they apply to various aspects of our lives.

Swords into plowshares

Nuclear explosives were born as weapons of war, and the destruction that can be wrought by nuclear weapons has been widely publicized. In recent years, however, a considerable amount of research has centered on using the vast energy from nuclear explosions for peaceful purposes. The constructive force offered by nuclear explosives is no less awe-inspiring than the destructive force of nuclear weapons. We visualize great canals to aid transportation or bring water to arid regions, harbors on forbidding coastlines, explosions deep underground to aid in recovery of natural resources, and explosions for scientific research to aid man's understanding of his own world and the universe. All these peaceful uses, involving nuclear explosions detonated underground, are currently being studied in the AEC's Plowshare program.

The energy source

The energy for a nuclear explosion comes from within the nucleus of the atom by two different reactions, the fission or splitting of heavy nuclei and the fusion or combining of light nuclei. Each of these two nuclear reactions involves less than a millionth the weight of the materials required in the chemical reactions of more conventional explosives. For example, the complete nuclear fission of 56 grams of fissionable material releases the same amount of energy as the chemical explosion of 1,000 tons of TNT.

Uranium-233, uranium-235, and plutonium-239 are the only nuclear fuels which can be produced in quantity that will also spontaneously fission to sustain and propagate a nuclear chain reaction to release the atom's energy. These fuels are very expensive because of the effort required to obtain them in a pure enough form to be an efficient fuel. Fortunately, however, their expense can be considerably offset by combining the fission reaction with the much cheaper fusion reaction.

There are a number of reactions involving the fusion of light nuclei to release energy. Lithium and the two heavy isotopes of hydrogen, deuterium and tritium, are the fuels of greatest interest. Temperatures of several million degrees are required to initiate the fusion reactions, however, hence the name "thermonuclear" reaction. Presently, thermonuclear explosives use the fission reaction to produce temperatures high enough to start the fusion reaction. The relatively low cost of thermonuclear fuels enables the yield of an explosive to be increased one hundredfold, from 10 kilotons* to 1 megaton,† at less than double an increase in cost.

The nuclear explosion

Nuclear explosions are characterized by the extremely high temperatures and pressures associated with a nearly instantaneous release of large quantities of energy. The temperatures are so extreme that all materials subjected to them have the properties of an ideal gas consisting of electrons and positive ions. These gases at high temperature and pressure expand rapidly giving rise to a pressure, or shock, wave in the surrounding medium, for example, the surrounding rock in underground explosions. In an underground explosion the gas continues to expand until the pressure is balanced by the weight and strength of the overlying rock or until the ground surface is broken.

Nuclear excavation

Figure 1 illustrates the cross section of a typical nuclear crater and defines some necessary terms. Figure 2 illustrates the effect of the depth at which the explosive is buried upon the crater's size and shape. Maximum crater dimensions result if the nuclear explosive is buried at the optimum depth, as indicated.

A nuclear-explosive detonated at the ground surface will form a crater primarily by compaction and plastic deformation of the local material as a result of the high pressures previously described. This is a very inefficient way to use the energy released for excavation since most of the energy dissipates to the atmosphere in the form of radiant energy and blast. The radioactivity produced in the explosion is also almost entirely released into the atmosphere.

**An energy equivalent to 10,000 tons of TNT.*
†An energy equivalent to one million tons of TNT.

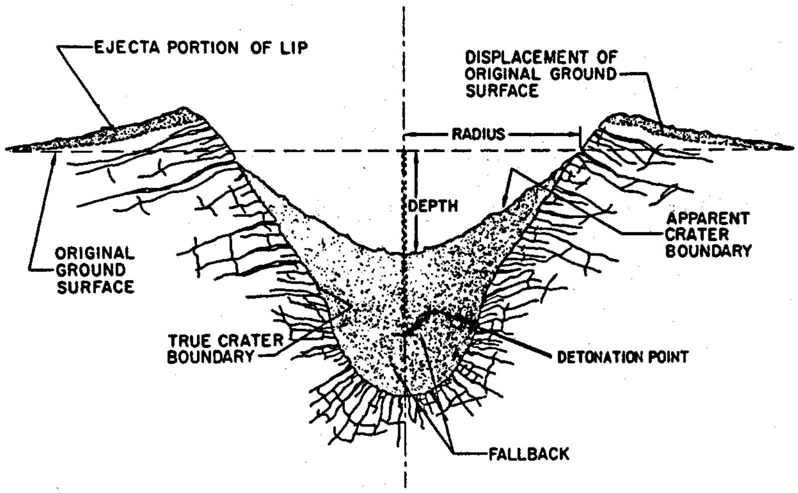
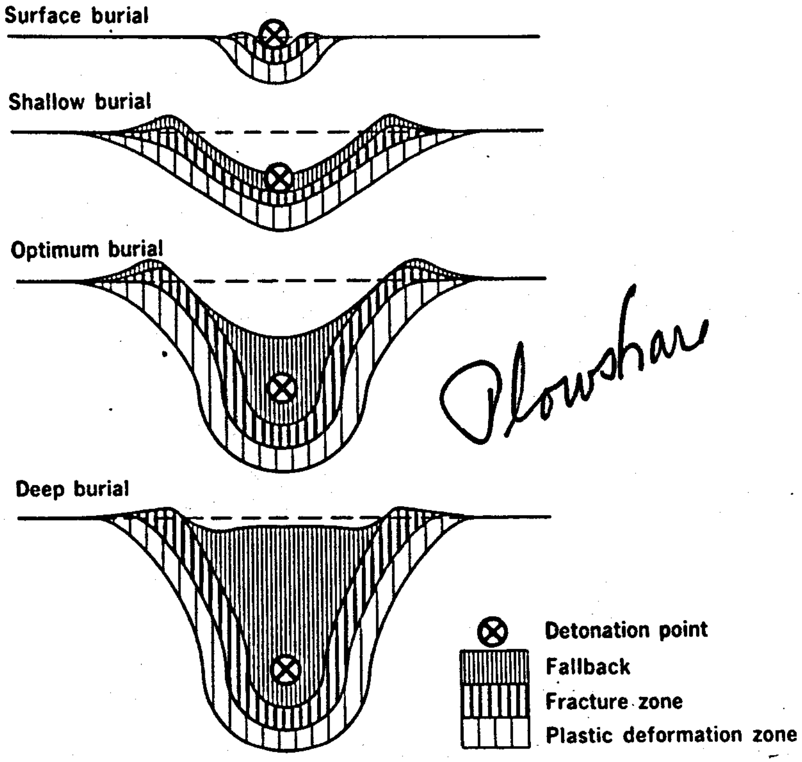


Figure 1. A typical nuclear crater.

In crater formation from a nuclear explosive detonated at the optimum depth, the shock wave and pressure initially fracture the overlying rock and set it in motion, as illustrated in A of Figure 3. The rapidly expanding cavity pushes against this rock and bulges the ground surface upward. In C and D, as the cavity continues to expand, cracks and fissures open through the surface allowing escape of the high-pressure gas. In D about half of the material originally above the explosion is thrown out to the crater sides. The remainder does not reach a high enough velocity to clear the crater and falls back into the cavity.

The series of photographs shown in Figure 3 record the 100-kiloton SEDAN explosion at 635 feet below ground. As shown, the desert bulged up 290 feet before the explosion broke out. Some 12 million tons of rock and earth was flung up by the explosion, and over 8 million tons fell outside the crater. When the rock and dust had settled, a crater 1,200 feet across and 320 feet deep remained. This was the largest excavation ever produced by a single man-made explosion.

Our experience with nuclear cratering has been limited. A large number of physical processes take place concurrently and successively in a nuclear excavation explosion, and these processes proceed almost instantaneously. Therefore measurements are very difficult; there is little wonder that nuclear cratering has not yet advanced to the state



Plowshare

Figure 2. Effect of explosion depth.

of a precise technology. Computer calculations based on experience in the U. S. Plowshare program, however, are becoming increasingly accurate in describing the explosion and predicting the crater dimensions. For example, in one experiment U. S. scientists simultaneously detonated five 1-kiloton nuclear explosives to see if a linear crater with a smooth bottom and even sides could be produced. This was the first such experiment carried out by the United States using nuclear explosives, and information processed by computers was used to determine how deep the explosives should be buried. The experiment was entirely successful, producing a ditchlike crater of the type needed for digging canals or roadways through mountains (Figure 4).

Radioactivity from cratering explosions

In a nuclear explosion radioactivities are produced in varying but predictable amounts. In the U. S. Plowshare program, thermonuclear explosives, relying mostly on the cleaner fusion reaction and producing relatively little radioactivity, are being developed for nuclear excavation. During cratering with these explosives, some of the radioactivity condenses in the split second before a crater forms and is trapped in a puddle of glass below the point of the explosion. Most of the remaining radioactivity filters out of the gases as they escape through the overlying material and is buried in this material in and nearby the crater. A small portion of the radioactivity produced is injected into a dust cloud, becoming attached to the dust particles and falling to earth under the influence of gravity during the first few hours after the explosion as the wind moves the cloud away from the crater. An exceedingly small portion of the radioactivity remains airborne for a longer period, becoming so widely dispersed by the wind and decreased by radioactive decay that it is practically undetectable after a few tens of hours.

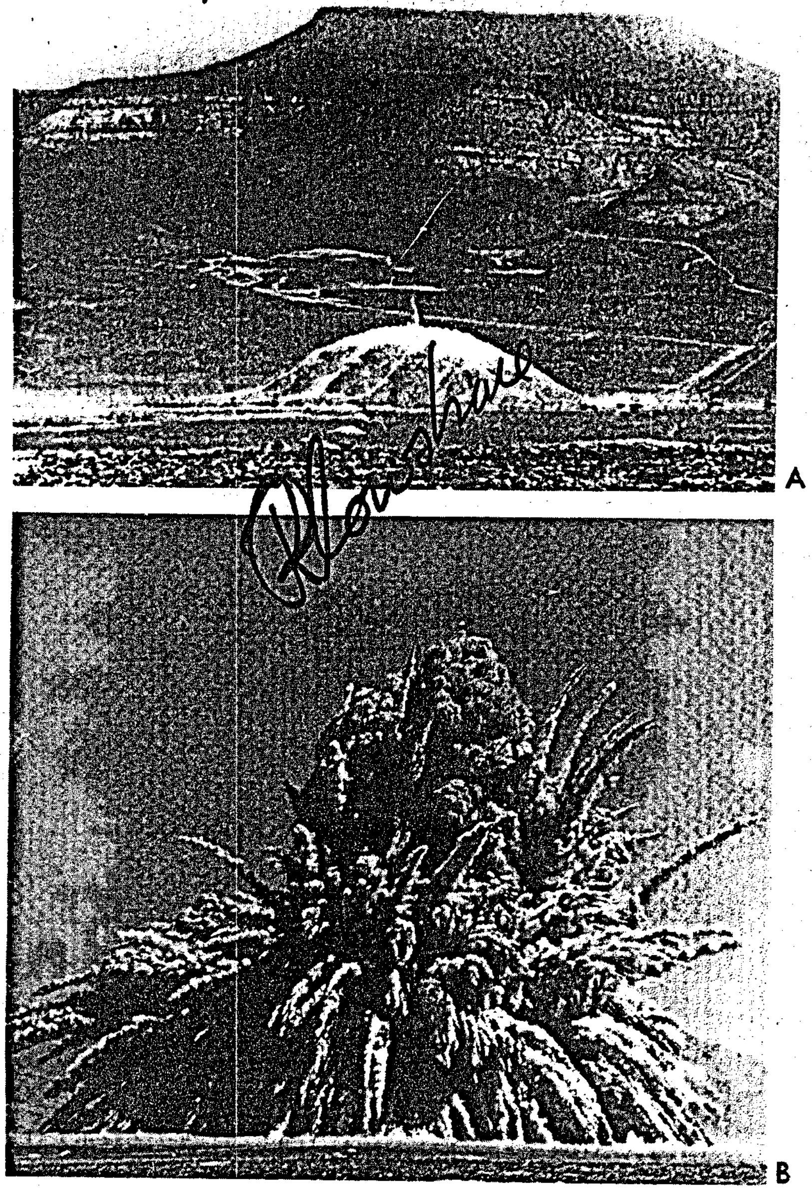
Advantages and disadvantages of nuclear excavation

Cost is a major consideration in any excavation project. As a large energy source, nuclear explosives are unrivaled for economy. A 2-megaton nuclear explosive might be 100 times cheaper on a cost per ton basis than the equivalent yield of TNT.

Comparative energy costs

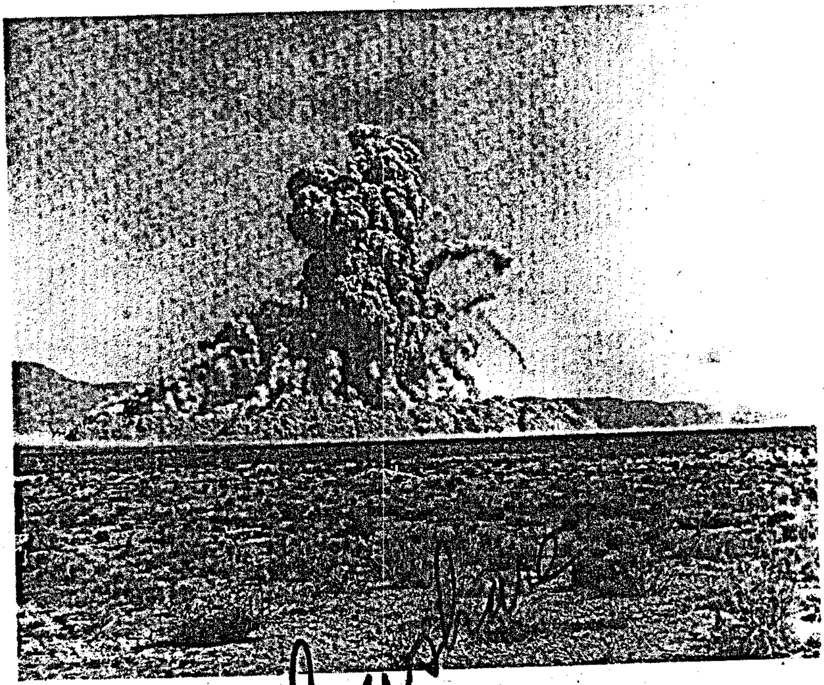
Energy source	Cost per million (10^6) Btu
2-megaton thermonuclear explosive	$ 0.075
Lignite	0.14 to 0.17
Soft coal	0.15 to 0.20
Natural gas	0.20 to 0.15
Water power	0.89
Gasoline	1.50
Electricity ($0.006/kwh)	1.78
Ammonium nitrate	4.50
10-kiloton thermonuclear explosive	8.75
TNT	250.00

Unit costs for nuclear explosives increase with decreasing yield, but, in the energy range as small as several kilotons, they still enjoy a significant economic advantage in comparison to chemical explosives.



Plowshare

Figure 3. Crater formation from a nuclear explosion.



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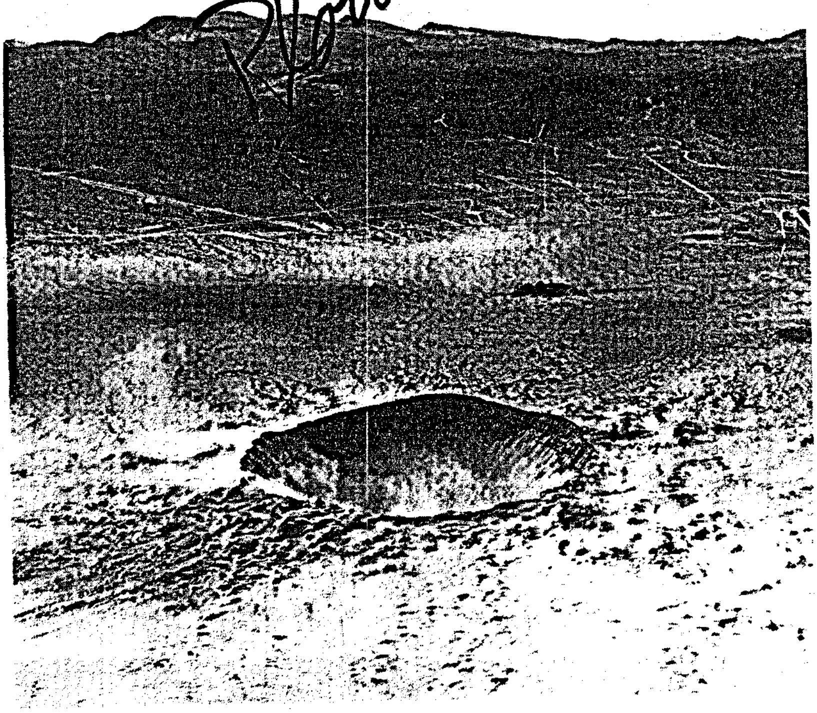

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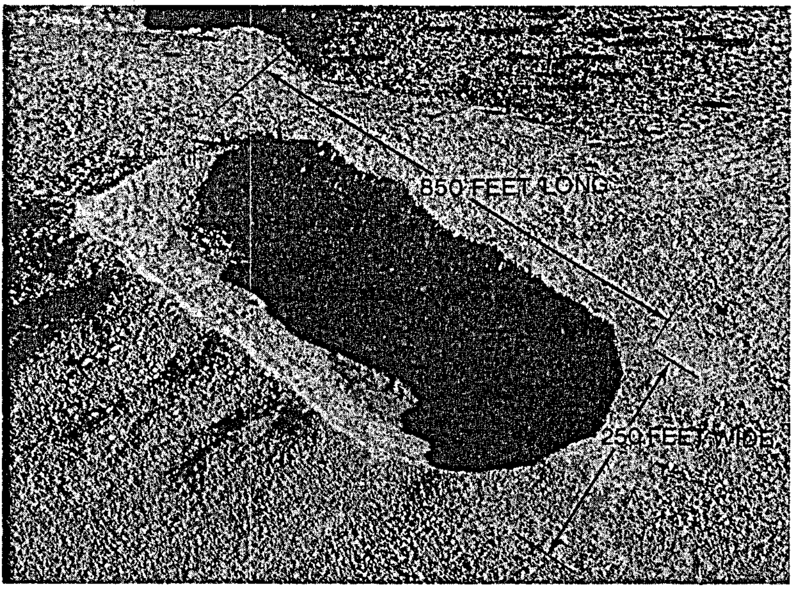


Figure 4. Ditchlike crater.

The compactness of nuclear explosives is an indirect economic advantage. A 2-megaton nuclear explosive can be emplaced in a drilled hole a little over 1 meter in diameter and would weigh perhaps a few thousand kilograms. An equivalent energy yield from chemical explosives would require enough material to fill a volume of several thousand cubic meters and would weigh two million tons. The consequent production, logistics, and emplacement construction involve unimaginable problems.

On construction projects large enough to consider nuclear excavation, the same excavation by conventional means would require, in addition to chemical explosives, their combination with various earth-digging and earth-moving machinery. So any valid cost comparisons must contrast the most efficient conventional means with nuclear excavation techniques or must consider a combination of both techniques. In general, nuclear explosives could probably compete where they could be used in yields equivalent to several kilotons of TNT or more.

Many safety considerations are involved in nuclear excavations. Of most importance, exposure of people to the radioactivity must be controlled so that no one receives any hazardous amount. This requires an explosion area at least temporarily uninhabited and requires selection of detonation times when wind conditions will direct the radioactivity into this controlled area. Under these conditions the radioactivity problem is manageable.

The radioactivity escaping from a nuclear excavation depends both on the total amount produced by the explosion and the fraction that escapes into the atmosphere. In the illustration of radiation patterns from fallout (Figure 5), the diagram on the left shows the pattern observed in 1962 from the 100-kiloton SEDAN experiment. Explosives development and improvements in emplacement techniques are expected to reduce the radioactivity released from nuclear excavations

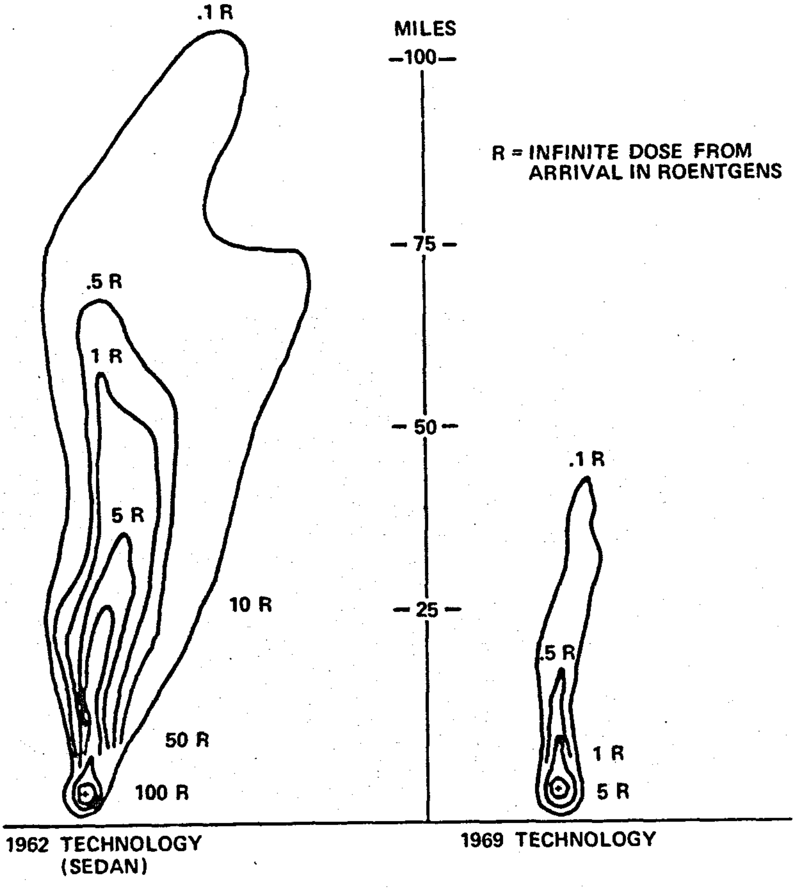


Figure 5. Reduction of radiation resulting from 100-kiloton nuclear cratering detonations in alluvium.

to the amounts shown in the right-hand drawing. The amount of radioactivity released is relatively independent of the explosion size. These fallout patterns indicated the dose of external gamma radiation a person living outdoors for a lifetime could receive at the specified distances from the excavation. For comparison, the average external gamma dose that a person in the United States receives from natural sources of radiation is about 0.1 roentgen per year.

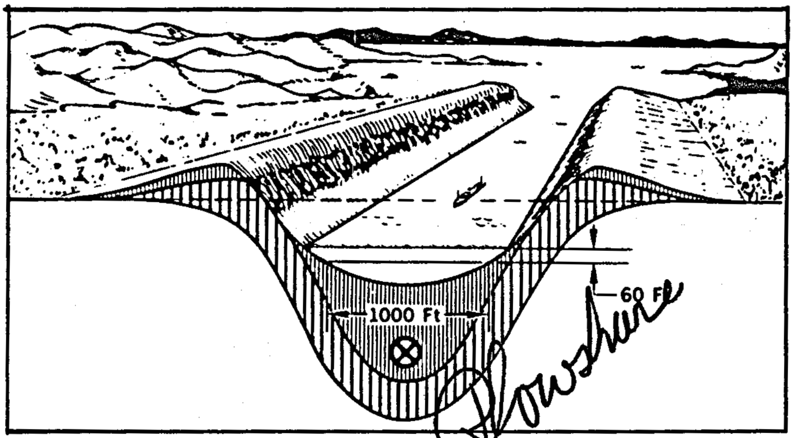
Two other safety hazards in cratering explosions are the seismic shock and the characteristic acoustic wave. Projects must be located some distance from built-up areas to avoid structural damage from seismic motion. The acoustic wave is an *air blast* that can cause structural damage close to the explosion and sometimes more distantly when the acoustic waves become focused by atmospheric conditions.

Radioactivity, seismic shock, and acoustic waves tend to limit applications of peaceful nuclear explosions, but, fortunately, as will be noted next, construction projects suited best for nuclear excavation tend to be located naturally in sparsely populated areas.

Excavation applications

Geography has often tantalized man by forcing him to travel long sea routes because he was cut off from his destination by a narrow ribbon of intervening land such as the Isthmus of Panama or the Isthmus of Suez. The first breaching of one of these major obstacles, the Suez Canal, required 10 years to build not quite 100 years ago. The Panama Canal also required 10 years to build, excluding a 9-year false start, and was opened about 50 years ago. The Panama Canal required a complex lock system and was the engineering marvel of its time, but, in the 54 years since it opened, the Panama Canal has become inadequate. Many ships are now too large for the locks, and ship traffic exceeds the capacity of the canal. Ships are often delayed, waiting their turn to make the tedious single-lane crossing through the locks. A sea-level canal with no locks, wide and deep enough to permit two-way traffic for the largest ships across the American isthmus, would solve the problem. Such a solution may be possible with peaceful nuclear explosions. Preliminary studies indicate that such a gigantic construction project might be completed in possibly three-years construction time at a cost possibly less than one billion dollars.

Certainly the number of such grand canals to connect oceans is limited, but one need only look at a map to envision numerous possible



Plowshare

Figure 6. Canal dug by nuclear explosives.

examples of canals connecting two navigable rivers to broaden inland waterway transportation systems (Figure 6).

Similarly, water might be transported from a water-rich region to an area of dry wasteland in canals constructed with peaceful nuclear explosions. Also, some arid areas of the world are dry only because there is no way to retain the rainfall. Large lined craters formed by peaceful nuclear explosions could retain this water as needed for irrigation. In other water-poor areas, rainfall quickly runs off as surface water. Dams might be constructed by nuclear explosions in several ways. The lip of the crater itself could serve as the dam, a part of a canyon wall could be blasted onto the canyon floor, or a mountainside could be collapsed into a valley (Figure 7). Even in conventional dam construction, nuclear explosives, deeply buried at a conventional site, could break rock.

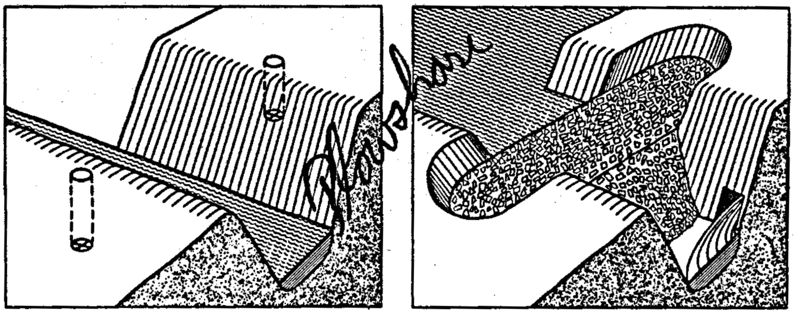


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Figure 7. Dam from a mountainside collapsed into a valley.

The deprived nature of many lands that would benefit most from nuclear excavations causes them to be uninhabited; so explosions should be safely possible. The results of these massive excavations could so enhance the area that populations might move in and efficiently use this previously uninhabitable land. Rich natural resources remain relatively untouched in many areas of the world because of the high costs of transportation to market. Peaceful nuclear explosions could create harbors for ocean shipping to solve this transportation problem.

These represent just a few of the general ways in which nuclear explosions might greatly benefit mankind by performing the massive excavations required in different kinds of large construction projects. They require careful planning and the utmost attention to public safety, but such explosions are manageable, can be safely conducted, may offer economic advantages, and can be put to work for man.

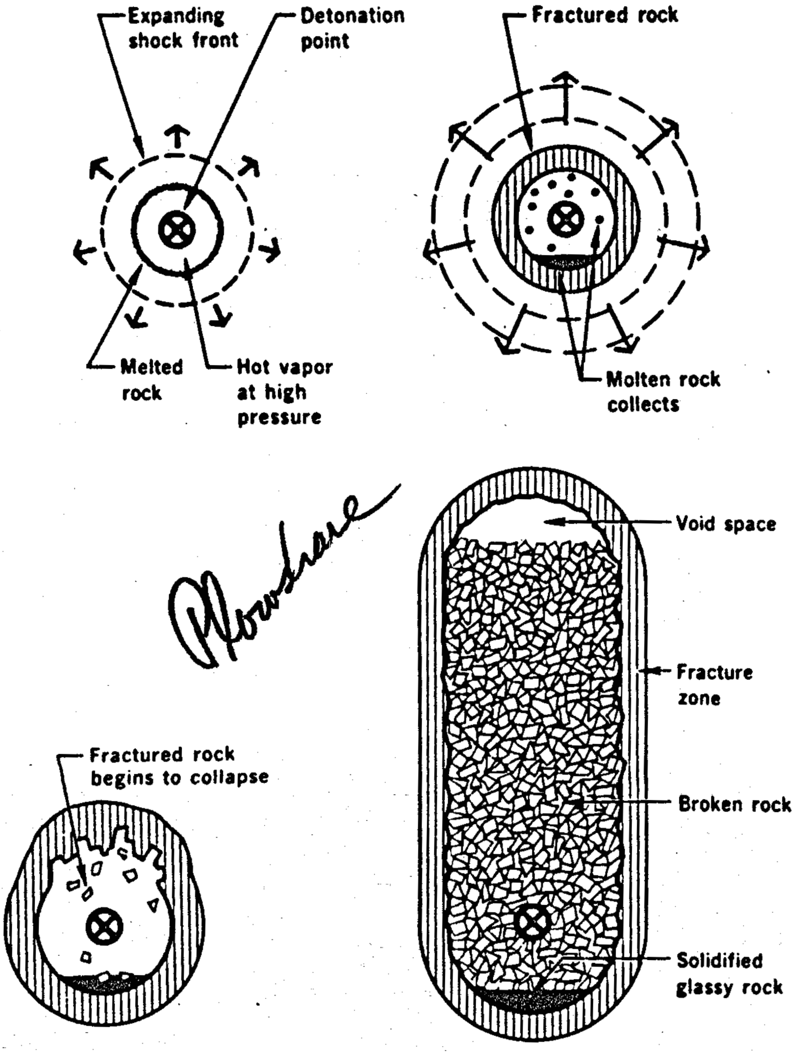
Underground engineering

Excavation, however, is just one possible peaceful use for nuclear explosions. Equally important are the various benefits envisioned for nuclear explosions deep underground.

If a nuclear explosive is emplaced far enough underground, the blast does not break the earth's surface. The following summarizes the sequence of events following the detonation of a 100-kiloton device buried at a depth of 900 meters; this is illustrated in Figure 8.

The total energy releases in less than one millionth of a second following the detonation. A strong spherical shock front moves outward, vaporizing, melting, crushing, displacing, and cracking the rock. Most of the energy of the shock wave deposits locally in the form of heat and as work on the surrounding rock. The rock vaporized by the shock wave expands as a gas bubble, forming a cavity that grows until the gas pressure approximately balances the overlying rock pressure. Cavity growth stops at a radius of about 45 meters. At this time the cavity is lined with about 60,000 metric tons of molten rock, and the cavity gas temperature has risen a few thousand degrees centigrade.

The cavity may persist for a while as vapors condense, temperatures and pressures drop, and a molten puddle collects at the cavity base. Then under most circumstances the roof of the cavity collapses to form a nearly cylindrical chimney of broken rock.



Plowshare

Figure 8. Chimney formation phases.

A hemispherical cavity forms at the chimney top, as typically illustrated by the GNOME explosion of 3.1 kilotons detonated 1,200 feet beneath the ground. The cavity is about 75 feet high and 134 to 196 feet across. In Figure 9 note the man standing on rubble, right center.

The rock outside the cavity—chimney region contains a zone with many cracks and fractures. These rock failures generally mean enhanced permeability for a distance away 2 to 4 times the cavity radius, a valuable effect for certain purposes.

Figure 9. Hemispherical cavity at chimney top.

Development and storage of petroleum resources

Deep underground nuclear explosions could enable the production of liquid or gaseous hydrocarbons from nonproductive deposits of petroleum, natural gas, and oil shale. Also, oil or natural gas could be stored in void spaces within the nuclear chimney formed by such explosions. These two types of potential applications of deep underground nuclear explosions are now being considered.

Stimulation of natural gas formations

Nitroglycerin detonated in certain natural gas wells, a practice today, stimulates their production. We expect the increased rock shattering effect of contained nuclear explosions to be much more effective, when the thickness, depth, and nature of the formations permit their use. Unless this technique or similar significant technological progress in production points the way, much of the world's natural gas may never be recovered.

In Project Gasbuggy an underground nuclear explosive was detonated to stimulate production and increase ultimate recovery of natural gas from a gas-bearing geologic formation of low productivity. This was the first joint government–industry experiment in the AEC's Plowshare program to develop peaceful applications for nuclear explosives. A nuclear explosive with a yield of about 26 kilotons was lowered 4,200 feet through a 47-cm-diameter casing and was detonated in a remote area of the San Juan Basin in northwestern New Mexico on Dec. 10, 1967.

Single detonations of 950 to 2,400 liters of nitroglycerin were formerly used in the San Juan Basin to stimulate gas-well production. By comparison, the Project Gasbuggy explosion equalled the energy of about 12 million liters of nitroglycerin. At the Project Gasbuggy site, gas recovery with conventional stimulation might, after 20 years of production, be 10% of the gas originally there. However, the gas recovery with stimulation by a nuclear explosion, after 20 years of production, should be as much as 70% of the gas originally there, a sevenfold increase over conventional stimulation.

A second experiment, Project Rulison, is currently underway near Rifle, Colo. The nuclear explosion for this experiment, on Sept. 10, 1969, equalled 40,000 tons of TNT and was 8,000 ft below the surface. The increased gas pressure at the wellhead indicates that the gas yield will be substantially increased.

Stimulation of oil reservoirs

As in gas stimulation, the major effect of a nuclear explosion in an oil reservoir would be to increase the effective well-bore diameter by creating a chimney and a region of increased permeability. Also, the chimney region would serve as an underground storage tank for periods of peak demand.

Oil reservoir stimulation may be more attractive economically than natural gas stimulation because, for equal reservoir volumes, the value of oil may be 3 to 4 times greater than that of gas.

Production of shale oil

Oil shale is a fine-grained calcareous rock containing a solid hydrocarbon called kerogen. When heated above 350°C, kerogen decomposes into various gaseous and liquid hydrocarbons and a carbonaceous residue. For more than a century retorting—heating—has been used to produce oil from oil shale. Today only in the Soviet Union and China is shale oil produced commercially, and there only in small quantities.

Oil shale could be broken up in-place by means of nuclear explosions to create a chimney of fragments of oil shale surrounded by the relatively impermeable shale. This chimney could then be retorted in-place, liberating the shale oil. However, the techniques for in situ retorting have not yet been developed.

Underground nuclear explosions to extract the oil would avoid bringing the shale to the surface. This would minimize disturbance of the natural landscape and should also avoid water pollution and ash disposal problems associated with aboveground methods. Success in this method could lead to the recovery of an oil reserve with a value some have estimated as high as $3 or $4 trillion.

Storage of natural gas in nuclear chimneys

Natural gas fields are often located far from the large consumer markets. Natural gas from these remote fields, if used, must be transported to market by tankships or in long-distance high-pressure pipelines. Under these circumstances considerable effort has usually been expended to accumulate storage facilities near the consumer area to meet peak demands during cold weather.

The major form of gas storage has always been underground in depleted gas or oil fields, but such fields available for storage are growing scarce. The possibility of storing natural gas in the porous and the impermeable rock of nuclear chimneys is now being seriously considered.

Development of mineral resources

Deep underground nuclear explosions for extracting minerals fall into two main categories, in situ leaching of suitable ore bodies and removal of the broken ore by block caving. These methods have greatest potential in large, massive, regularly shaped ore bodies too deeply buried for open-pit mining.

The copper in many large low-grade and small high-grade deposits cannot be recovered economically by conventional methods because recovery cost exceeds the value of the copper in the deposits. The large low-grade deposits are suitable projects for nuclear fracturing. Fracturing of such deposits with a nuclear explosive would permit circulation of dissolving solutions through the rock and recovery of the copper at a cost estimated to be lower than by conventional methods which require mining, concentrating, smelting, and refining. This technique could double the U. S. copper supply.

Still another concept for underground nuclear explosions, from a group of coal engineers, is to gasify thick beds of low-grade coal in a 100-square-mile area of Wyoming.

Development and management of water resources

The rubble-filled chimney formed by a nuclear explosion might help develop and manage groundwater. The voids within the chimney would provide storage space for water equivalent to about 3 million gallons per kiloton of explosive yield. This space, if formed in rocks of low porosity and permeability, could store water in areas of special need, such as arid or permafrost regions and certain ocean islands. This would avoid the loss of water by evaporation which occurs in surface reservoirs. Similar nuclear chimneys could also serve as reservoirs to dispose of various types of liquid waste.

Because a rubble chimney is extremely permeable, it might also be located to create a conduit between aquifers (Figure 10). In addition, a rubble chimney might also breach partitions of a compartmented aquifer system or act as a well of very large diameter. In these applications, the purpose would be to increase the potential yield of a naturally occurring aquifer system.

Scientific applications

In addition to the possible uses of nuclear explosives for various excavation and deep underground purposes the nuclear explosion has become a unique research tool that provides an extremely intense source of heat, pressure, electromagnetic radiation, radioactive isotopes, plasmas, neutrons, and subatomic particles—undoubtedly some of which are, as yet, undiscovered—a source that is far beyond the reach of the conventional scientific laboratory.

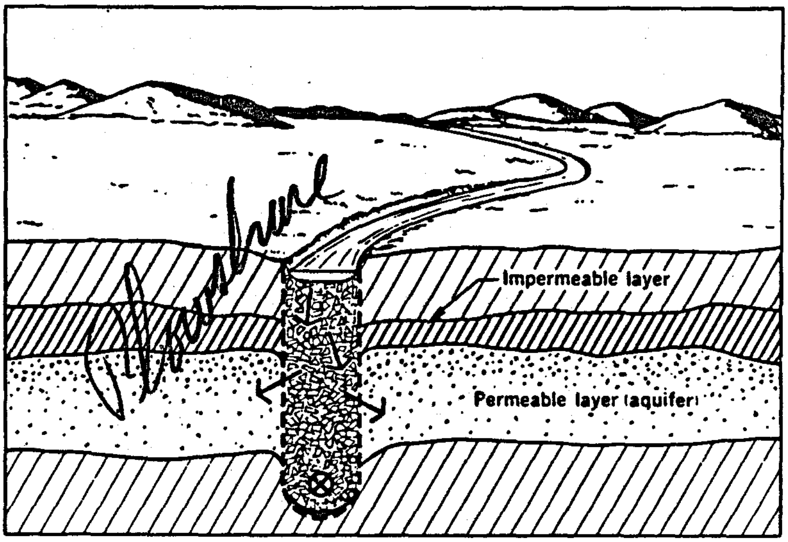


Figure 10. Nuclear explosion used to break through a barrier to permit run-off water to be used to recharge underground aquifers.

Ideas and schemes for scientific research are many and varied. No one could hope to list all the possible scientific applications of nuclear explosions, but the following examples are the more widely known.

In recent years man has succeeded in creating at least 11 elements heavier than uranium, the heaviest naturally occurring element. In fact, one of the most important nuclear fuels, ^{239}Pu, is artificially produced. The major portion of the isotopes of these transuranium elements have been produced by nuclear reactor irradiations and charged particles, including heavy-ion bombardment. However, two of the elements, einsteinium and fermium, were discovered in the products of the world's first thermonuclear explosion in 1952. These elements were formed by successive neutron capture in the parent uranium atom.

Heavy isotope production in a nuclear reactor follows the capture—decay—capture chain, whereas the target nuclei in the nuclear explosion successively absorb up to 18 or more neutrons almost instantaneously, becoming neutron rich. These nuclei subsequently decay to elements of higher atomic number by beta particle emission. Thus, despite the fact that ultraheavy isotopes become increasingly unstable and have exceedingly short half-lives as their mass numbers increase, the possibility exists that the intense neutron flux from a nuclear explosion could be used to produce very heavy elements in sufficient quantities to study their chemical characteristics. At the same time, the isotopes could be studied with very high beta-decay energies. The difficulty, of course, is in recovering the neutron-irradiated material quickly enough from the underground explosion site to study the material before the rapidly decaying isotopes disappear.

Other physics experiments that appear attractive as subjects for research with nuclear explosions include neutron capture reactions; neutron—neutron scattering; small angle scattering, such as the possible interaction between neutrons and electrons; and neutrino—electron interactions.

In another field of scientific inquiry, the seismic signal from an underground nuclear explosion can aid man's understanding of the composition of the earth. A nuclear explosion providing a source of known seismic-wave strength can be precisely located in the area of interest and can be detonated at a precise and previously agreed upon time. By using nuclear explosions seismologists have already increased their precision in the knowledge of seismic-wave propagation through the earth.

Much is yet to be learned about nuclear explosions, and, conversely, much is yet to be learned about far-ranging fields and disciplines by using nuclear explosions. The technology and understanding of peaceful nuclear explosions has, however, advanced to the state where they can be safely, efficiently, and beneficially used for earth moving, for recovering natural resources, and as research tools for man's understanding of his environment.

The nonproliferation treaty

As of Apr. 10, 1970, the Treaty on the Nonproliferation of Nuclear Weapons had been signed by 97 governments, including the United States, the United Kingdom, and the USSR.

The negotiations showed the world's interest in nuclear explosions for peaceful purposes. The participating countries recognized early in their negotiations the inescapable technological fact that a nuclear explosive device intended for peaceful purposes could also be used as a weapon. Any nation able to make nuclear explosive devices for peaceful purposes would also be able to make nuclear weapons. Therefore, in the treaty's provisions, states having no nuclear weapons were prohibited from manufacturing or acquiring, not only nuclear weapons, but also nuclear explosive devices intended for peaceful projects.

However, the negotiating nations saw that these states could not equitably be denied the full benefits of nuclear explosions for peaceful purposes, although they are prohibited from acquiring or manufacturing nuclear explosive devices. So the United States and the USSR agreed to furnish peaceful nuclear explosion services to requesting parties to the treaty at the lowest possible cost and under conditions consistent with the nonproliferation principle. The cost would exclude charges for research and development.

The treaty terms further specified that the potential benefits from any peaceful applications would become available to these states on a nondiscriminatory basis either through an appropriate international body, such as the International Atomic Energy Agency in Vienna, or through bilateral agreements. To assure the ready availability of these services through the international body, negotiations will begin promptly after the treaty enters into force. The services will be subject to international observation, whether obtained through the international body or through bilateral arrangement, and the nuclear explosive devices will remain in the custody and control of the nuclear-weapon state supplying the service.

The United States has long practiced sharing with the world the results of its research and development program on the peaceful applications of nuclear explosions. We do this by publishing hundreds of detailed technical reports on this subject, and it is our intention to continue this. The United States is also willing to become a principal supplier of peaceful nuclear explosion services under the treaty terms.

The U. S. representatives on several occasions during the negotiations emphasized that the United States anticipates no scarcity of the nuclear explosive devices for these services once the technology of nuclear explosions for peaceful purposes has been developed. They also emphasized that the United States would not charge other countries more than it charges its own domestic users of peaceful nuclear explosives. Moreover, we have underscored our intention to continue pursuing a vigorous research and development program in this area and to continue our policy of sharing the results with other countries.

Peaceful nuclear explosions will certainly contribute importantly in many fields in the years ahead. The benefits of this technology—now accessible to only a few nations—will also certainly be widely available to many other countries as a consequence of the nonproliferation treaty.

Man and the atom—by the year 2000[*]

When it comes to speaking about the atom in the year 2000, I am not in as bad a position as it might seem, mainly because of three things. First, although we have never seen the nucleus of the atom, we have seen what it can do—both destructively and constructively, and we know also of its ever-growing potential for peaceful uses. Second, the year 2000 is not that far off. (To some it is already too uncomfortably close to be a visionary future.) And, finally, I am not going to confine myself to the state of affairs in the year 2000. Even though everyone seems to be talking about that year, we are not going to be able to fall asleep like some modern-day Rip Van Winkle and wake up in a utopian or nightmarish (take your choice) age three decades from now.

We are already very much involved in making that age, and the next thirty years will see us engaged in what may be the most crucial struggle of mankind's existence—the struggle to prove that one "mankind" as a physical entity and not just as a glorious idea can be created and can survive. In this sense I am talking about mankind as a global civilization—men and nations not only coexisting with each other and with nature but essentially living and acting as an organic whole. This is more than a utopian dream. *It is the new imperative,* the goal toward which we must all move. Though each may phrase it somewhat differently, this seems to be the consensus of most of the thoughtful philosophers, scientists, and educators speaking, writing, and thinking today. There seem to be few if any viable alternatives to moving in this direction.

I do not wish to sound like the voice of doom, but I would not fulfill my obligation as the final speaker at this convocation if I did not stress this point and if I did not emphasize the responsibility involved in our near-term future—the importance of the vital day-to-day decisions and

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[*] *Remarks at the Edward T. T. Williams Memorial Convocation, Fairleigh Dickinson University, Teaneck, N. J., Mar. 7, 1968.*

work in each coming year—in forging the long-term future that so many are discussing and projecting today.

In spite of the tension and turmoil so apparent in the world today—just reading the daily newspaper is enough to give one a headache—in spite of this, there are some hopeful signs that we are doing some of the right things and moving in the right direction.

If the first step in dealing with a problem is the recognition of that problem, then certainly we are well on our way toward meeting some of the major challenges ahead. Today we view with growing concern the assault on our environment, the pollution of our atmosphere and our waterways to an intolerable degree. We are now painfully aware that most of that pollution originates from the same technologies that give us our products and power and that, if we are to enjoy the blessings of the latter without being plagued by the former, we must make certain adjustments and pay some price for them. (Though not everyone is yet convinced that he must share the cost of clean air and clean water.)

I think we are also being forced today to realize that our general affluence and rising Gross National Product bring with them new responsibilities we must accept. We are facing, domestically and internationally, social and humanitarian problems of unprecedented proportions. Because of the events of the day, we are undergoing some serious soul-searching and perhaps developing a new national conscience that could help guide us more successfully in the future.

We are not only realizing the extent of our problems today; we are and have been doing things about them. Sometimes I think it is unfortunate that our newspapers, magazines, and TV and radio networks do not emphasize more of the *good* news of the day, the positive and promising things that are going on, and the programs that are making progress. Such things are happening, and, if occasionally more light was shed on some of the things that are right with America and on its attributes and successful programs, many of us might take a healthier, more positive approach to improving ourselves and suffer less from the despair and frustration abounding today.

In education we have increased by several millions the number of undergraduates attending college today. Our health programs and our medical research continue to grow and improve, with more and better care becoming available to more people and more health problems being solved. We know we have a long way to go in eliminating poverty and bringing more of the good things this country can offer to all people, but this does not negate the fact that we are experiencing continued economic growth; employment is increasing; personal income is rising; and millions more Americans are able to own their homes.

I am not citing these things to encourage self-righteousness or complacency, only to discourage some of the debilitating negativism so prevalent today. The point is that, having become aware of our problems, we must not become obsessed by them. We must seek and support positive solutions. If, as I have mentioned before, we have discovered that some advances in science and technology have produced certain undesirable side effects that could grow intolerable, why not think in terms of using other aspects of these great tools to reduce and eventually eliminate those undesirable effects? In a few minutes I will give you some specific examples of this positive approach.

Today it is essential that we encourage new directions and new dimensions to our thinking and our actions. We have to break down many of our ingrained prejudices, old habits, and traditional attitudes and achieve a new degree of flexibility, imagination, and innovation. There is no doubt that we will have to do this "on the run" so to speak. Unfortunately, we cannot call a "time out" between now and the year 2000. Therefore we must learn to gain and maintain public understanding and support of positive programs. We must learn to overcome new obstacles that arise, because even in the best-made plans there are flaws, and we may often find ourselves having to make changes to take advantage of new innovations, to shift emphasis, and to readjust timetables and goals. But not to choose goals, not to plan, and not to act now for fear of making the wrong moves could be far more disastrous.

Before relating all this to the role of the atom and what it might contribute specifically to our goals for the year 2000, I want to make two last points concerning the combined role of science and technology in general. They are points that I believe should be stressed because they can give us cause for optimism and reason to be positive at this time when, as I have stated, so much pessimism and negativism seem to abound.

The first is that science can dramatically affect our way of thinking, with regard specifically to scientific matters and generally to other aspects of life. Over 100 years ago Clerk Maxwell alluded to this when he said: "Experimental science is continually revealing to us new features of natural processes and we are thus compelled to search for radically new forms of thought for their description." If Maxwell were alive today he might refer to science as a "mind expanding" force in our society. And there is abundant evidence that he would be right. Current thinking in science and technology not only affects our method of dealing with specific matters, but it has also given us a new outlook or insight into dealing with broader problems.

As a result, there is a vital two-way force at work for man today. For many decades now science has been "scoping down" on the objects of its investigation, breaking into greater numbers of disciplines as it seeks more knowledge about more things. At the same time technology has been applying the results of this greater amount of knowledge to larger and more complex systems. New interdisciplinary fields of science are also developing because we are discovering the importance of so many interactions that cut across specific lines of study.

What does this all mean to those not in science and engineering? Well, this type of thinking—combining both the rationality of scientific method with the interdisciplinary approach of systems engineering—is being adopted outside science and technology. It is influencing the thinking and actions of people involved in industrial, economic, social, and educational matters. It is helping all of us to see our world in a different light—one that will allow us to understand its complexities better and to deal with them more rapidly, more efficiently, and more totally. In this context the computer is playing and will continue to play an increasingly important role in our society. It makes possible the extensive use of the systems approach, of such vital management tools as cost analysis and operations research. The value of these special influences is just beginning to be realized, and over the coming decades they may be among our most important assets in dealing with our new world.

The other general point I want to stress involves a concept that could also have a great influence on the outcome of the next three decades and the position in which we will be by the year 2000—if we could get men and nations to accept it and act on it. Perhaps it can best be explained in this way.

Throughout the ages men, from peasants to kings, have believed and acted on the belief that their material world was like the proverbial pie of a certain size, that it contained just so much, and that the more it was divided the less each person received. From this it followed that life was a constant struggle to see who could get more at the expense of the others who, consequently, would get less. If some, through their intelligence, daring, or sheer power, managed to gain a great deal, the share of the others diminished greatly and many suffered.

Today we are still thinking and acting strongly on the basis of this belief, but through modern science and technology I believe we can prove that the belief is no longer totally valid. In a sense, the pie can be made continually larger and more satisfying if only we who share it would devote the time and energy we spend disputing over each portion as intelligently, and perhaps as fanatically, to the solving of some very basic human problems. Perhaps developing new modes of human behavior could affect what many of us have always felt to be some kind of immutable economic or social truths.

To put it a bit more scientifically, although our world is not unlimited in its resources, we have potentially more than enough energy, materials, and space to sustain a population far greater than the number of people on earth today at a living standard at least as high as that enjoyed in most of the developed areas. I am not advocating that we reduce our efforts toward birth control. But I would like to point out that at the moment we are making use of only the most minute fraction of the energy and resources we know are available and much of which we already have the knowledge and technology to use. In another sense, we are enormously wasteful and inefficient and are just beginning to learn how meager our current efforts are compared with our potential. Let us take just one example. Today our major source of mechanical energy comes from the heat of combustion, the burning of fossil fuels—coal, gas, and oil. We are beginning a shift to nuclear power, which over the coming decades will make use of the world's vast supply of uranium and thorium and greatly expand our energy potential. The development and use of the "breeder" reactor, the technology of which we are hard at work on now, will give us an even greater amount of power—perhaps enough for thousands of years—and may radically expand our applications of energy, as I will point out in a moment. In common seawater there is still another fuel, the atoms of heavy hydrogen. If the energy in these atoms could be extracted through controlled thermonuclear fusion—a technology being pursued today—we could obtain from the Pacific Ocean alone enough energy to generate electricity for the entire world at its present rate of consumption for at least as long as the universe has existed. That would mean enough power for many billions of years!

If we can learn to extract such energy in a highly economic way, or even to make full use of the energy that breeder reactors will bring us, we may in time be able to use incredibly large amounts of this energy to create new matter and to rebuild, reshape, and reuse all matter. This means that our relationship to all our basic needs—food, water, shelter, clothing, a liveable environment—could change drastically. Eventually we might use matter and energy, time and space, like building blocks. A whole new logic would guide our production and distribution of the necessities of life. There would hardly be such a thing as waste; hence there would be relatively little pollution. Almost everything would be recycled and reused or returned to nature in a near-natural form and distributed so as to maintain a balanced environment.

At this point, many of you think that I am talking a lot of theoretical nonsense and that we could never achieve such a world, not by the year 2000 or any year thereafter. To some extent I agree, and I will turn a bit more realistic and specific shortly. However, while we are still thinking theoretically, imagine what we might accomplish today, and in the next thirty years, if all the nations of the world were to work in a constructive and harmonious way toward the common goal of peacefully achieving, not Utopia, but even a limited liveable world.

I think there are very few people who would not agree that under such conditions, with the cooperative application of science and technology, we could solve most of the problems involving the material needs of man, problems that seem apparently unsolvable today. We could stabilize population and bring it into balance with food production, increasing the latter to more than just a subsistence level—to a good healthy diet. We could comfortably house such a population, even though, as has been pointed out, the next thirty years will demand the construction of as much shelter as has been constructed since the beginning of man's history. We could probably see almost all such a population enjoying close to the highest standard of living enjoyed today—and without suffering most of the undesirable side effects I mentioned before.

If all this is possible, why are we not doing it?—to paraphrase the old rejoinder, "If you're so smart, why ain't you rich?" If science and technology can make the pie big enough for all of us to have enough all the time, what are we waiting for? The answer to this lies in our finding ways to solve the major social, economic, and political problems involved—to gain what amounts to a consensus of such means to achieve what science and technology have placed within our grasp. All this presupposes that we will succeed in avoiding the annihilation that the destructive potential of nuclear energy has placed at the disposal of mankind. There is no doubt that science and technology have brought us to this point. In this sense perhaps science and technology are forcing us not only to a new level of rationality but also to a new level of morality—to the point where we must also accept and act on the moral truths we have for ages professed to believe.

In view of all this, I think we are about to witness what so many of today's great thinkers seem to refer to, each in his own way, as the next step in our creative evolution. Having this new awareness that I spoke of previously and realizing in what directions we are heading, we must take this next step. We are not a suicidal species, and we will prevail.

Now let me shift from this theoretical and philosophical approach to one that is more specific and is based on forces and events of the moment. Let us examine nuclear energy and its future in terms of man's future. In other words, let us attempt to add to our thinking and actions what I referred to before as those "new directions and new dimensions." Perhaps there is no better subject to use for this purpose because the energy of the nucleus of the atom can be either a destructive or constructive force on such a grand scale. It might be most interesting to look at nuclear energy in terms of some of the subjects we have discussed—peace, the basic needs of water and food, the problems of production and pollution, and such vital subjects as urban development, transportation, communication, and education.

Hardly a day goes by during which our newspapers do not remind us of the grim potential of nuclear war. Yet there is hope that we can avoid such annihilation, that the very threat of it will someday lead us to undertake a step-by-step program of arms control and disarmament. I would hope that as we carry out this escalation toward peace, as we release our resources reserved for defense, we can channel them into positive instruments of peace. In this regard, nuclear energy would be one of our greatest assets since its peaceful uses are proliferating every day.

The power that can be developed by nuclear reactors is adaptable to a number of vital peaceful uses. Foremost among these at the moment is the generation of electricity. Electricity is not only our most versatile form of energy today but our most civilizing. Almost every important advance made during the past few decades has been related directly or indirectly to a growing sophistication in the use of electricity. The fields of these advances have ranged from medical exploration to space exploration and have affected our communications, our transportation, our education, and almost every aspect of our daily lives that we can think of. If we tie this to the needs of our increasing population and the energy needs of our growing industry, it is little wonder that in the United States our demand for electricity has been doubling every ten years.

Historically speaking, nuclear power as a source of electricity has come on the scene just in time. This is true for more reasons than just its ability to supplement our limited fossil fuels at a time of growing demand for electricity. Nuclear power has surged forward remarkably in the past few years because it is now realized that, in addition to being reliable, safe sources of power, large nuclear reactors can provide increasing amounts of electricity at economic costs and can do so cleanly, without adding to the burden of air pollution. In fact, as I will point out in a moment, nuclear power could play a significant role in helping us reduce many forms of environmental pollution.

First let us look at nuclear power from the standpoint of economic benefits, particularly in terms of how the decreasing energy costs that future reactors might bring about could affect various aspects of our lives. To begin with, we must understand that most of the reactors in operation today are of relatively small sizes. Those now under construction and on order are considerably larger, and these are the plants that appear to be economically competitive with other sources of power. The even larger nuclear plants conceived for the future will show increasingly greater economy. But size is only part of the story. The technology of today's light-water-moderated reactors allows these plants to use less than 1% of the energy locked in the uranium found in nature. The nuclear plants of the future, making use of the "breeder" reactor technology now under development, will be able to use upwards of 50% of our natural nuclear fuel resources by converting the non-fissionable isotopes of this fuel to fissionable isotopes at the same time that they are producing power. The net effect of this is to multiply manyfold the amount of energy we can extract from the world's large supply of uranium and thorium. Such reactors will not only breed new fuel but also will proliferate the uses for their power as the cost of this power drops.

In a talk before the International Atomic Energy Agency last September, Dr. Alvin Weinberg, Director of AEC's Oak Ridge National Laboratory, outlined some effects of the reduced costs of nuclear power, particularly how decreasing power costs affect our use of raw materials. For example, at a cost of about 4 mills per kilowatt hour it is economical to produce aluminum via nuclear electric power; at about 2.5 mills per kilowatt hour for nuclear generated electricity, the direct reduction of iron ore through electrolytic hydrogen becomes economical; nuclear electric power at 2 mills per kilowatt hour would make it possible to produce magnesium metal at today's cost of aluminum (and, since there is a vast amount of magnesium in the world's oceans, this might make magnesium one of the major metals of the future); a price of 1 mill per kilowatt hour for nuclear electric power—if indeed such a low cost could be reached—would make it worthwhile to produce pipeline gas from coal; and nuclear power at a cost somewhere below 1 mill could give us economic general purpose heat and even make it possible to produce gasoline from coal at a price competitive with current petroleum processing.

However, long before we reach this point we will see nuclear power being used in connection with one of our most common and vital commodities—water. Current nuclear reactor technology will some day be applied to the desalting of large amounts of seawater and brackish water. This would be highly significant in a world where sufficient water often means the difference between life and death.

But there is a significance to nuclear desalting beyond its use to bring water to large population centers. We are already seriously examining the possibility of building multipurpose nuclear centers in coastal desert areas where certain conditions exist that are conducive to agricultural production but others are lacking. The existing conditions are the right temperature range and sunlight for long growing seasons, the proper terrain and acceptable soil, and location at the seacoast. The conditions that are lacking, but which can be supplied through the nuclear center, are fresh water and fertilizer, which the nuclear plant could help to produce in abundance.

I will not go into detail on what these nuclear powered agricultural centers might produce other than to point out that our studies to date indicate that such centers, using the products of reactors operating in the multimillion kilowatt range to support highly scientific farms, each in the few-hundred-thousand acre range, could supply billions of pounds of specially developed grain annually and a large additional amount of fertilizer for off-site export. It is estimated that a billion pounds of this grain could supply about 2.5 million people a basic diet of 2400 calories a day. The total effect of all this would mean that we would be using modern science and technology to put to use currently unproductive land and seawater to feed tens of millions—and eventually hundreds of millions—of people who might otherwise starve or live on the fringe of starvation. In addition, such centers would bring population to currently uninhabitable areas, establish communities and ports, and perhaps lay the groundwork for other industrial activities making use of the area's natural resources and the nuclear power available. This might include, for example, extracting minerals from the seawater brine or establishing a fishing industry off the coast.

Of course, creating such nuclear agro-industrial centers is an expensive undertaking and one requiring no small amount of human resources and cooperation. But, although building a large complex like this costs, as has been estimated in some of our studies, about $1 billion, remember that the nations of the world pay more than *$150 billion* for military arms every year. Think what a fraction of this budget might do if it went into the highly productive centers I have described.

Before leaving agriculture, I want to point out a few more ways that nuclear developments might help in supplying the world with sufficient food. One general way in which the atom serves agriculture is in the extensive use of radioisotopes to study plant and livestock development to ascertain how we can raise the most productive crops and farm animals. One of the most important elements in the success of the agricultural centers I discussed before would be the use of very high-yield crops, disease resistant, weather resistant, and ideal for mechanical harvesting. Radiation might play a role in creating desirable plant mutations that could be selectively bred to produce these special types of crops.

Another aspect of agriculture making use of the atom has to do with the eradication of pests. We have been successful in controlling, through our irradiation technique, one deadly pest that has plagued our cattle industry in Florida. By a program of sterilization and release of massive numbers of male screwworm flies, who mate only once, we have virtually eliminated that pest in the Southeast.

We can also use radiation to control pests that attack food in storage and transport. In some areas of the world as much as 50% of the food production is lost during storage and transport. We are now testing bulk grain irradiators in the United States and abroad and are confident that such units can be used to deinfest large amounts of wheat and other grains.

Extending the shelf life of perishable foods by irradiation pasteurization is also a technique that should aid us in the better distribution of certain food.

There are myriads of other ways in which nuclear energy can directly and indirectly help agriculture; these range from studies of weather cycles and rainfall employing radioisotopes on earth and in space satellites to the use of nuclear generated electricity to tap vast underground reservoirs of water and the application of underground nuclear explosions to create storage cavities for water. Rather than go into detail on these, I will move from the farm back to the city and to industry to see what the atom might do to help solve some of our urban problems.

As I pointed out before, there is a significant relation between the decreasing cost of energy that larger and newer reactors will allow and the way we will be able to use our resources. If energy can be made cheap enough and if other technologies, such as our chemical engineering, become sophisticated enough—as they seem to be doing—our industrial production and much of the way we live can become, in a sense, a whole new ball game.

Just as an exercise in positive thinking, let us look ahead a few decades and imagine we have reached an era when the cost of nuclear electric power is substantially below the cost of electric power today, when we have developed a new alchemy in dealing with our resources and our wastes, and when we have finally reached the enlightened stage socially and politically to put all this knowledge and power to good use. How might our industry be operating under these conditions?

Imagine a vast industrial center whose energy heart would be a group of large breeder reactors in the multimillion kilowatt range with their own fuel recycling facilities. Into this complex would pour, via cargo transport and pipelines, a variety of new raw materials and old waste. The waste would be of the same variety we have today, but we would no longer be burdened with the job of trying to store it and stack it until we could burn it, bury it, or dump it into our waterways. This waste would be sorted and separated into basic materials and then routed with the new raw materials into the proper manufacturing plants to become new products. Whatever could not be reused might be returned to nature, but only after it had been put into readily absorbable and relatively nonpolluting forms. There would be a minimum of excess heat from the reactor coolants to pose any environmental problems because we would be applying so much of the heat productively, in ways ranging from desalting to space heating of buildings.

With a little further stretch of the imagination, one can foresee such large nuclear powered industrial complexes—Nuplexes—highly automated, efficient, and clean, as the nuclei of a nation's major industrial areas responsible for most of its products and power. Incidentally, there would be no forest of chimneys rising from these Nuplexes since much of the complex would be composed of underground arteries—pipelines and conveyor systems—over which would be parklike areas.

What of the people? Where are the cities, and what are they like in this nuclear age future? If we follow the workers (they are few in number and well paid for their 20-hour week) home after their workshift, we travel via a high-speed electric train or compressed-air-tube vehicle through an underground channel to a city of tomorrow. This is not a sprawling megalopolis, an unmanageable collection of problems that have multiplied as the population exploded—in more ways than one. Ideally, this city of the future is one that will be built from the ground up following the concept of the Experimental City now being developed by a group in Minnesota spearheaded by such farsighted thinkers as Athelstan Spilhaus, President of the Franklin Institute; Buckminster Fuller, the noted architect and futurist; and a number of imaginative individuals, industrial firms, and government organizations. It will be a city of limited population—somewhere between a quarter and a half a million people. Most of its servicing facilities, including a great deal of its transportation, would be underground and its facilities and living space above ground would be designed for maximum human comfort and convenience. I cannot go into all the details on what would make this city so liveable and the center for commerce and culture that a city should be, but I would like to comment briefly on the role the atom might play here. Initially it will have played a major role by taking all heavy industry away from the city and placing it at the Nuplex I described earlier. The city itself would require a great amount of nuclear generated electricity. Most of its services would be highly automated and would require extensive electronic and electrical equipment, including its complex but convenient communications system. As Dr. Spilhaus describes this system:

> The current view is that radio frequencies should be reserved for purposes, such as communication to or from a vehicle in motion, where wires are not feasible. The substructure of the Experimental City would be wired, and coaxial cable would reach to every point where, conventionally, there would be a telephone. These wires and cables can be planned and located in the substructure even before we have a clear-cut idea of what terminals, picture-phones, computers, facsimile machines, and the like may ultimately be needed. . . .
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> Such a communication system can provide access from any point to large high-speed digital computers, for purposes of city management (on the basis of real information), crime prevention through the use of video monitors, and maintenance of the up-to-the-minute data banks for the social experiment that the city constitutes. The same lines, in conjunction with smaller computers and other video terminals, can provide a means of decentralizing schools and hospitals and of bringing together electronically the now separated functions of shopping, charging, banking, credit, and business. Video terminals can even provide "tele-babysitting."

These are some of the ways that Dr. Spilhaus sees electricity being used in the Experimental City.

There would be no combustion engine automobiles on the streets of this city, although they might enter the city underground where their effluents would be filtered and pumped out of the city. Ground-level transportation would be via small, electric, computer-controlled "pods" that would take people directly where they wanted to go silently and without delay. Moving platforms would also be prevalent. There would be no parking problems and no parking meters. In fact, the Experimental City Committee envisions the entire transportation system as free, paid for from an overall service cost of living in the city.

A good portion of the city would be under a huge dome and would be climate controlled throughout the year—another reason why large blocks of nuclear power would be necessary. The nuclear electricity for all these purposes could come from the reactor center within the Nuplex outside the city, coming in through underground cables perhaps paralleling the transportation channels.

There are many other aspects of our lives that could be affected by the atom, but I will conclude with mention of just a few that might have the most significance.

Nuclear medicine should continue to grow in its importance. The hospital and medical center of the future may depend to a large extent on nuclear science, making use of a growing variety of radioisotopes to explore biological functions and diagnose and treat diseases. We may see astounding advances in biology and medicine from the combination of the atom, the computer, and electronics. Such techniques as whole body activation analysis, irradiation from highly specialized medical accelerators, and advanced surgery via the laser might be in common practice.

Within the next few decades we should see the atom playing a major role in space. It will power synchronous communications satellites that will make global television direct to the home a valuable medium for education and cultural exchange. It will fuel nuclear rockets that will make possible deep-space explorations with a heavier payload and will power life-sustaining systems that will allow longer manned space voyages. Perhaps, beyond the year 2000, it will give us the transportable power to establish a colony on the moon sometime during the twenty-first century. I hope that by then we will have made the earth the most desirable place to spend most of our time, however.

In the spirit of this convocation, I have spent much time looking toward a future that would be free of many of the problems that plague us to-day. I have not sought to offer specific solutions to these problems as much as to try to evoke a new spirit and approach to their overall challenges. I believe that many changes in our attitudes and our ways of thinking could prevent much of our current haphazard planning and misguided action. I question whether we can afford to have so many individual forces at work—often at cross purposes—and so much power being wielded unwisely. How much longer can we attack each crisis unilaterally and separately and live from crisis to crisis?

The time has come for more consensus and commitment toward common goals and common dreams. All would not be frozen in these goals as in some master plan for humanity. There will always be changes and conflict and new ideas and new values evolving from them. But not to establish some goals and dreams worthy of a massive degree of effort and the necessary sacrifice leaves us at the mercy of a future without a future—one in which technology would compound and reinforce all the errors of our past. We can no longer afford to have the sins of the fathers visited upon their children. If we are to arrive at the year 2000 and view about us a world worth living in and worth turning over to future generations, we must conceive most of that world today and build it with every succeeding tomorrow. This is the time, we are the people—and perhaps America is the place—where it might all begin.