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PROGRESS IN THE USE OF ISOTOPES

The Atomic Triad - Reactors, Radioisotopes and Radiation

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I. INTRODUCTION

That the first of the peaceful benefits of the atom is peace itself needs no elaboration. Aside from peace, however, reactors, radioisotopes and radiation are the major benefits in the peaceful pursuit of atomic energy. They form an inseparable unit which I have chosen to term "The Atomic Triad". The goal of abundant power and fast, economic propulsion from nuclear reactors has been the common theme of international atomic enterprise. The most immediately applicable atomic benefits, however, are those from radioisotopes. In addition, we must also enlist for man's well-being the third aspect of the atomic triad -- radiation. I will, therefore, speak to you on progress with radioisotopes and radiation in the United States and potentials for development of these atomic resources.

II. PROGRESS WITH RADIOISOTOPES

Uses of radioisotopes have become so diverse and widespread, now extending to over 60 countries, I cannot hope to cover them with any degree of completeness. Nor would it be desirable for me to do so in view of the many others scheduled to speak on the subject. Instead I will pick out developments which seem to me to be particularly interesting.

Medicine

Medical research continues to benefit profoundly from the availability of radioisotopes. The ability to follow dynamic, complex and submicroscopic body processes, coupled with extreme sensitivity of measurement, makes isotopes invaluable tools for life science studies. Routine diagnostic tests and new methods for treatment are outgrowths of this research.

Progress in the medical use of radioisotopes in the United States is perhaps best reflected by the creation in 1957 of a national Society of Nuclear Medicine. This society already has over 1,000 members and its annual meetings reveal continuous progress in medical research and clinical applications. A further indication of progress is the decision of the American Board of Radiology to require qualification in nuclear medicine as a prerequisite for certification in radiology.

Several reviews of progress in nuclear medicine appear yearly. These reviews demonstrate increasing successful use of radioisotopes in diagnosis and treatment of thyroid disease, treatment of cardiac disease, measurement of blood and plasma volume, determination of cardiac output and circulation times, study of rate of production and average life of red blood cells, diagnosis of pernicious anemia with radiocobalt labeled Vitamin B_{12}, localization of brain tumors, and many other uses.

Out of this vast area I wish to select a few examples that hold forth hope of important extensions in clinical applications. Iodine-131 still is the most important single isotope in terms of the very large number of patients involved and the expanding number of using physicians, hospitals, and clinics. Although I^{131}, which decays with an 8-day half-life, has proved satisfactory, there are applications that may be better served with a shorter half-life isotope. An ideal diagnostic tool would be one that reveals the desired information quickly and then rapidly disappears from the metabolic pool. Twenty-five minute I^{128} may approach these requirements. Use of I^{128} would substantially reduce exposures in thyroid uptake and other diagnostic studies. The supply problem has greatly hampered use of this radioisotope. However, installation of research reactors throughout the U.S. will make I^{128} routinely available ~~and~~ along with other short-lived radioisotopes of high specific activity. Development of the Szilard-Chalmers process for enhancing the specific activity of reactor-produced radioisotopes holds promise of making small, inexpensive reactors valuable producers of very useful, short half-life radioisotopes.

Strontium-85, a 65-day half-life, gamma emitter is showing promising results in the study of bone diseases. Since this isotope may be detected externally, the continuous rate of uptake, total activity and retention of strontium may be readily measured. This should permit differentiation between normal and diseased states of bone.

A startling radioisotope technique has recently been devised to diagnose defects within the heart. By measuring the activity of blood samples taken from heart cavities, following inhalation of krypton-85 gas, the location and approximate size of any defects may be determined. This technique is remarkably successful in determining, without the risk of exploratory operations, types of heart malformations and necessary corrective measures.

Teletherapy devices continue to be a major medical use of radioactivity. Over 160 cobalt-60 units in the U. S., at an average of 1,000 curies each, make teletherapy devices a sizeable portion of the whole demand for radioisotope production. Cesium-137 is coming to the fore as an alternate source of clinical radiation energy. Several kilocurie cesium-137 teletherapy units are now being tested. Cesium-137 has the skin sparing and depth dose advantages of supervoltage radiation, comparable to an X-ray machine operating at one Mev. With the very large quantities of cesium-137 now available it should play an increasingly significant role in radiation therapy.

Agriculture

Radioisotope techniques and radiation continue to advance the frontiers of agricultural science. Because of the complexity of animal and plant systems important to our economy, the potential for use is virtually unlimited.

Many of the medical applications of radioisotopes are now being applied to veterinary medicine. Iodine-131, for example, is utilized in studying factors affecting thyroid activity in cows. These investigations indicate that high milk yields are dependent upon optimal function of this endocrine gland. Marked changes in thyroxine secretion with seasonal changes have been noted and are being investigated. If thyroid gland variations are related to productivity, calves that will be poor milk producers may be eliminated early from the herd.

Increased crop yields have resulted from research results made possible with radioisotopes and radiation. Radiotracers are being used to determine the uptake, rate of entry, and the movement of nearly all nutrient elements in plants, and the mechanism of their transfer from the environment to the plant cell interior.

Many tracer studies continue on soil fertility and uptake of fertilizers in crops under various soil and growth conditions. Application of these tracer results to practical agricultural problems is of great economic consequence. More recently much attention has been directed toward foliar or leaf application of nutrients during crop growth. In these studies of foliar application, available radioisotopes of all known major and minor nutrients have been used and the absorption, transport and intra-plant mobility investigated.

The art of grafting the top (scion) of one plant on the root (stock) of another has been long known, yet many of the intricate relationships between the stock and scion have remained obscure. The effect of the graft union and scion orientation on the transport of isotopically labelled nutrients has been studied in tomatoes. In whip-tongue grafted tomato plants, the union per se does not interfere with transport. A union formed by grafting together the apices of two forced laterals effectively blocks the transport of calcium-45 but not of phosphorus-32. Further tracer studies of the influencing of grafting on intra-plant nutrition will be valuable for proper feeding of the top and root of such plants.

In the field of radiation genetics, good progress is being made in developing new strains of hardy, disease-resistant plants. Spontaneous mutations are slow in providing the plant breeder with new varieties for experimental purposes. Ionizing radiation from radioisotopes can be made to cause mutations to occur more than 100-fold faster than in the natural environment. With this abundance of new genetic material, the plant breeder can bring intense effort to bear upon improving crop varieties.

Industry

In the three years since our last Geneva meeting the world-wide growth in industrial use of radioisotopes has been vigorous. Advances have been made along the entire industrial front. Not only the United States, but every one of the highly industrialized countries participating in this conference have active programs for accelerating industrial radioisotope utilization. Many industries are only beginning to realize the impact of peaceful uses of radioisotopes and radiation; more are yet to experience this impact.

The economic importance of radioisotopes is amply illustrated by the experience of American industry. We have estimated the tangible contributions of radioisotopes to the U. S. national economy from industrial uses as follows: in 1953, $100,000,000; in 1956, $400,000,000; and in 1957, $500,000,000. A study is under way by the National Industrial Conference Board of current industrial savings due to isotopes and it appears reasonable to anticipate that the figures will soon total one billion dollars annually. These do not take into account the intangible but rich benefits in medicine and agriculture. Also, since 1953, the number of industrial plants in the U. S. utilizing radioisotopes increased about 3 times. The total curies of radioactivity we distributed in the same period multiplied 18 times.

Much of this economic growth and increased utilization results from extension of conventional radioisotope techniques, such as industrial radiography, thickness gaging and oil well logging. Research and development now under way, however, is pointing the way to additional applications.

For example, industry has many uses for soft X-ray sources, but unfortunately suitable gamma-emitting isotopes are not usually available. Multicurie size beta-ray excited X-ray sources now being developed, combined with recent development of image intensifiers, make the possibilities for low energy isotopic radiography very promising. Also such sources, combined with discriminating detectors, such as proportional counters, may provide a rapid, widely useful means for elemental chemical analysis by means of selective or characteristic X-ray absorption. Use of several energies of X-rays excited by beta ray emitters permits quantitative measurement of different elements in a mixture, as for example H, C and O in certain organic compounds. Beta-ray excited X-ray sources would also provide new versatility to the already developed technology of thickness gages. The long-time stability of such X-ray sources forecasts high precision measurements for density, fluid detection, phase change, and other applications in low density materials.

A basically new system is being developed for monitoring the concentration of toxic gases in the atmosphere by means of a radioisotope exchange technique. Air containing the non-radioactive, toxic gases is passed through a suitable radiochemical reaction bed to undergo a gas exchange reaction. The quantity of effluent gas, as determined from its radioactivity, is a direct measure of the concentration in air of the toxic gas. Sulfur dioxide is an outstanding example of a material detectable by this method, as follows: SO_2 (gas) plus $Cl^{36}O_3$ (solid) yields $Cl^{36}O_2$ (gas). This reaction, used for many years as a commercial process for the production of chlorine dioxide, is known to be 97% efficient. Consequently, measurement of the Cl^{36} which is possible at very low levels permits SO_2 determination below usual chemical procedures.

Feasibility studies are progressing to extend this system to other toxic materials. Phosphorus and arsenic compounds are widely produced and used in fertilizers, insecticides, and in certain smelting operations. Standard methods of analysis of these toxicants are time-consuming, complicated, and in many cases, not sufficiently sensitive. A single, rapid and sensitive system similar to the one described will be extremely useful.

One untapped industrial area of vast importance is process control through radiometric analysis of diverted minute fractions of a process stream.

Investigations are being pursued of radiometric techniques applied to ionic analysis and control in aqueous solutions. Radiometric analysis involves a phase change of a radioactive constituent. For ionic solutions, a solution-to-gas or solution-to-solid conversion is followed by measurement of the radioactivity of one of the phases. A radiometric analysis of an ion in a process stream would involve the following sequence of operations: (a) measurement of the volume of the process stream, (b) addition of a measured excess of a radioactive reagent which stoichiometrically precipitates the ion, (c) measurement of the radioactive reagent remaining in the supernatant after separation of the precipitate, and (d) calculation of the ion concentration from the difference between the added and remaining radioactive reagent.

Experiments with a laboratory model of a radiometric analyzer for phosphorus in boiler water have shown it capable of automatically measuring phosphate concentration in the range of 5 to 50 ppmm to ± 5% accuracy.

Neutron activation analysis has been routinely used in the laboratory for determining minute traces of contaminants in a wide variety of industrial materials. This technique is usually applied to batch processes; however, the advantage of adapting such a technique for continuous production-line process control is obvious. Neutron sources are now available with the required intensity and stability for minimum desirable activation of process stream elements.

With low-level counting techniques now available the small quantity of activity induced in the process stream will present no hazard to either the operator or consumer. Development of production line activation analysis already is under way in the U. S. This could find use in as many industries as the beta thickness gage.

The foregoing are but a few developments in applications of radioisotopes in the United States. There are still many unborn uses, however, which one can readily invent.

UNBORN USES OF RADIOISOTOPES

It is well to realize that most uses of isotopes now being made could have been made 20 years ago and that really discovery of the chain-reacting pile was not strictly necessary. Before discovery of fission, the development of the cyclotron had made isotopes sufficiently abundant to permit a burgeoning growth of isotopic applications in research, especially in biology.

Of course, the chain-reacting pile and fission reaction have made certain isotopes much cheaper and more abundant, and this is very important for certain widespread industrial applications. The prime and limiting factor, however, is imagination and interest in the development of these new uses. I think that there have been few occasions in the world's history when such a wealth of opportunity for technological development existed as does exist in the applications of isotopes and radiation to industry, agriculture and medicine. Indeed, anyone with familiarity with technical matters and with isotopes can think of at least one new use every five minutes.

Let us consider what some of these possible uses of isotopes might be. Well, here is a book. Books are difficult to keep. Of course, you may find that most books are not worth keeping, but let us for the moment consider the problem of how to keep books and how to preserve them from deterioration. The factor that limits the lifetime of a treasured book is oxidation by air of the organic matter of which the book is composed. Suppose we make the book radioactive. How? Three years ago at the first Atoms for Peace Conference, we described how, at the Argonne National Laboratory, plants are grown in fully radioactive form labeled uniformly with carbon-14. The cellulose from similar plants could be obtained and book paper could be made which could be tested for its keeping properties. Making such tests is a perfectly feasible procedure because recently a colleague of mine, Dr. Dwight Conway, and I published a paper on the measurement of very slow reactions. It was found that by using radioactive alanine in which a small fraction of 1 percent of the carbon atoms had been replaced with radioactive carbon, we could measure the extremely slow rate at which this amino acid decomposes at temperatures just slightly above room temperature. The rate of decomposition corresponded to one part in 5 million per day. Now we could do much the same experiment with a sheet of the book paper. The technique would be to place a sheet of book paper in a closed container and collect the gaseous carbon dioxide liberated by oxidation due to the attack by air. One could thus measure the amount of the attack and compare this with similar tests on other sheets of the paper treated with various additives. By these techniques it would probably be possible to prepare a paper which would last however long one wanted, 20,000 years, perhaps.

I have just outlined a perfectly practical procedure and one which could be applied to a lot of things besides books.

As a second example, this time in the field of pharmaceuticals, let us recall that physicians now routinely use radioisotope capsules for a variety of diagnostic purposes. These now use radioiodine and radiocobalt. Why should a doctor not be able to utilize a radioactive pill for detailed metabolic diagnosis, one labeled with radiocarbon or tritium at such low concentrations that the radiation dose is extremely low? The rate of metabolism of a pill made of a biochemical important to the body would be most revealing as to the biochemical health of the individual.

Work needs to be done to establish the sequence and expected response for presently undetectable or impending pathological conditions. With tritium labeled pills, the tritium content of blood and urine would measure the combustion to water. For radiocarbon labeled pills, the blood and urine can be measured for the original labeled chemical as well as its degraded forms. This is a potential area of such great importance that much more work should be done on developing the use of carbon and hydrogen isotopes for everyday diagnostic purposes. Nearly all of these tests could be performed with amounts of radiation comparable to that naturally present.

A third unborn use might be in the field of agriculture in the elucidation of mechanisms of food decay for the purpose of developing preventive measures. This could help alleviate the pressing food supply problem. We might grow certain radioactive foods, labeled with carbon or hydrogen isotopes, and then observe from the exudation of radioactive gases, as a result of attack by the atmosphere and biochemical processes, the rates at which these very slow changes are occurring under normal conditions. As a result of being able to observe them, we should determine how to prevent them. It would be extremely helpful to be able to observe very small degrees of degradation, occurring even with sterilized or otherwise preserved foods. By the use of radioactive food of any sort, we could observe quickly the onset or course of degradation reactions and try various additives and treatments to protect them.

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A/ unborn industrial use would be automatic control of petroleum refining by introduction of a small amount of radiocarbon or radioactive hydrogen compounds at various stages; that is, either in the crude oil, or into specific fractions occurring in the refining process. For example, normal octane which contains radiocarbon could be introduced and might be particularly important in controlling the plant operation. One might, for example, select a half-dozen particularly important constituents of crude oil and introduce them in labeled form at specified times and follow them through the plant. Eventually this could be developed into an automatic isotope process control system. There is not the slightest doubt that this kind of application of radiocarbon and hydrogen could be of practical value within the next few years.

For a fifth use, radioisotopes possess outstanding capabilities as detectives in "law enforcement" problems. They might be used, for example, to make the counterfeiting of money more difficult. Since paper is normally radioactive, we have three possibilities for positive identification. One way would be to make money from non-radioactive paper by growing pulp on non-radioactive carbon compounds derived from coal. This paper, unique and different from all other paper, could be used to make currency. Another method for spotting counterfeit money would be to mark bills with an innocuous quantity of a radioisotope. There are countless possibilities for varying the isotope and position of marking. Perhaps the most appropriate marking technique would be to incorporate a stable-isotope code into the bill. Bills in question could be exposed to a small neutron source and the identity of the bill determined by activation analysis.

Thus one sees that there are many invisible marking techniques which would be equally useful in identifying revenue stamps, tax-free gasoline, re-claimed motor oil, and countless other everyday items open to question.

A sixth problem in which isotopes can be exceedingly helpful is the ancient problem of the weather. We have begun to understand the world-wide patterns of the movement of air masses that are systematic and reasonable. Much of the information has come from cooperative efforts such as the International Geophysical Year. The study of radioactive fallout has also contributed to our knowledge of the atmospheric circulation problem. We have also learned a good deal from the study of naturally occurring isotopes which come in from outer space or are produced by cosmic ray bombardment of the upper atmosphere. We know the atmosphere is divided roughly into two layers--the stratosphere and troposphere. In the stratosphere the mixing is probably quite rapid in that strong winds blow, but the winds are dry and there is a tendency for stratospheric air to remain segregated from the lower part of the atmosphere, the troposphere. Wherever moisture exists, clouds form, rain falls, and all the other weather phenomena we know occur. We have learned from these isotopic studies that the troposphere and stratosphere are essentially two separate and different systems. We have learned that the troposphere is rapidly cleansed by the action of the rainfall, so that matter put into the troposphere in solid particulate form will be precipitated in about one month, whereas the same material put into the stratosphere will stay for a period of five to ten years on the average. We have evidence that this is also true for gases put into the stratosphere, and we therefore know that the stratospheric mixing with the troposphere is slow indeed. Now, we have learned all that I have described from isotopes generated by cosmic rays, a process over which we have no control, or from the study of radioactive fallout. What can we do if we really get serious and move at this with purpose? I think it is clear that the meteorologists can, on a day to day basis, mark specific air masses and follow them by the use of available radioactive isotopes. Water movement also can be followed by the purposeful injection of radioactive water containing tritium. This has been done and can be done again. It is possible in this way to follow the movement of selected water masses and to observe the contribution of various air masses to precipitation and to follow their movement. In this way we should indeed be able to answer some of the questions that the meteorologist needs answered for better understanding and prediction of weather. If we can learn to predict weather more accurately, we can perhaps come to understand how we might possibly improve or change it, but that is another subject. I am sure isotopes would be useful in that development, too. Isotopes have already helped us in understanding air moements and in our knowledge of weather phenomena and their contributions will continue.

Now the foregoing uses can be easily and immediately realized if only we want to. The necessary equipment and techniques for low level counting have already been developed and have been used for years. Although additional engineering development and ruggedization needs to be done, the important fact is that the commercial equipment is available. What is needed most today is for large numbers of people to begin to use what is available. The radioisotopes which are most useful in an everyday way are the soft radiation emitters, carbon-14 and tritium. These two isotopes hold the greatest potential for countless unborn uses which we all hope will soon materialize.

IV. RADIATION ENERGY

I would now like to turn to the third aspect of the atomic triad--namely use of radiation energy. With the continued growth of the nuclear power industry, hundreds of thousands of kilowatts of radiation inescapably will be produced. Development of industrial applications of these vast radiation resources would convert them into a valuable asset. This would also reduce the cost of chemical processing of spent reactor fuels and indirectly contribute toward reduction of costs of nuclear power.

Irradiation is a unique way of adding energy to a process system. The energy of gamma radiation is enormous relative to the energy available from ordinary chemical reactions. Energies in radiation applications are usually measured in million-electron volts, whereas chemical and heat energy changes are usually a few electron volts. To illustrate: a gas, each molecule of which had an energy of one electron volt, would be at a temperature of 11,000°C. Furthermore, radiation energy is applied directly to the internal structure of molecules to ionize, rearrange chemical bonds, and initiate chain reactions. The mass of the process material is not heated by the radiation, thus avoiding undesirable thermal effects in processing and in products.

One consequence of the ability of radiation to break chemical bonds is the formation of new molecular bonds in materials impossible to obtain satisfactorily by chemical or physical procedures. Radiation may thus produce polymerization and cross-linking in new ways to yield valuable products not otherwise obtainable. For example, entirely unique plastics can be obtained by the process of radiation-induced graft polymerization. Effective surface grafting is possible for the first time. Under irradiation, a plastic film having desirable surface properties, such as chemical or flame resistance, can be "plated" onto a polymer having, for example, desirable tensile properties. Interior grafting also can be accomplished; for example, to increase temperature stability by grafting silicones to polymers having other desirable properties.

Another example of a unique plastic product made possible by radiation is an improved ion exchange membrane. These membranes are components of an electrodialysis apparatus currently used for desalting brackish water or sea water. A superior ion exchange membrane has been prepared by immersing films of polyethylene in styrene and exposing them to gamma radiation. This produces a strong graft copolymer. The styrene-polyethylene films are then treated with chloromethyl ether and trimethylamine to produce anion exchange membranes of optimum mechanical and electrical properties.

Use of these new membranes to desalt sea water requires only one-third the electrical power of currently available membranes. Important applications of improved membranes can be expected in sugar purification, caustic soda cell operation and battery separators.

In the rubber industry, radiation is certain to find vulcanization applications. Although it is possible to vulcanize an automobile tire with radiation alone, this is wasteful of radiation. A process more certain of commercial success is the simultaneous radiation grafting and vulcanization of mixtures of natural rubber and various polymers. New radiation vulcanized materials are obtained having a broad range of elasticity combined with other valuable properties such as oil resistance.

Radiation also will be used in manufacturing improved varieties of familiar chemical products. Detergents, for example, have been produced by the reaction of sulfur dioxide and oxygen with hydrocarbons in a gamma radiation field. Radiation initiates the process in which long-chain sulfonic acids are formed. Yields per unit energy absorbed are exceptionally high, so that radiation requirements are relatively small. The process could become an economical method for manufacturing new types of detergents for commercial use.

The petroleum industry is outstanding in its support of radiation research. Almost all the conventional refining operations can be duplicated through the use of radiation. Stimulating research studies have shown that radiation can crack crude oil to form gasoline, inhibit gum formation in stored petroleum products, and by grafting side chains to straight-chain hydrocarbons increase octane ratings. The feasibility of such applications may depend largely on economic factors.

Radiation preservation of foods, of course, is a process which would have world-wide consequences. Progress in this field in the United States has reached the point of building a center for radiation processing of substantial amounts of foods under carefully controlled conditions. The U. S. Atomic Energy Commission is cooperating in establishing the U. S. army Ionizing Radiation Center, to be located near Stockton, California. The Army Quartermaster Corps has undertaken--in conjunction with the food industry--a program which will solve many of the basic problems and which will show the extent to which this new technique can be used to meet the military demands.

I think it quite likely that this Army program, and others which will undoubtedly be undertaken by the food industry itself, will show that the sterilization or pasteurization of foodstuff by irradiation techniques will be useful and that these techniques will supplement those already in existence to give us ever improving methods of preserving and storing food.

V. ISOTOPE DEVELOPMENT PROGRAM

In the United States, the Atomic Energy Commission has an Isotope Development Program which is dedicated to the purpose of developing new uses of radioisotopes and to expanding the application of established uses.

In order to do this, we have an educational program to teach people the techniques of measurement and utilization, and it is likely that this, in conjunction with a number of dramatic applications to stir the imagination, will lead to wider use of every-day applications.

But the surface has only been scratched. The current savings result almost entirely from three types of industrial application: thickness gaging, radiography, and process control. When you consider that there are literally hundreds, if not thousands, of other types of industrial applications of the isotope, any number of which offer as great a potential for industrial savings as those which have already been partially exploited, you can understand why I am so enthusiastic about the impact of radioisotopes and radiation on the economy and well being not only of the United States but of the world. I am confident that the current economic value of radioisotopes, as great as it may seem, will appear insignificant by comparison with the real benefits which will be realized when the administrative and technical leaders of all industry are awakened to the potential of the new tool that is available to them.

VI. PLOWSHARE

I would like to mention a new development which was first disclosed at the UNESCO Conference on Isotopes held in Paris a year ago next month.

On the 19th of September of last year the first deeply buried nuclear explosive device was fired.* From this important first step in the non-military applications of atomic explosions, we have learned that this development holds great promise, and in the United States we have launched a project called Plowshare to develop these uses. One of the important prospective uses is the production of isotopes. It is possible in a few millionths of a second to produce quantities of isotopes which take months and years by ordinary methods, and it is possible to produce isotopes in this way which cannot be produced except in the very most valuable and expensive chain-reacting piles of the very highest flux. I speak of the isotopes which are formed by the rapid assimilation of several neutrons one after the other by one atom. This is possible because of the extremely intense, though very short-lived, flood of neutrons which come into any medium surrounding an exploding atomic or thermonuclear device. It appears that ultimately we should be able to produce isotopes more easily and in some instances perhaps more cheaply than any other way. But before we realize these low costs we must solve the technical problems of mining the congealed material which is vaporized and then subsequently cooled and which contains the isotopes formed as a result of the nuclear reaction, and we must select the most economical methods of purifying the desired isotopes. Of course, it has been clear for many years that most of the uses of isotopes are not limited by the cost of isotopes, but there are some that are, particularly the large-scale industrial uses. For example, I spoke of labeling gasoline and it turned out that it cost one cent a gallon to label it with radiocarbon. Well, this is an appreciable cost. One

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*Other papers in the conference will treat this subject also, particularly the ones by Drs. Harold Brown, Gerald Johnson, and F. B. Porzel.

could do it with tritium at a much lower cost, but the labeling with tritium may be for many purposes not quite as useful as the labeling with radioactive carbon. Now at the present time in our country a curie of radiocarbon sells for $22,000, whereas tritium is $2.00 per curie. Now if we could reduce the cost of radiocarbon by producing it by surrounding an atomic device with carbonaceous material in conjunction with a highly effective moderator, one might be able to produce radiocarbon at a very much lower price than at present. This would greatly help some of the larger-scale industrial users, particularly the organic chemicals business.

There are very many other uses which we are considering for atomic and thermonuclear explosive devices. Perhaps the most obvious of these is excavation to form harbors and canals. Another is the breaking-up of underground rock for mining purposes or for the formation of acquifers to store water and to supply a reservoir. Placing a bomb at just the right depth so that several million tons of rock are shattered and rendered porous would make it possible for surface water in great quantities to be stored in this way. This may be a very important application. It is also clear that highly fractured rock would make certain minerals available for mining by leaching methods. For example, in copper mining where leaching is a very effective method for removing the valuable product, fracturing ore in place could prove to be of extreme importance.

Atomic power and thermonuclear power may be attained by the use of explosive devices. An important part of our Project Plowshare is to see whether by firing under the proper conditions it will not be possible to recover a considerable fraction of the energy released and to put it to useful work as electricity or heat or steam for heating homes. It is obvious from first principles that great quantities of energy can be made available in this way much as one has in natural geysers and natural hot springs. The problem is to solve the technical questions which remain and require solution before a true assessment can be made. A major objective of our Project Plowshare is to settle these technical questions which must be resolved before we can proceed with atomic and thermonuclear power and the other uses envisaged.

These great possibilities will rest, of course, on the practicality, the cost of the devices, their size and ease of handling. It is, of course, necessary to bury the largest yield devices deep in the earth to contain them and the cost of burying them to such great depths is great. Therefore, the importance of size and ease of handling is considerable. We expect that devices which will be used for the non-military applications will not be military devices in general, because the military devices have been designed for different purposes, weight being at a premium and size and shape being major considerations. There is no consideration for weight in most of the non-military applications. There are considerations, obviously, of maximum dimensions in determining the size of the drill hole or tunnel, but if it were possible to assemble the device out of smaller pieces all of which could pass through the drill hole, the total weight would be a matter demanding little consideration in general. By increasing the weight it should be possible to increase the explosive efficiency and the yield from a given amount of fissionable material or from a given amount of thermonuclear fuel. This possibility of increasing the yield as compared to the yield realized in weapons is an important aspect in the non-military applications which must be borne in mind. One might say that the cost per unit energy released, which is based on the experience with military devices, would be an upper limit to the cost for the non-military devices. We plan to give, in the near future, some rough numbers for the purpose of making preliminary estimates and judgments of feasibility.

VII. THE FUTURE

The future holds much good for the world if science can keep pace with the challenging job which needs to be done. We must forever grasp the helping hand the atom extends us. Most important of all we must proceed in such a way that our education is adequate to the opportunities nature affords us. Young scientists and engineers must be prepared for the promising atomic future unfolding so clearly before us.

We must teach about the atomic nucleus, radioactivity, isotopes, and the atom. It is very important that these instructions be put in every secondary school and college classroom in the civilized world so the students can come to know and use safely radioactivity and isotopes as a normal thing. With this type of instruction, students will naturally learn about isotopic techniques and methods which are necessary to the development of new uses. It will not be a strange matter for them.

As I have stated earlier, seldom in history has such a wealth of opportunity existed for technological development to improve human welfare. With ample education and technical training throughout the world --and with a universal bringing to bear of human resources and imagination rapid realization of the promise of the atomic triad is certain--the almost unlimited benefits of reactors, radioisotopes and radiation.

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