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REPORT OF THE RESEARCH PROGRAM COMMITTEE

715897

Introduction

The field of nucleonics has reached the stage where it is fairly clear as to what should be the next immediate steps. The section of this report dealing with the social and political problems indicates several choices which face the nation concerning the future of this field. It is believed that irrespective of the choice made and irrespective of whether or not the point of view is one which envisages an armament race or is one which happily contemplates a peaceful development, the immediate problem is unaltered. The time scale, however, on which the work is carried out will be very much affected by the realities of international policies.

The quantity production of fissionable isotope is now realized only at the expense of a raw material which is not at all abundant in our country and exists in rather limited quantities in the world as a whole. At the present rate of destruction of this material it cannot be imagined that a wide-spread use of fissionable isotope will be permitted. The wasteful utilization of this raw material is forced upon us by the necessities of war, but the advisability of continuing present methods of production far into the future even for military needs can be doubted. It follows that research directed towards a more efficient utilization of the primary material is the main problem of the nucleonics program.

If a sizable percentage of the isotope uranium-238 could be burned and if, in addition, useful fissionable isotope could be realized from thorium, then the whole future of the development would be on much more secure grounds. It is of paramount interest, therefore, that the fundamental research necessary to the design and construction of "breeder" piles be undertaken vigorously. It is only by demonstrating the practicability of the "breeder" principle that a sufficiently ample supply of fissionable material can be produced to permit the nucleonics program to proceed on the scale indicated by the benefits to be derived. It is also necessary that research and development leading to the useful utilization of the power from nuclear burning be vigorously supported. The ultimate goal here would be to operate machines which produce useful power and which at the same time produce as much or more fissionable isotope than is consumed. Under these circumstances no real limit could exist to the application of nucleonics to all phases of our scientific and industrial life.

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The accomplishment of the goal set in the previous paragraph is not possible without an extensive program for basic research in physics, chemistry and metallurgy. The present state of the art is such that new designs of reactor units invariably suggest situations about which no information is available. For the long term development of the field the research in the basic sciences will be of more importance than any immediate pile design or engineering. It is possible that the real future of atomic power does not involve the burning of uranium but rather other elements at the light end of the periodic table. Progress in this direction can only come if all possible freedom and support is given for investigations concerning the nucleus.

In the following paragraphs are indicated some of the immediate questions which should be investigated. The problems listed are meant to illustrate the type of work required for a sound development of the field and in no way can be considered a program for anything but a beginning. New information and new discoveries will rapidly alter any planned program of research.

For the purpose of preparing this report the subject matter has been divided into the fields, physics, chemistry, metallurgy, biology, medicine, health protection and pile development. Experience has shown, however, that this division is artificial and that no sharp boundaries exist. Inasmuch as many of the benefits to be derived from the nucleonics program result from the application of the radioactivity and radioactive tracers to the fields of biology, medicine, chemistry, engineering, etc., there is also included a partial program of studies which should be continued and initiated in these fields. The auspices and arrangements under which this work might be carried out may be somewhat different than the nuclear program itself, but it is no less important that these studies be given full support in order that the new discoveries may become a boon to the public as rapidly as possible.

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I. Pile Development

The following types of piles and problems connected with pile design are suggested.

1. Enriched piles for "breeding"

These piles are best classified according to the energy of the neutrons which support the reaction.

a. Piles operating with thermal neutrons

This pile may be either the heterogeneous or homogeneous variety. For the heterogeneous type the main problems are the preparation of rods or plates of fissionable material, the protection of these from corrosion, the effect of fission product poisoning on the reaction, the periodic removal of fission products. For the homogeneous type the main problems are the stability of the homogeneous mixture under irradiation, bubble formation, cooling and purifying of the very active mixture.

b. Piles operating with neutrons in the energy range 1 to 1,000 eV - the so-called resonance neutron pile

There is a complete lack of information on the resonance properties of many of the materials of pile construction and very meager information on the nuclear constants of the fissionable material in this energy region. Resonance absorption of the fission products is completely unknown.

c. Piles operating with fast neutrons

The absorption and inelastic scattering cross sections for pile construction materials are unknown for fast neutrons. Similarly precise information concerning most of the constants of the fissionable material is lacking in this range.

These three types of piles may be considered to operate with any of the isotopes 25, 49, or 23 and can be considered to generate either 49 or 23. It is not clear which of the three types listed will provide the best practical design and which will yield a reasonable amount of new fissionable material. The chemical problems are somewhat similar, however, and involve the development of high yield chemical methods for the periodic or continuous removal of fission product poisons from Pu^{239}. Solvent extraction, precipitation and other methods for fission product separation should be studied. Deuterated organic solvents would be useful. Efficient methods for the separation of U^{233} from Th and decontamination from Pa^{233} and fission products must be found.

A number of experimental type pilot piles should be constructed. It is not necessary that these pilot machines should themselves be producing units but rather each should test some point of the "breeding" principle.

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2. Power Piles

The information in the fields of physics, chemistry, engineering and metallurgy necessary to the operation of a pile of sufficiently high temperature so that the power could be usefully removed should be secured as rapidly as possible. The neutron absorption properties in various neutron ranges for liquid metal and other coolants, the heat transfer properties of these coolants and the engineering problems connected with their use should be investigated. Attention should be given to the design of units small enough to be portable in submarines and warships. The problems involved in the design and construction of piles operating at very high temperatures (i.e., 2000°C) should be investigated. In this connection also, the efficient conversion to mechanical power by, for instance, gas turbines, is an important problem. High temperature operation requires study of new corrosion problems and development of corrosion-resistant pile materials. Separation processes for high temperature piles will emphasize volatilization processes and volatilization behaviour of fissionable isotopes and fission products.

3. Natural Uranium Piles

All designs and materials should be examined with the view of finding the best type of pile for the use of natural uranium. As moderators Be and BeO as well as the present D_2O and C should be explored. The use of uranium in the form of metal, carbide, oxide and hexafluoride and in solution of D_2O or in a liquid state is possible.

4. Piles for Special Purposes

It may be desirable to design and build piles for special purposes such as: the conversion of Pu^{239} to U^{233}; the manufacture of radioactive elements by neutron capture; the collection of fission gases for the manufacture of radioactive tracers; the creation of a high intensity source of radiation for experiments in nuclear physics, radioactive chemistry and biology; the therapeutic use in medicine. Each of these uses would require a somewhat different design. In some cases the pilot plant for a power pile or for an enriched breeder pile would provide the necessary facilities, in others the design would uniquely fit the special use.

5. Production Piles

It is assumed that the present production facilities would be operated until they can be replaced by ones which provide a greater utilization of raw material.

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II. Physics Research

1. Nuclear Reactions

The constants of nuclear reactions induced by neutrons, gamma-rays, and charged particles are fundamental in the science and especially now require thorough investigation. The Metallurgical Project to date has concerned itself mostly with those parts of nuclear physics which seemed most directly to affect the design of piles. This work should now be broadened to include all nuclear reactions and the study of the properties of all elementary particles. These studies will require the use of cyclotrons, linear accelerators, betatrons and chain reacting piles.

2. Reaction Cross Sections

The following cross section measurements should be made: continuation of study of neutron reaction cross sections for all isotopes; cross sections of heaviest elements for various processes as a funtion of energy; α-n cross sections for light elements; n-α, n-γ, n-p cross sections in the resonance region and as functions of energy; D+D and other light element reaction cross sections.

3. Fission

The fission of any isotope induced by any of the projectiles which are generated by the instruments named in 1 must be investigated.

4. New Elements

The creaction of new elements by fission or other processes, the study of the physical and nuclear properties of these elements and the formation of new radioactive chains require further work.

5. Nuclear Structure

A general study of the structure of nuclei should be undertaken. This involves work in the following fields: mass spectroscopy, natural and artificial radioactivity; reactions involving the light elements; searches for new types of nuclear constituents and studies of the properties of these constituents. Typical problems are: mass spectrograph analyses to find mass defects; betatron work to find binding energies; spin and magnetic moments of the neutron, of the fissionable elements and of high cross section nuclei in order to interpret velocity selector data.

6. Radiation Physics

Typical problems are: β and γ activities of the early fission products, decay of the neutron, search for the neutrino, number and energy of instantaneous γ rays in fission, γ radiations from (n, α) reactions in moderator, chain maintainer and other materials, long range α particles from fission.

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7. Pile Physics

Measurements should be continued on the number, period and energy of delayed neutrons, neutron ranges in various moderators, shielding with respect to γ and neutron radiation, the periodic perturbation of piles.

8. Theoretical Physics

Theoretical descriptions of nuclear processes on the basis of the findings of the researches suggested should be encouraged and supported. Subjects to be investigated are the interpretation of mass defects, interpretation of spins and magnetic moments, interpretation of angular distributions, generalization of resonance picture, effect of radiation on various materials, appearance of fission products. Theoretical pile studies must be continued. The possibilities for chain reactions of the light elements must be investigated.

9. Classical Physics

Fundamental studies of heat transfer and the efficiency of cooling devices must be given a high priority in the work in nucleonics. Useful power from the chain reaction will involve new and difficult problems in heat transfer and cooling. Some topics are: turbulence, formation of crystal nuclei and bubbles, diffusion of fissionable material and fission products in solids, solubility of salts in water above boiling point.

10. Nucleonics Standards

A laboratory or a part of a laboratory should be organized which has the responsibility to provide proper standards of measurement for the nuclear program. It would be the duty of this laboratory to provide calibrated sources of α, β and γ radiation, to prepare neutron sources of known strength, to test pile construction materials especially for neutron absorption, to calibrate instruments. It would also be the duty of this laboratory to prepare the exact definition of radiation constants and to act as a laboratory of reference for the various agencies engaged in the work.

11. Instruments

The invention, design and construction of instruments for the detection of all types of nuclear radiation is an important part of the development. In particular instruments for the detection of radioactive tracers, especially C^{14} and H^3 which can be easily constructed and used are required. Similarly, instruments useful for the control of reactor units and for the protection of personnel working in the field require further development.

12. Separation of Uranium Isotopes

Vigorous efforts should be directed towards finding the most efficient and most economical method of separating uranium-235. This must be done not only that this isotope become available for use, but in order that as far as possible our country be assured that in this field, no "easy" solution of the problem has been overlooked.

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13. Separation of Other Isotopes

Study of the methods for the separation of isotopes in all parts of the periodic table. The separated isotopes have wide application in nucleonics as well as in other fields. Many of the nuclear investigations suggested in this report would be greatly expedited by the use of the isotopesof the elements rather than the mixture now usually available. Also the use of separated isotopes as moderators in chain reactors and as materials of construction is a point of obvious importance. D_2O, N^{15} and Fe^{56} are examples of separated isotopes which would be useful for this purpose.

14. Military Weapon

Researches directed towards the military utilization of atomic power.

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III. Chemistry Research and Industrial Development

1. General Investigation of the Heavy Elements

a. Preparation of isotopes by positive ion bombardment

All conceivable heavy isotopes should be prepared by the positive ion bombardment of isotopes of the heavy elements. The isotopes Th^{230}, Th^{232}, Pa^{231}, U^{233}, U^{234}, U^{235}, U^{236}, U^{238}, Np^{237}, Pu^{239}, Pu^{240}, 95^{241}, etc. should be bombarded with positive ions such as protons, deuterons, helium ions, etc. Methods should be developed for the use of bombarding projectiles such as lithium ions, beryllium ions, carbon ions, etc. The machines to be used for this purpose, such as the cyclotron, should be further developed to deliver larger ion currents and higher energies. The possibilities of the production by this method of conveniently large research amounts, i.e., industrial development, should be explored.

b. Preparation by intense neutron bombardment in piles.

All conceivable heavy isotopes should be prepared by means of intense neutron bombardment of all the available heavy isotopes in piles. This will lead to isotope production by second, third, fourth and even higher order reactions with respect to neutron utilization. Examples are Pu^{239}, Pu^{240}, Pu^{241}, Np^{237}, 95^{241}, 96^{242}, etc. Methods for the chemical plant recovery of isotopes such as Np^{237}, 95^{241}, 96^{242} should be worked out for industrial scale application. The decay chains of some of these isotopes, e.g., U^{233} should be investigated.

2. Basic Chemical and Physical Properties of Elements 89-96.

The evidence accumulated thus far indicates that the elements 89-96 compose the beginning of a new rare-earth-type of series. This relationship among the heavy elements is useful in predicting and correlating the chemical properties so that investigation of any one of them advances knowledge with respect to any other or all of them. Investigation should cover the following:

a. Atomic structure

Ground states should be determined from emission spectra. The x-ray spectra should be studied. Raman spectra of the ions and the effect of complex ion formation on the magnetic properties of the ions should be studied. Magnetic deflection of atomic beams and ionization potential measurements should yield fundamental and important information.

b. General chemistry

The oxidation potentials, complex ion formation and activity coefficients should be determined. The preparation and properties of inorganic and organic derivatives including coordination numbers, ionic radii and solubilities should be determined.

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Measurements on the rates of reaction such as oxidation-reduction reactions should be made. Coprecipitation studies and hydrolysis investigations should be made. The dry chemistry should be investigated. Thermodynamic measurements, such as heats of solution, heats of formation of ions, heat capacities from low to high temperatures, and heats of combustion should be made. A complete investigation of the metals, including the physical properties and thermodynamic data should be included.

c. Crystallography

Crystallographic investigation of the metallic states and compounds. Determination of type of chemical bonding and determination of formulae and atomic radii.

3. Development of Natural Sources

a. Methods of extraction of U and Th from ores.

New and more efficient means for the extraction of U and Th from ores should be developed. Solvent extraction is an example. Systematic prospecting for new ores, development of methods of analysis for aid in prospecting as well as processing. Methods suitable for low-grade ores are needed.

b. Recovery of Ra, Pa, Io, Ac, MsTh, etc. from ores.

Many of these isotopes have scientific value and are now lost. Development and modification of U and Th recovery procedures leading thethe recovery should be undertaken.

c. Search for new isotopes in nature.

A search should be made for isotopes of transuranic elements in nature.

4. Chemical Problems of Pile Development

a. Investigation of structural materials and the preparation of new corrosion-free, low neutron-absorbing alloys, study of corrosion inhibitors, development of natural sources of elements such as Be and the methods for processing. Development of special neutron-slowing compounds such as fluoro-carbons, etc. Study of colloidal behavior of fissionable heavy isotopes and fission products. Study of recombination of gases and radicals, such as the decomposition products of water, including catalytic aspects.

b. Fission Products.

Investigations of all the fission products of all the fissionable nuclei including determination of all the fission yields and the chain relationships, half-lives and radiation characteristics of the fission products. Studies of pile poisoning, including

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determination of solubilities, complex ion formation, studies of exchange between active and inactive isotopes, reactions in non-aqueous solutions, oxidation-reduction potentials, gas phase reactions of fission product elements. Development of physical methods for separating fission products, such as mass spectrographic, Clusius column, and distillation of volatile compounds. Development of large-scale plant methods for recovery of fission products for use in isolation from high energy piles. Fundamental investigations such as determination of fission thresholds and energy per fission. Study of products produced by second order reactions, that is, produced as a result of the absorption of neutrons by primary fission products.

c. Production of radioactive substances

Use of piles to manufacture radioactive isotopes for use as tracers. Development of methods of chemical processing and isolation of such tracers. Development of chemical methods of processing and isolation of fission products for this purpose. Use of such radioactive isotopes as portable substitutes for x-ray apparatus in the medical field, as in field hospitals, in industry, as in testing for defects in castings, in luminescent paints, and to produce ionization and electrostatic precipitation of solid and liquid particles from gases, etc. Therapeutic uses of such radioactive materials as in the treatment of cancer, for localization of radioactive iodine in the thyroid, for localization of calcium and phosphorous in the bone, etc. Agricultural applications of such tracers, such as following the distribution of inorganic constituents through soil, the labeling of plant products, etc. Uses in connection with public health, such as the detection of water pollution, labeling of bacterial organisms, etc.

5. Fundamental Chemistry

a. Solvent extraction.

Solvent extraction methods have such a broad application in the atomic power field that fundamental investigations are indicated. Determination of the formulae of the extractable compounds of the heavy isotopes and of some of the fission products and the study of oxidation and reduction reactions in the organic phase. Study of complexing agents to yield solvent-soluble complexes. Behavior of aqueous-organic systems in counter-current extracting apparatus. Specific investigation of solvent methods for separations involving the elements Pu, U, Th, Pa, Np, 95 and 96. Correlation of properties of useful solvents with molecular structure to form a basis for synthesis of ideal solvent.

b. Radiation chemistry and photochemistry.

Effect of radiation on gases, including measurement of number of ion pairs produced, types of reactions occurring, stopping

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power of radiation, etc. Effect of radiation on liquids, including study of primary processes involved, special effects of different particles, study of other liquids as well as water, etc. Effect of radiation on solids including specific effect of different types of radiation, fundamental theory for explanation of effects, induced changes of one compound to another, etc. Effect of radiation on separations processes, colloidal systems, semi-permeable membranes and other membranes. Development of new chemical processea and new methods for producing chemicals utilizing intense radiation of alpha-, beta- and gamma-rays and neutrons.

c. Less known elements of importance to atomic power.

Investigation of basic chemistry of elements such as columbium, tantalum, etc. which are important in connection with piles. Also elements such as cadmium, indium, etc. which are of importance as tools in nuclear research.

d. Mechanism of co-precipitation.

Investigation of the mechanism of carrying in an attempt to establish the basic principles involved. Isomorphism, anomalous mixed crystals, surface adsorption, internal adsorption, etc.

e. Natural radioactive families.

Investigation of the chains of decay, especially hitherto undiscovered branching, half-lives, type, quantity and energy of radiations of the three natural radioactive families. This information is useful in connection with chemical and radioactive and nuclear investigations of the heaviest elements and in many cases is inadequate at present.

6. Methods of Analysis and Instruments.

a. Chemical methods.

Development of methods of analysis for all the important elements in the atomic power field. For example, the analysis of many of the less-known elements such as the rare earths, Cb, etc., is important. Development of new methods such as polarographic methods and the use of solvent extraction. Electrometric and colorometric methods. Fundamental work in connection with analytical problems such as the determination of the oxidation states and oxidation potentionals, solubilities, complex ion formation, etc., of a number of the important but hitherto unfamiliar elements.

b. Physical methods.

Study of spectroscopic methods, including the study of spectral lines and molecular spectra. Development of new methods such as vacuum fusion and mass spectroscopic methods.

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c. Radiochemical methods. [redacted]

Development and improvement of electronic instruments and attendant apparatus such as beta- and gamma-ray counters, alpha-ray counters, and neutron and fission counters. Alpha-ray pulse analyzer apparatus. Photographic methods. Instruments for the counting of alpha-rays in the presence of high beta- and gamma-activity. Improvement of magnetic and electrostatic alpha- and beta-ray spectrographs. Development of coincidence counters.

7. Use of Tracers.

a. General applications to chemistry.

Reaction mechanisms; investigation of reaction mechanisms and rates, exchange reactions, etc.; behavior at extremely low concentrations; reactions of extremely high energy atoms (hot atoms); measurements of the surface area and adsorption relationships; analytical chemistry; investigation of completeness of precipitation. Application to increased sensitivity of detection and determining recoveries. Diffusion in solids, liquids, and gases; diffusion in metals; investigation of self-diffusion made possible. Neutron irradiation to produce radioactive isotopes as a method of analysis.

b. Industrial applications.

Process control. Metal processing baths and electroplating baths; cleaning and coating and control of the minor constituents; textile processing and rayon processing baths; control of minor constituents, such as lead, nickel. Process and equipment operating performance. Phase separation operations; infiltration, centrifugation, distillation, and adsorption. Testing of moving and storage equipment for leaks. Raw materials. Analysis for minor constituents by irradiation to form radioactive isotopes. Product control. Reactions involving materials where freedom from impurities is important, such as analytical reagent manufacture, pigment manufacture, ceramic manufacture, etc.

c. Radioactive carbon.

The importance of carbon and availability of C^{14} from pile sources makes it worthwhile to give radioactive carbon special consideration. (a.) Use as tracer in general organic chemistry, (b.) use as biochemical tracer.

8. Isotope Separation.

a. Chemical development connected with the electromagnetic method.

Construction and operation of machines. Development work on construction material from the standpoint of corrosion resistance, better ion collection chambers, better ion sources, etc. Should include investigation of new alloys. Improvements in methods of production of uranium halides used in ion source. Develop-

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ment of new ura[redacted] use in ion source. Study of large-scale man[redacted] materials. Development of methods for the conversion of product from other isotope separation plant, such as the one utilizing the diffusion method, to a form suitable for the ion source.

b. Chemical processing of product.

Development of improvement in yield, time cycles, etc., in the present method of processing the partially separated and finally separated U^{235}. Development of new methods, particularly solvent extraction methods. Particular emphasis on improvement of yield on handling product between end of alpha cycle and beginning of beta cycle. Improvement in method of analysis for the product.

c. Chemical development connected with the diffusion method.

Construction and operation of plant. Improvement of present membranes and development of new membranes. Development of better construction material by means of new alloys, etc. Improvement in the method of production of the present process gas, UF_6. Chemical processing of product. Improvement in methods for chemical processing of product in connection with its utilization as a starting material for the electromagnetic method. Development of new methods. Improvement in the analytical methods.

d. Chemical development connected with the thermal diffusion method.

Development of corrosion-free materials of construction. Development of methods of manufacturing proces gas, UF_6, and its chemical processing as the plant product. Development of analytical methods.

e. New methods of separation.

All possible new methods of separating U^{235} should be investigated. Solvent extraction and adsorption methods are particularly hopeful. Other possibilities are competing chemical reactions, fractional electrolysis, centrifugal methods, etc.

9. Military Uses.

a. Development work on the present type of device.

Chemical purification problems in connection with the use of Pu^{239}, U^{235}, and U^{233}. Chemical investigations in connection with the isolation, purification, and handling of Po. Development of very concentrated sources of high energy gamma-ray emitters such as Sb^{124}, including investigations of the Szilard-Chalmers technique. Development of the chemical processing in connection with very intense sources of gamma-rays such as La^{140} for use in radiography. Development and production of the present refractory materials and the development of better refractory materials.

b. Industrial explosives.

Under special conditions there may be some application of fissionable material as industrial explosives.

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IV. Program of Research and Development in Metallurgy

The program of research and development in the metallurgical fields, as needed in the development of nucleonics, may be thought of in two parts. The first, fundamental studies of the solid state, with emphasis on metals, and secondly, development and study of specific materials of construction.

The first part does not need to be outlined. In order to pursue it, one merely sees to it that men who are interested in this branch of science are supported and used effectively. The need for the knowledge gained by the study of solids derives from the fact that the carrying out of the nuclear reactions on a scale to produce either materials or power subjects materials of construction to a variety of conditions, the effects of which are not well understood.

The development of materials of construction, on the other hand, needs to be outlined in some detail. However, detail is warranted only in the case of those tasks which we know to be of immediate importance. It is sufficient that manpower and facilities be provided to take care of the specific tasks which can be foreseen and carry out the fundamental studies mentioned above.

1. Pure Metals, preparation, structure, properties

   Studies on highly pure uranium, thorium, beryllium and other special materials would be valuable for two reasons: (1) to establish the true properties of the metals, (2) to evaluate the effects of minor impurities.

2. Alloys of Special Materials

   The structures and properties of metals can be altered by alloying with one or more other elements. Any thorough study of the alloys of special metals would involve the determination of phase diagrams of each of these metals with all other elements. In this connection it should be pointed out that relatively few alloying elements have sufficiently low cross sections to be useful in thermal piles but that such limitations do not necessarily apply in fast neutron piles.

3. Properties of Metals and Alloys

   The applicability of a metal or alloy depends upon the properties of the material and the conditions under which it is to be used. Properties such as the corrosion resistance to various cooling media, the mechanical strength, ductility, thermal and electrical conductivity, the coefficient of thermal expansion, density, vapor pressure, the melting and transformation points are all of importance in evaluating the usefulness of a metal or alloy for a particular application. Further, the properties should be measured over a considerable range of temperatures. The effect of heat treatment upon structure and properties and the stability of desirable structures at elevated temperatures must be determined. Diffusion reactions, recrystallization, etc. should be studied.

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4. Liquid Metal Coolants [redacted]

The use of liquid metals as pile coolants would have many advantages, particularly as a means of obtaining useful energy from the pile reaction. Lead, bismuth, mercury, lead/bismuth eutectic, sodium, sodium/potassium alloys have all been proposed as coolants. Before such a pile can be constructed a thorough study of the effect of these coolants upon all materials with which it comes in contact must be made. The pumping and circulation of such coolants must also be carefully studied.

5. Oxide Systems

Oxide piles in which the fissioning element and moderator are present as oxides rather than as metals may be operable at high temperatures. The melting point diagram of the proposed oxide combinations should be determined since the melting point sets an upper limit on the operating temperature. The thermal, physical and mechanical properties of the oxides and the effect of coolants must be studied in detail.

6. Effect of Fission upon Properties

The fission process results in the formation of two new atoms from one fissionable atom. The extra atoms must be contained in the space lattice of the fissioning material and presumably would result in considerable lattice strain. The embrittlement associated with such strains may be sufficient to cause fracture and fragmentaion of the material, particularly during thermal cycling. Methods of simulating the effect and of testing fissioned material should be devised.

7. Metallographic and Testing Techniques

The common metallographic and testing techniques require rather close personal contact with the material being tested and would require considerable modification if they are to be applied to highly radioactive and poisonous materials.

8. Use of Radioactive and Radiation Techniques in Metallurgy

As in other fields artificially radioactive elements may help in various tudies. Some of these are: analysis, diffusion, segregation, structure, i.e., in rate, transfer and mechanism problems in general. Various applications of radiography are possible., e.g., soundness, self radiography by parallel rays, by pinhole optics or electron optics. Recoils may be of some use in special case., e.g., surface contamination.

9. Mining and Metallurgy

Surveys, prospecting, development of natural resources, development of procedure for refining and fabrication of essential materials such as uranium, thorium, beryllium and other metals are important to the field of nucleonics as a whole.

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10. Metallurgical Handling Problems

The work in metallurgy, which has been done to date, has required development in the field of ceramics, methods of study at high temperatures, heating methods and vacuum practice. Further development of materials and techniques of this sort will be necessary.

V. Biology and Medicine

There is a reciprocal relationship between nucleonics and research in biology and medicine which requires that both advance as rapidly as possible. On the one hand, the chance for living organisms to be affected by the release of nuclear energy has been increased enormously by the development of the fission chain reaction. Extensive knowledge of the nature and extent of the biological effects is necessary for the continuing and safe growth of nucleonics. On the other hand, nucleonics makes available new, better and more powerful means for following and modifying life processes. These tools will be used with increasing effectiveness in the investigation of fundamental biological and medical problems.

1. Uses of Biology in Nucleonics

A. Protection

The protection of personnel against injury by radioactivity has been one of the outstanding problems in the present development. The general problem of biological protection will continue and will increase in importance with development of the scientific, industrial and military aspects of nucleonics.

a. Tolerance - The present arbitrary standards of protection should be replaced by tolerance levels established on a scientific basis as soon as possible. As wide a variety of measurements as possible must be made of the effects of all significant radiations, radioactive and other toxic materials, at a wide range of dose levels and durations of exposure and observations, and much further work must be done on the translation of results from animal experiments to predictions of effects and tolerances for humans.

b. Diagnosis - More sensitive and more specific indices of early damage are urgently needed. Despite several years of intensive investigation, the white blood cell count is still the most sensitive diagnostic test, but its lack of specificity leaves much to be desired. The present studies on porphyrin metabolism and white cell chemistry should be extended and many other biochemical and hematologic approaches must be made.

c. Therapy - Means for the removal of deposited toxic materials must be discovered. Methods of treatment where damage has occurred are required. These problems must be approached by a continued emphasis on investigation of the metabolism of toxic materials and on the fundamental nature and extent of injuries produced [redacted] y of organisms

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B. Additional Military Aspects [redacted]

In addition, the military considerations require a knowledge of the effectiveness of the release of nuclear energy in its various forms upon living organisms. Besides the hazards of dispersed fission products and plutonium, the effects of the pressure and radiation waves accompanying an explosion should be known. The possibility of the direct use of fission products in warefare should not be ignored.

Although much of this work must continue under pressure, it is obvious that it should expand into fundamental biological and medical studies as rapidly as support and security will permit.

2. Use of Nucleonics in Biology

Nucleonics has contributed two effective tools to research in biology and medicine; radioactive tracers and sources of radiation. The fission chain reaction makes some tracer materials and radiations more available and adds new ones.

A. Tracers

The experience of the past decade has demonstrated beyond question the necessity for radioactive tracers in biological and medical research. They have been used extensively for: a. Tracing and analyzing exchange processes in the metabolism of normal chemical constituents without disturbance of steady state conditions, b. investigation of absorption, distribution, deposition and excretion of rare, toxic and foreign materials.

It is obvious that there will be much wider use of tracers in such fields as intermediary metabolism, analytical biochemistry, special organ and tissue physiology. In addition, there will be many applications to plant chemistry, metabolism of micro-organisms and to the fields of agriculture, biological industry and public health. In the field of medicine the clinical diagnostic and investigative uses of tracers can be expected to become quite extensive.

The extent to which the above fields have been broadened by the use of a few isotopes, notably P^{32}, makes it clear that the progress to be made with C^{14} alone will represent a series of major advances in science.

B. Radiation Effects

Much further investigation is necessary to achieve an understanding of the fundamental nature of the effects of radiation on living systems. Along with this path of research, various radiations will be widely used to modify and so aid in the analysis of a wide variety of biological processes. These problems must be attached from many points of view, among which the following seem foremost: Physiology, biochemistry and histology of higher animals; tissue metabolism and enzymes; cell division and general cytology; cell physiology; genetics, carcinogenesis; aging, and radiochemistry of solutions.

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C. <u>Radiation Therapy</u> [redacted]

Clinical and therapeutic use of newly available radioactive agents can in some cases be made on the basis of present knowledge, and in many other cases will require extensive studies on the effectiveness and tissue distribution of the agents. These uses include: activated gamma ray sources such as Ta^{182} and Co^{60} for radiography and therapy; pile neutrons; beta-emitting activated plaques, P^{32} and Sr^{90} for superficial therapy; internally deposited isotopes such as P^{32} and Sr^{89}; and internal deposit ion of chemical compounds or of materials which can be activated in situ by neutron exposure.

VI. Health Protection

Although there is a large fund of information already accumulated in the past in our own laboratory and others on radiation biology, such research will be necessary in medicine, biology, physics, and chemistry to make the operation of production plants and individual research activities in the field safe for the personnel. Some of the steps which must be taken to provide such protection are listed a below:

a. Training of personnel in health protection work. This involves the training of physicians and physicists in the reaction of living tissue to radiation and the training of all personnel concerned, in the necessary protective measures. The advent of nucleonics multiplied by many orders of magnitude, the radiation hazard in industry, research and medical institutions. The radiation hazard prior to the advent of nucleonics arose largely through the manufacture and use of radium and the generation and use of x-rays.

b. Development of more accurate radiation survey methods and instruements. Great strides have already been made during this emergency period but much further work is necessary.

c. Development of methods and instruments for monitoring of human excreta.

d. Research and development of clinically applicable procedures for discovery of incipient damage to personnel exposed to the products of the nucleonic industry or research. At the present our only clinical procedures are those (such as blood counts) which indicate significatnt alteration only when external or internal radiation has caused extensive and usually irreparable and irreversible damage to the body.

Any program, whether it be on an industrial or research scale, but which involves radiation sources or materials, requires a health protection unit. The magnitude and character of the undertaking dictates the organizational set up. In general it should suffice to say that physicians familiar with radiation biology and physics, physicists familiar with the biological aspects, and radiation surveyors form the essential nucleus.

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VII. Industrial Program

Many of the problems presented in the research program will lead to useful applications of nucleonics. Some industries will wish to participate in the fundamental research and carry on into the applications. Other problems may require the specialized knowledge and experience which industry alone has. Particularly the construction of large scale production units will require the cooperation of industry and therefore a participation of industry in all phases of the research and development will simplify the full scale production problem.

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