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Human Studies Project

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Summary

PART I. RADIOACTIVE WASTE DISPOSAL

1. Fate of Trace Elements and Radionuclides in Terrestrial Environment

Tests with several organic suspending agents have resulted in maintaining dispersion of clay-size minerals in the density-gradient solution. Mineral segregation has thus been achieved with standard clay minerals as well as with different soils and with calcareous sediment. Results show that the purity of the standard clay minerals is suspect. With soils, minerals heretofore undetected were identified through concentration in the gradient solution. Calcium carbonate was segregated from the clay minerals, and this permitted better characterization of the forms of phosphate existing in the sediment.

2. Disposal by Hydraulic Fracturing

The waste disposal injections are now going well, and a total volume of about 1,500,000 gal of water and slurry, containing nearly a quarter of a million curies, has now been pumped down our disposal well. More observation and rock-cover monitoring wells are being added as funds become available. Drilling into the waste-filled fractures deep underground raises minor problems of contamination. The initial work in New York State suggests that our experiments there can be carried out much as planned, although some minor modifications will be required.

3. Disposal in Natural Salt Formations

Most of the effort in this program is now directed toward the establishment of an actual high-level waste repository capable of accepting all of the power reactor wastes until about the end of the century. This effort is currently along three different lines: (1) the development of a computer program modeling the long-term deformational behavior of mine pillars of different designs under the influence of stress, elevated temperatures, and thermal gradients; (2) the development of a mine management program capable of defining the spacing required between successive cans of waste; and (3) the preparation of a report providing information on where the disposal facility should be located, how big it should be, and when it should be ready for operation.

Other work is continuing, including the preparation of a final comprehensive report on the demonstration experiment, Project Salt Vault, and the examination of rock types other than salt which might be usable for radioactive waste disposal. This latter work has been concerned recently with the determination of the effects of heat, stress, and radiation on the deformation of limestone.

4. Engineering, Economic, and Safety Evaluation

The amount of transuranic nuclides anticipated in the wastes from processing of reactor fuels is such that it must be considered in the management of such wastes. The major potential hazard seems to be associated with inhalation as the exposure mode, and containment times on the order of hundreds of thousands of years would be required. Rehandling of the waste, especially after the container and its contents had lost integrity, would be hazardous to operating personnel.

In view of the extremely long containment times required, consideration of long-term geologic alterations in the earth's crust is under study. Some examples of the rates of these changes are given.

Many exposure pathways must be investigated to estimate the potential internal dose to population groups from radionuclides that may be released by nuclear facilities. This involves consideration of foods consumed by man as well as ingestion of water and inhalation of air. A preliminary version of the computer program PATHWAY has been formulated to trace the movement of ^{131}I, ^{137}Cs, and ^{90}Sr through environmental food chains to man.

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5. Earthquakes and Reactor Safety

Laboratory and field tests have been made to determine the usefulness of the photoelastic coating technique on representative samples of the rock column for assessing geotectonic activity. Preliminary investigations have been made to define the mechanisms causing slope instability in portions of the Atlantic and Gulf coastal plains. A description of the recently activated ORNL seismological station is given, along with a report of significant recordings during the past year.

6. Dose Estimation Related to Peaceful Uses of Nuclear Explosives

Estimates have been made of the dose equivalents to various population groups from the hypothetical utilization of natural gas and other products from the Gasbuggy cavity. The major radionuclides of concern, ^{3}H and ^{85}Kr, would be transported through the collection, processing, and distribution system and would be released during combustion of the gas.

Study continues of the radiological safety feasibility of using nuclear explosives to excavate a sea-level canal across the isthmus of Central America. Modifications have been made in the computer code EXREM, which is used to estimate external dose. Complex parent-daughter decay chains can now be handled directly in any external dose calculation. Internal dose calculations will be limited to ingestion of radionuclides in food and beverages. The list of potentially significant radionuclides to be studied in detail has been reduced to 31. Estimates of internal dose will be made for five age groups of indigenous populations, as follows: 0 to 1 year, 1 to 5 years, 5 to 10 years, 10 to 15 years, and over 15 years. Selection of age-dependent parameters required in the dose calculations is discussed.

A hypothetical cratering event is used to illustrate application of internal and external dose estimation codes. Only ^{137}Cs-^{137}Ba is assumed to be vented during two cratering detonations spaced 30 days apart. Cumulative dose equivalents to total body are calculated as a function of time and age since the first detonation for a number of potential exposure modes.

7. Related Cooperative Projects

Representatives of other agencies continued to participate in the Radioactive Waste Disposal Section's studies. One alien guest was in residence during the year. One member served as assistant news editor for the United States for *Health Physics* and as an assistant editor of *Nuclear Safety*. Two members of the Section taught courses at the University of Tennessee. Members of the Section participated part time in the Nuclear Safety Information Center, the Civil Defense Research Project, and the agroindustrial complex study.

PART II. RADIATION ECOLOGY

8. Responses of Animal Populations to Ionizing Radiation

Primary objectives of our growing and diverse research on radiation effects in animals are: (1) comparative measurements and interpretations of consequences of acute and chronic irradiation in wild species of animals and (2) evolution of models for prediction of radiation effects in animal compartments of ecological systems. Implicit in these objectives is the requirement that interactions of biotic and abiotic environmental factors be delineated and quantified. Separation of effects of specific environmental factors in ecosystems is difficult, and current studies are employing laboratory research to complement field experiments. Systems analyses (compartment models) of population responses to radiation stress involve extrapolations of laboratory-derived theories to natural habitats and subsequent comparisons of actual field data for tests of long-term predictive capability. It is already clear that laboratory results, although useful for single-factor analyses and initial design of field experiments, are insufficient for realistic extrapolations and predictions of radiation effects in actual environments.

Current studies include measurement of genetic, cytological, individual, and populational effects in vertebrates and invertebrates receiving acute and/or chronic irradiation. Parameters being tested include tissue damage, changes in radionuclide incorporation rates, radiation profiles, survivorship, fecundity, chromosomal aberrations, metabolism, food consumption, energy flow, competition, temperature, and RBE. Dosimetry for such studies is critical, of course, and refined techniques must be developed for measuring acute and chronic gamma and beta radiation in tissues and environmental sites of interest.

Construction of a field facility and contamination of 100-m^2 enclosures with ^{137}Cs-tagged fallout simulant (88 to 177 μ, 22 mc/m^2), funded by the Office of Civil Defense (OCD), permitted initiation of field studies on dosimetry, movement of fallout particles, ^{137}Cs incorporation into the biota, environmental factors that affect cesium movement, and radiation effects in the animals within the enclosures. Application of the fallout simulant was completed in August 1968. Effects

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of physical and chemical factors on ^{137}Cs movement and incorporation into plants are discussed elsewhere in this report. The dominant vegetation in these enclosures is a fescue, *Festuca arundinacea*. Biological and ecological responses of invertebrates and rodents living in the pens and exposed to acute and chronic radiation from external and internal sources are being examined seasonally in replicated experiments under natural or seminatural conditions. The honeybee is one of the most valuable agricultural animals because of crop pollination, and another OCD-funded facility is permitting the first studies on the effects of radiation on colonies under field conditions. This research also is the first study of radiation effects on intact populations of a colonial insect.

9. Responses of Plants to Ionizing Radiation

Small white pine (*Pinus strobus*) and red oak (*Quercus rubra*) trees were contaminated in the field with a fallout simulant consisting of 88- to 175-μ-diam quartz particles containing ^{134}Cs. Whole plants were harvested at intervals up to 33 days after application of the simulant, and the ^{134}Cs retention by each species was determined.

The initial fraction of the simulant retained by foliage was higher in the oaks (0.35) than in the pines (0.24). However, after 1 hr, the broad-leaved oaks had lost 90.5% of the initial ^{134}Cs concentration, while the pines had lost only about 10%. These early retention differences are related to the effects of wind on the two distinct foliage types.

Effective half-lives were calculated for both species at intervals of 0 to 1, 1 to 7, and 7 to 33 days. For pine trees these values were 0.25, 4.53, and 20.66 days, respectively. For oaks they were 0.12, 1.41, and 24.86 days. Loss of particles (^{134}Cs) was due, primarily, to the weathering action of wind and rain during the study. The effects of wind and the first rain following contamination accounted for a large percentage of the total radionuclide loss during the study.

10. Radionuclide Cycling in Terrestrial Ecosystems

Research on processes and components of terrestrial ecosystems emphasizes (1) the structure and mechanisms governing the function and ecological organization of natural landscapes, for example, nutrient cycling, productivity, and energy flow; (2) the relation of these processes to the distribution and flux of radionuclide and other pollutants in the environment; and (3) the application of radioisotope techniques and computer simulation to developing predictive mathematical models of ecosystem performance.

The need for the capacity to understand, describe and develop predictive capabilities about the performance of natural ecosystems follows from recognition that man's impact on his environment should be anticipated before damage is done, not afterward. Such ecological competence is a prerequisite to anticipating the pathways and fluxes of radionuclide contaminants, other environmental pollutants, and vital nutrient resources. The experimental application of radionuclides and tracer techniques continues to be invaluable in extending our knowledge of fundamental ecological processes.

Ecosystem research on radionuclide cycling has concentrated on a long-lived fallout radionuclide, ^{137}Cs, in two contrasting ecosystems: a mesic *Liriodendron* forest and a *Festuca-Andropogon* grassland. In these studies techniques are being developed and tested using radionuclide tracers to identify and quantify ecosystem processes, for example, plant-soil-root relations, productivity, animal food chains, and microbial activity. Plant production and food-chain studies also have examined the pathways and fluxes of important nutrient elements in these ecosystems using ^{47}Ca, ^{22}Na, ^{42}K, and ^{54}Mn. Other research includes the cycling of selected radionuclides (e.g., ^{60}Co and ^{144}Ce) in plant-soil systems based upon nutritional requirements of the species and position of the element in the periodic table. Objectives are to develop predictive capability for chemically related elements, whose radionuclides may be potential environmental contaminants as by-products from nuclear operations. Further investigations using other radionuclides will eventually be required to round out knowledge of radionuclide and stable element dynamics in contrasting terrestrial ecosystems. Emphasis has been placed on synthetic interpretation of trophic level concentrations and transfers of biologically important radionuclides to develop mathematical descriptions of radionuclide behavior in the environment.

11. Radionuclide Cycling in Aquatic Ecosystems

Research in aquatic ecology is providing data on radionuclide movement in surface waters such as rivers and lakes. These data are needed for interpretation and quantitative prediction of the behavior of radionuclides in aquatic habitats. Such research investgations also increase our knowledge of the functioning and organization of aquatic ecosystems and provide data required for application to practical problems of atomic energy

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programs such as nuclear power, desalination, radioactive waste disposal, or Plowshare projects.

White Oak Lake continues as the focal point for studies of radionuclides under natural environmental circumstances. Organisms living in the lake are essentially in equilibrium with waste radionuclides such as ^{90}Sr, ^{137}Cs, ^{106}Ru, and ^{60}Co; hence, extrapolations can be made to steady-state conditions. Laboratory studies in conjunction with the field work provide data needed for more sophisticated predictive models of nonsteady-state situations. These data are pathway description, turnover rate, and fractional assimilation coefficients of radionuclides from various foods. These investigations provide a better quantification of radionuclide behavior in aquatic food chains.

12. Watershed Aquatic Habitat Interactions

This project is organized to assess the potential ecological inpact of new technology being applied to the field of natural resource management. These studies coalesce the efforts of aquatic and terrestrial ecologists with those of earth scientists into a unified program directed toward elucidating the interactions between land and water. The project will contribute to the understanding of biogeochemical relationships between aquatic habitats and associated watersheds through the synthesis of an empirical watershed model which will (1) relate the water quality and productivity of the stream to the characteristics of the adjacent terrestrial ecosystem, (2) equate the net loss of chemical elements through streamflow to the rate of mineral cycling, (3) establish the relationship between the hydrologic cycle and the mineral cycle, (4) provide bench-mark information of natural terrestrial-aquatic ecosystems for comparison with those modified by man's cultural practices, and, finally, (5) apply the knowledge gained from this small, controlled drainage basin study to broader landscape units to evaluate the impact of man's activities on the total ecosystem.

Industrial technology is advancing at an accelerated rate. Accompanying this technology is a continual degradation of the environment from the release of by-products, wastes, and misused chemical amendments. Assessment of the impact of new technology on the landscape is imperative if we are to abate the chronic degradation of our natural ecosystems which is now occurring.

Localized problems have developed in water bodies and water courses adjacent to agricultural areas from intrusion of agricultural fertilizers, agricultural chemicals, and animal wastes. When normally innocuous inorganic fertilizers and pesticides flow into streams via groundwater and runoff, a chemical enrichment results which can cause eutrophication of the water, resulting in excessive plant growth and impairment of general water quality.

Presently these problem areas are localized. However, when forest fertilization becomes a widespread practice as a means to increase forest productivity, serious eutrophication problems may result. It appears that forest fertilization will be necessary to compensate for urban encroachment and land-use pressure if the nation's future timber demand is to be satisfied. Average rates of fertilizer application for forestry purposes usually exceed those of normal agriculture several-fold; frequency of forest fertilization, however, is generally less.

A potential problem could develop if large acreages of forest were fertilized, because our water supplies originate in upland forested regions prior to entering the agricultural and industrial regions downstream. Presently, these virgin waters contain only natural chemical enrichment resulting from normal cycling and decomposition. If, however, the watersheds also contribute significant inorganic salts lost from fertilized forests, the problem will compound the effect of present agricultural, industrial, and urban pollution and perhaps exceed a threshold which could result in a costly and serious degradation of water quality.

The Walker Branch Watershed project is presently emphasizing the characterization and modeling of the undisturbed, natural forest ecosystem. Within three years this initial characterization will be completed, and one subwatershed will be fertilized to measure the differential effect of fertilization on the ecosystem. Fertilizer effects will be related to biomass growth, animal and plant species-diversity, enrichment and rate of movement of chemicals through the soil-water system, and stream water quality and aquatic productivity.

Studies have been initiated to evaluate the transfer rates and characteristics of the transfer functions among the principal components of the watershed ecosystem. This year's report summarizes the initial data evolving from some of these subsystem studies.

13. Systems Ecology

The overall purpose of the ORNL ecological systems analysis program is to provide a practical methodology that ecologists can use to make useful predictions about the outcome of environmental interactions, both empirical and theoretical. Progress has been made in evalu-

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ating the pertinence of recent ecological literature to the modeling of ecosystems, a biogeochemical ecology information center was established, and several systems analysis computer programs were written and tested on various ecological problems.

PART III. RADIATION PHYSICS

14. Theoretical Radiation Physics

A report of the task group on high-energy radiation for Committee III of the ICRP has been prepared. A new model for calculating the penetration of high-energy neutrons and protons through matter has been described which neglects the effects of binding and grouping of nucleons within nuclei. A Monte Carlo method has been used to determine the distribution of track lengths in cavities of various shapes and to unfold LET spectra from pulse-height measurements made with energy-proportional detectors. This unfolding procedure promises to bring LET spectral determinations within the grasp of health physics surveyors routinely.

A calculation has been made of the spectral and angular distribution of optical radiation from metal surfaces due to radiative decay of tangential surface plasmons excited in the metal by grazing incidence electrons. These theoretical results, together with sufficiently detailed experiments, should allow determination of parameters which can describe the irregularities of metal surfaces.

We have studied the influence of surface plasmons on the reflectivity of a nonuniform, bounded electron gas. This theory should be valuable in the analysis of experimental results on the surface plasmon effect.

The mean free path has been derived for the second-order process of double-plasmon excitation due to the interaction of a fast charged particle with a free-electron gas.

The theory of low-energy electron scattering by atomic systems was considered through new developments in two standard approaches in the quantum-mechanical theory of scattering. The Wigner R-matrix analysis was applied to the atomic scattering problem including long-range interactions, and an expression was obtained relating the elastic scattering phase shifts with the scattering energy. In another study a new variational method was developed for application to problems in atomic scattering theory where long-range forces play a significant part in determining low-energy cross sections.

The ground-state energy eigenfunctions for an electron bound to a finite dipole which were earlier obtained in elliptic-hyperbolic coordinates have been analyzed in spherical polar coordinates. These results serve as a first step in determining the effects of other interactions and of molecular rotation on the binding of an electron to a real physical dipole potential.

The stopping power of matter for extremely relativistic protons and muons has been treated through a relativistic quantum-mechanical calculation. Expressions for the stopping power contain contributions from the spin, anomalous magnetic moment, and form factors for the proton and muon. The stopping power of aluminum has been determined for a wide range of extreme relativistic energies.

15. Interaction of Radiation with Liquids and Solids

Optical constants in the vacuum ultraviolet have been determined for Rb, Na, and K, and for the organic liquids C_6H_6, C_6H_{14}, CH_3OH, C_2H_5OH, and DC704 pump oil. Interpretation is in terms of free electron effects, interband transitions, and collective oscillations. The collective oscillation seen in benzene, presumably involving the π electrons, is the first known reported observation of a collective oscillation in a liquid insulator. The hexane and alcohols are of basic interest because they are used as solvents for other organic compounds, and the pump oil is of interest because it is present as a contaminant in vacuum monochromators using this as a pumping fluid.

Photoemission measurements have been made on Mg and Al as a function of time after film deposition for various incident photon energies. These data can be interpreted in terms of the growth of an oxide layer on the surfaces. Changes in the photoelectron energy distribution curves with time after film deposition have also been correlated with changes in the work function and in the reflectance.

Considerable refinements have been made to the ultrahigh vacuum ellipsometer and to the methods used in the analysis of the data obtained with this apparatus.

The optical emission spectra from Al films bombarded with high-energy electrons have been investigated experimentally, and it is possible that radiative surface plasmons have been detected. Surface plasmon resonance effects in the light diffracted from concave diffraction gratings with various overcoatings have also been observed and interpreted.

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16. Atomic and Molecular Radiation Physics

The Atomic and Molecular Radiation Physics Group has obtained new information on the following specific topics: scattering of slow electrons by polar molecules, energy lost by slow electrons in collisions with molecules, electron swarm energy distribution functions, electron attachment to N_2O, azulene, oxygen containing biologically important molecules and other organics, and long-lived polyatomic negative ions formed by electron capture in the field of the ground and excited electronic states of the parent molecule. Also, new information has been obtained on degradation spectra, efficiencies of photosensitized ionization, molecular complexes, transient molecular photoassociation, and lifetimes of excited fluorescing species in organic liquids. Our experimental and analytical techniques have been refined and standardized. Accurate sets of electron swarm energy distribution functions have been well documented. Low-energy electron-polyatomic molecule studies have revealed new physical phenomena not observable in simple molecules. Formation of long-lived negative ions by electron capture in the field of an excited electronic state of a polyatomic molecule has been discovered for the first time. Negative-ion autoionization lifetimes and absolute capture cross sections have been measured as a function of the electron energy and have been related to basic molecular structure, yielding molecular electron affinitics and molecular electron accepting capacities. Biologically important molecules containing $n \rightarrow \pi^*$ transitions have been found to attach electrons forming long-lived (lifetimes of the order of 10^{-5} sec) parent negative ions with simultaneous excitation of a "lone-pair" electron. Evidence for electron capture into various vibrational modes of the molecular skeleton has been obtained also, the negative-ion lifetime decreasing with energy. The effect of molecular structure and geometry on electron capture has been investigated; to this end a detailed study of the N_2O molecule has been made. Evidence has been obtained also which suggests that electron capture may be accompanied by a simultaneous excitation of more than one orbiting electron, the parent molecular ion so formed being long-lived. Our experimental data also suggest that the electron affinity of a molecule in an excited electronic state may exceed that of the ground state.

17. Electron and Ion Collision Physics

Electrons with energy barely sufficient to excite an energy level of an atom or molecule can undergo a completely inelastic collision and be reduced to zero energy. Also, when the electron energy is sufficient to ionize the gas, it is found that a fraction of the collisions produce zero-energy electrons. We have employed the SF_6 "scavenger" and "trapped-electron" techniques for studying threshold excitation of the rare gases, ammonia, xenon hexafluoride, xenon tetrafluoride, and a number of organic molecules. For the rare gases the number of slow electrons produced above the ionization potential is fairly constant with increasing incident electron energy. Some evidence is also observed for inner-shell ionization. The most interesting threshold excitation spectra of the rare gases are found in the region of the two-electron excitation states. Here simultaneous excitation of two electrons may cause the incident electron to be "thermalized." Doubly excited states have been detected in the ionization continuum of helium, neon, and argon. Triply excited negative-ion resonances are also evident in the slow-electron spectrum of helium. Negative-ion resonances in helium at 57.2 and 58.3 ev are also seen as strong "dips" in the cross section for production of He^+ ions.

The formation of long-lived ($>10^{-6}$ sec) temporary negative ions has been studied extensively with both electron swarm and electron beam techniques. Slow electrons are known to temporarily attach to sulfur hexafluoride with a cross section approaching the theoretical maximum for *s*-wave capture. A mass spectrometer search for negative ions of hexafluoride molecules formed from atoms directly below sulfur in the periodic chart revealed no detectable SeF_6^- or TeF_6^- ions. Uranium hexafluoride likewise does not directly attach slow electrons. However, molybdenum hexafluoride readily forms MoF_6^-. Surprisingly, SeF_6, TeF_6, and UF_6 negative ions can be easily formed by charge exchange with SF_6. The lifetime for temporary attachment of electrons to complex molecules has also been determined for a number of theoretically important attachment reactions.

A technique for studying charge exchange and ion-molecule reaction cross sections in the energy region from 0 to 2 ev has been applied to a number of interesting collision partners, for example, H^-, H_2O; O^-, NO_2; Cl^-, NO_2; I^-, NO_2; and others. Charge exchange between the halogen negative ions and NO_2 is believed to exhibit a very sharply increasing cross section with decreasing ion energy.

18. Graduate Education and Vocational Training

The Health Physics Training Program included fellowship students from Vanderbilt University, University of Tennessee, Georgia Institute of Technology, University

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of California, and the University of Kansas. These reported to ORNL for summer on-the-job instruction in applied and research health physics.

Division personnel visited 20 colleges and universities to give seminars on various research problems of current interest and also to help interest qualified students in the fellowship program.

The Health Physics Division provided research facilities and advisors for 19 Oak Ridge Graduate Fellows, AEC Fellows, and USPHS Fellows who were conducting thesis research. A total of 34 university personnel ranging from undergraduates to professors spent the summer in the Division.

Teaching assistance was given to the University of Tennessee for its program in Radiation Physics and to Vanderbilt University for its course in Radiation Physics. Lectures and tours were given for several university groups visiting ORNL.

Assistance and consultation was given to eight schools that were interested in establishing health physics courses or programs in their science departments.

The Division cooperated with ORAU in the presentation of a ten-week course in applied health physics and in the screening of applicants for AEC Fellowships.

19. Physics of Tissue Damage

A dispersion analysis incorporating an internal field correction has been made of the optical properties of liquid water in the vacuum ultraviolet. This analysis, which uses our previously obtained optical constants, yields energies, line widths, and oscillator strengths for the absorption peaks.

The possibility of observing transition radiation from electron-bombarded liquid water has also been investigated. Calculations have been made of the theoretical transition radiation spectra, and indications are that it should be observable. An apparatus has been constructed to observe such radiation, but so far efforts have been frustrated by intense background light.

Work was continued on the interaction of low-energy electrons with metals. Attenuation lengths and stopping powers in aluminum were measured. The general shape of the electron transmission curve as a function of energy was compared with theory, and semiquantitative agreement was found.

An analytical expression for the electron slowing-down flux was derived using an empirical form for the stopping power. The electron flux from ^{64}Cu beta rays slowing down in lead was measured to determine the influence of bremsstrahlung absorption in generating secondary electrons. Work was initiated on the measurement of the electron flux generated by alpha particles and of the slowing-down spectra in germanium and silicon semiconductors. Work was also begun on developing a slowing-down theory using more accurate cross sections.

PART IV. RADIATION DOSIMETRY RESEARCH

20. Dosimetry for Human Exposures and Radiobiology

The calculations of LET and dose distributions in man-sized phantoms, important in nuclear accident and Ichiban studies, were extended to different neutron spectra and to beams of limited area. Calculations of neutron dose and fluence for geometries used during Operation HENRE were completed. An analysis of the blood sodium activation in swine exposed during HENRE was also completed. Thermal-neutron fluences for distances up to 3500 ft from the HENRE accelerator for several heights were measured.

21. Spectrometry Research and Development

The final analysis of the energy and angular distributions of the radiations from the HENRE accelerator was completed; the most important results are related to the failure of 14-Mev neutrons to come into transitory energy and angular equilibrium and the effect of this on radiation propagation and shielding.

Zone refining techniques have been used to purify organic scintillators, with important improvements in the light output of these detectors as the result. In particular, paraquaterphenyl, after zone refining, shows a light output efficiency comparable with anthracene.

An analysis and compilation of x-ray absorption coefficients for low energies have been made. For several elements the results of calculations and measurements by several groups of researchers were found to agree to within a few percent for x rays down to a few kev of energy.

22. Applied Research

Major advances were made in the development of solid-state detector systems. Important progress was made in understanding the basic mechanisms and in the application of insulating solids as charged-particle track detectors. In particular, the breakdown of electrical insulation in thin plastic foils after irradiation and etching led to the development of ultrasensitive detectors for alpha particles and neutrons; a sensitive

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personnel exposure detector for radon progeny for uranium miners was developed.

Thermally stimulated exoelectron emission (TSEE) from many substances was measured, and the characteristics of this phenomenon applicable to dosimetry were studied. A reader device for high temperatures was developed which led to the discovery of emission peaks at higher temperatures than those used previously.

In the field of radiophotoluminescence (RPL), a major improvement in the lithium borate detector resulted from the addition of 7.5% of BeO to the glass. The new glass is far less soluble and subject to weathering than without the BeO.

23. HPRR and Accelerator Operations

The Health Physics Research Reactor was used for an increased variety of both physical and biological research, and it operated almost flawlessly. There has been no change in the physical state of the core materials, and continued improvement in the reproducibility of the pulse yield was made. A low-yield neutron generator was installed to trigger bursts so that the precise time of the burst can be predicted. The sixth intercomparison of dosimetric systems was held July 7–18, 1969, with the emphasis placed on the work of representatives of nuclear materials licensees.

The DOSAR Low-Energy Accelerator was used primarily for calibration of neutron spectrometers and for stopping-power studies at low ion energies. The 3-Mv Van de Graaff was used extensively for spectrometry research and for studies of the LET dependence of solid-state detector systems.

PART V. INTERNAL DOSIMETRY

24. Internal Dose Estimation

The metabolism of iron is not governed by a simple compartment system such that the radionuclide present in the various organs or compartments is exchanged at a constant rate. It is well known that some of the iron deposits in red blood cells and remains there during the life of the cell, which is approximately 120 days. A generalized compartment scheme model has been developed which permits one to calculate the total microcurie-days of residence in the various compartments. In general, this would suffice for an estimate of dose commitment; but the method does not offer much advantage if one wishes to have the time course of the dose instead of merely the dose commitment.

When ^{232}Th or ^{228}Th enters the body, the first daughter produced is an isotope of radium. In ICRP Publication 2, it was assumed that this radium daughter, when produced, would be discharged to blood and recirculated, with only a fraction of the radionuclide returning to bone. The data on ^{228}Th from University of Utah dogs cast some doubt on this hypothesis, but because of the short half-life of the daughter ^{224}Ra, the Utah data do not suffice to determine the fate of the radium daughter of thorium. A four-compartment metabolic model has been defined which allows for a two-component representation for bone as well as a soft tissue compartment and the blood pool, and two cases have been computed: (1) a hypothesis is made that the radium daughter recirculates to blood and is then eliminated or redeposited as would freshly injected radium; (2) an alternative is to allow the radium daughter to remain in bone, where produced, and allow it to be eliminated as would freshly deposited radium. Using the Utah retention data for dogs, the exchange constants for such a system are obtained, and the amount of radium daughter present in bone is computed. The estimates of the two models bracket the Utah data but seem to lie somewhat closer to the results obtained by the first hypothesis, that is, recycling. It may be that the recycling of some fraction of the daughter element would produce better agreement. Estimates of microcurie-days residence for human retention are also obtained.

It is well known that the amounts of plutonium excreted per day fluctuate rather widely, although the trend is well represented by a power function. These fluctuations pose a problem for personnel monitoring. Since samples are not taken routinely with great frequency, when a high level is found the question arises as to whether it represents a high value due to a recent intake of the material or whether it is only a chance fluctuation. The distribution of these chance fluctuations has been studied and an attempt made to set limits such that if a urine sample exceeded these limits, one would be confident a new intake of plutonium had occurred. The results are rather disappointing in that the intake must be of considerable magnitude before the increase it entails would be clearly distinguishable from the chance fluctuations. Thus follow-up studies, which are both time-consuming and extensive, seem to be the only present answer to this problem.

25. Stable Element Metabolism

The program for revising and improving standard man as a model for estimation of absorbed dose of radiation

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