Lawrence Livermore Laboratory

E-DIVISION ACTIVITIES REPORT - FY 1977

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Compiled by H. H. Barschall

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CONTENTS

Abstract	1
Introduction	2
General Experimental Program	3
Neutron Interactions	3
Charged-Particle Interactions.	3
Representative Experiments	4
Fission.	4
Gamma Rays from Inelastic Scattering and Capture	4
Neutron Cross Sections Deduced from Proton Experiments	5
Neutron Cross Sections of Tritium and of Os Isotopes	6
Statistics of Nuclear Energy Levels.	7
Search for Nuclear Isomers	7
Integral Experiments	8
Accelerator Development.	9
Atomic Physics	11
Dense Plasma Focus	12
Safeguards	12
High Power Microwaves.	13
Fast Neutron Diagnostics for MFE Experiments	13
Material Science	13
Hydrogen Depth Profiling	15
Biomedical Studies	16
Publication List - Journal Articles and Letters	18
Publication List - Conference Proceedings	20

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E DIVISION ACTIVITIES REPORT - FY 1977

ABSTRACT

This report describes some of the activities in E (Experimental Physics) Division. E Division carries out basic and applied research in atomic and nuclear physics as well as in other areas related to the missions of the laboratory. The present report describes activities in the following areas: fission, gamma rays from inelastic scattering and capture, neutron cross sections deduced from proton experiments, neutron cross sections of tritium and of Os isotopes, statistics of nuclear energy levels, search for nuclear isomers, integral experiments, accelerator development, atomic physics, dense plasma focus, safeguards, high power microwaves, fast neutron diagnostics for MFE experiments, material science, hydrogen depth profiling, and biomedical studies.

INTRODUCTION

E (Experimental Physics) Division issues an annual report which describes some of the activities in the Division during the preceding year. The preceding report (UCID-17271-76) was issued in September, 1976. Not all the activities are included every year.

E Division carries out basic and applied research in atomic and nuclear physics as well as in other areas related to the missions of the Laboratory. Many of the activities are cooperative efforts with other Divisions of the Laboratory, and, in a few cases, with other laboratories.

Most of the activities of the Division are centered around four accelerators: a 100-MeV electron linear accelerator (Linac), a 400-kV dc high current (50 mA) accelerator, a 6-MV tandem electrostatic accelerator, and a 76-cm cyclotron. The cyclotron can be used as an injector for the electrostatic accelerator (cyclograaff).

The choice of experiments is often based on the availability of these accelerators and associated instrumentation. Many of the experiments are directly applicable to problems in weapons and energy, some have only potential applied uses, and others are in pure physics. With these accelerators, beams of neutrons, photons, and charged particles can be produced and the interaction of these projectiles with nuclei, atoms, and solids is studied.

There is also a continuing effort to improve the capabilities of the accelerators through work on ion sources, charged particle transport studies, target development, and better data handling capabilities.

GENERAL EXPERIMENTAL PROGRAM

Neutron Interactions

Although all the accelerators can serve as neutron sources most of the neutron experiments use either the Linac or the 400-kV accelerator. The Linac permits the simultaneous study of neutrons of energies from thermal to about 50 MeV by observation of the neutron time-of-flight over distances as long as 250 m. The 400-kV accelerator serves primarily as an intense source of 14-MeV neutrons.

During the past year the Linac experiments with neutrons have concentrated on studies of the fission in uranium, plutonium and trans-plutonic nuclides. The experiments with 14-MeV neutrons ranged from measurements of microscopic neutron cross sections and integral experiments to verify microscopic cross sections, to the effect of these neutrons on bulk properties of solids and on biological systems.

Charged-Particle Interactions

Most of the charged-particle-interaction experiments are performed with the cyclograaff. Reactions producing charged particles are studied with the aid of a high-resolution broad-range magnetic spectrometer as well as with solid-state detection systems. Low-energy gamma rays produced in charged-particle interactions are detected and their energy is measured in a Ge-Li detector, higher-energy gamma rays in a NaI scintillator with an anticoincidence shield. This latter detector has an unusually large volume: 10 dm^3 for the NaI crystal and 1 m^3 for the plastic scintillator that provides the anticoincidence signal. Neutrons produced in charged-particle reactions are detected and their energy is measured in a well-shielded time-of-flight facility that permits simultaneous observation at 16 angles.

Charged-particle-induced reactions studied during the past year include neutron production by protons bombarding tin and isotopes of samarium, high-energy gamma ray production by protons bombarding nuclides of masses between 56 and 206, and a search for nuclear isomers of rare earth isotopes by bombardment with Li.

REPRESENTATIVE EXPERIMENTS

Fission

The ratios of the fission cross sections of ^{232}Th , ^{237}Np , ^{241}Am , and ^{243}Am relative to the fission cross section of ^{235}U were measured as a function of neutron energy. Structure in the energy dependence of the ^{232}Th fission cross section was correlated with previous measurements of the anisotropy of the fission fragments, and this result could be interpreted in terms of the double-humped fission barrier.

The fission cross section of ^{245}Cm was measured in the neutron energy range from 10 meV to 35 eV.

The very high α -particle activity of the short-lived transplutonic nuclides makes measurements of fission cross sections difficult, but a chamber was developed which permits the observation of fission fragments in the presence of an α activity of the order of 50 MBq. This chamber served to measure the fission cross section of ^{241}Am , and currently the fission cross section of $^{242}\text{Am}^m$. The $^{242}\text{Am}^m$ sample consists of 800 μg of 99.3% pure material. The measurement of both the fission cross section and of the average number of neutrons per fission covers the neutron energy range from 25 meV to 14 MeV.

The decay of muonic atoms of ^{232}Th , ^{235}U , ^{238}U , and ^{239}Pu has been studied by observing fission fragments, neutrons, and decay electrons. The lifetime deduced from all three types of decay would be expected to be the same, but for ^{238}U the fission lifetime was significantly shorter than that for neutron or electron decay. This difference is likely to be caused by excitation of a shape isomer, and this effect is still under study.

Gamma Rays from Inelastic Scattering and Capture

Cross sections of reactions induced by neutrons are difficult to obtain by the measurement of the neutrons or charged particles emitted in the reaction, but the intensity of gamma rays from excited states formed in the reaction can be used to infer the cross section. For inelastic scattering the circumstances under which the gamma yield can be used to infer the reaction cross section

are more easily investigated with incident protons than with neutrons. Gamma measurements with incident protons established a correspondence between the inelastic proton-scattering cross section and the cross section for certain gamma decays. Gamma rays produced by 14-MeV neutrons were measured for several nuclides, including isotopes of Fe, Sn, and Pb. The inferred neutron inelastic-scattering cross sections generally agreed with available neutron measurements.

Experiments on radiative capture of protons above several MeV have continued with the aim of trying to deduce radiative capture cross sections for energetic neutrons from proton-capture experiments. Analysis of proton-capture data on ^{40}Ca and comparison with neutron data for the same nuclide shows the expected similarity between the two reactions; however, the ratio of intensities for the two reactions differs from predictions.

Gamma spectra following bombardment of nuclides of masses between 56 and 206 with protons from 7 to 25 MeV, and with 14-MeV neutrons were measured in order to study the systematics of the decays of the low-lying levels following inelastic scattering as a function of bombarding energy and mass, and to relate the intensities of the gammas to cross sections for inelastic scattering obtained by direct measurement of inelastic proton spectra. The gamma cross sections were also calculated theoretically. Conclusions from the proton experiments were that the intensity of the decay of the 2^+ first excited state agrees with the integrated cross section for inelastic scattering to levels below the nucleon separation energies, and that the gamma cross-sections can be calculated only with inclusion of pre-equilibrium and isospin-mixing effects in the statistical part of the calculation.

Neutron Cross Sections Deduced from Proton Experiments

Because of the experimental difficulty of performing accurate neutron scattering experiments, the charge-exchange reaction is being investigated as a means of obtaining neutron-nucleus potentials. This model assumes a simple charge-exchange force which converts a proton incident upon a nucleus to a neutron. Because the residual nucleus is left in a configuration, called the analog state, closely related to the target nucleus, it is possible,

in principle, to extract the neutron potential for the target nucleus. This has been done for the case of protons incident on ^{119}Sn , where the analog state was identified both by time-of-flight of the emitted neutrons and by the energy of proton decays. This technique was used to eliminate the continuous distribution of evaporation neutrons normally observed in time-of-flight measurements of the (p,n) reaction. The neutron potential extracted from these data was used to calculate neutron elastic scattering, non-elastic and total cross sections over the energy range corresponding to the (p,n) reaction. Agreement with existing neutron data was excellent and considerably better than that of some widely-used neutron potentials.

Charge exchange reactions have also been studied for the samarium isotopes of mass number 144, 148, 150, and 152. Previously, the emphasis was on ground state charge exchange reactions since they are directly related to the difference between proton and neutron elastic scattering. Proton and neutron inelastic scattering to low-lying levels are directly related to charge exchange reactions to excited analogs. These latter reactions in the samarium isotopes have been measured. Coupled channel theory makes possible the calculation of both elastic and inelastic neutron scattering by samarium isotopes.

Neutron Cross Sections of Tritium and of Os Isotopes

The total cross section of tritium was measured for neutron energies from 50 keV to 50 MeV with neutrons from the Linac. The tritium was in a 1 m-long cylindrical container at a pressure of 17 MPa. The measured cross sections agree with older data, above 1 MeV, but not below 1 MeV. The present data are, however, consistent with values deduced from proton - ^3He scattering on the basis of charge symmetry.

Measurements of the energy dependence of the capture cross sections of the isotopes of osmium of mass 186, 187, and 189 are of interest to applications in astrophysics, specifically for determinations of the age of the universe. This age determination is based on the known long half life of the β decay of ^{187}Re to ^{187}Os .

Statistics of Nuclear Energy Levels

The total neutron cross section of ^{89}Y was measured as a function of neutron energy with high resolution in order to study possible deviations from statistical theory at closed shells (^{89}Y has a closed neutron shell). Analysis of the data showed deviations from statistical theories. The work will be continued with other closed shell nuclides.

An understanding of the factors which determine level density parameters is of considerable importance, because of the role these quantities play in statistical model calculations of emission spectra. The traditional formalism for calculating level densities has been that of the Fermi gas model, involving the assumption that the nucleus can be treated as a group of non-interacting particles in a potential well.

Recent experimental work has established that predictions of the Fermi gas model for the spin distribution of nuclear levels do not agree with measurements. In the past year additional data have been acquired and compared with a new theoretical formalism, the theory of spectral distributions, which allows the inclusion of interactions between the nucleons. Results of the initial comparisons indicate that a much improved description of the spin distribution of levels results. More detailed analysis is currently underway, with the hope that both better information about level densities for specific nuclei and an understanding of the appropriate assumptions in level density calculations will result.

Search for Nuclear Isomers

For the interpretation of measurements using neutron-activation threshold detectors for high neutron fluxes emitted during short time intervals, one needs to know how many of the target nuclei were in excited states (isomers) at the time of the interaction with a neutron. This cannot be measured directly in the laboratory because the isomeric states are too short-lived. An experiment to search for isomers used in beam γ -ray measurements on nuclides formed by heavy-ion bombardment. Heavy ions form compound nuclei that have a spin distribution shifted to relatively high angular momenta. This favors the formation of isomers which can be studied if the states have lifetimes above a few nanoseconds.

A target enriched in ^{148}Nd was bombarded with 24-MeV ^7Li ions. The intent was to measure γ -rays formed in ^{152}Eu from the reaction $^{148}\text{Nd}(^7\text{Li},3n)^{152}\text{Eu}$. Although a number of prompt γ -rays were observed, only a few could be definitely assigned to ^{152}Eu . Subsequent measurements of the radioactive debris in the target showed a moderate concentration of ^{150}Pm formed from the $^{148}\text{Nd}(^7\text{Li},\alpha n)^{150}\text{Pm}$ reaction. The use of heavy-ion beams extends the range of nuclei and the variety of isomers that can be studied with the cyclograaff.

Integral Experiments

The neutron and γ -ray transport and resulting effects in large systems are usually calculated from microscopic cross sections. Because of the variety and large number of cross sections which are often required, integral experiments are of great importance in order to check the validity of the cross sections used in the calculations. Such experiments can also reveal errors in the computer codes.

A type of integral experiment that was developed for this purpose is the pulsed-sphere experiment in which a pulse of 14-MeV neutrons is produced at the center of a sphere of the material to be studied. The number and energy of the emerging neutrons and γ -rays is measured. Measurements have been performed on ^{232}Th , ^{235}U , ^{238}U , and ^{239}Pu . Preliminary comparisons between measurements and calculations indicate that the calculations overestimate the gamma production in ^{235}U , ^{238}U , and ^{239}Pu and underestimate the fission neutrons in ^{239}Pu .

Because of their wide use as shielding materials, iron, concrete, and water were studied extensively. Earlier measurements on these materials had been confined to the study of the neutrons transport, while in the present investigation the gamma rays were also studied. In these measurements 14-MeV neutrons were produced at the center of the following spherical configurations: 0.9, 2.9 and 4.8 mfp of iron, 2 and 4 mfp of concrete, and 1.1 and 1.9 mfp of water. Although calculations based on the presently used cross sections agree with the measurements of the neutron spectra, the differences between the gamma measurements and calculations for these materials range between 10 and 25%. Based on the present measurements the radiation doses in tissue have been calculated as a function of mfp for these materials.

Effects of residual radiations are of interest to the weapons program. Integral experiments have been performed to test calculations based on a compilation of activation cross sections. In these experiments, a desired neutron spectrum is produced by surrounding a 14-MeV neutron source with moderating materials in a spherical geometry. Small samples of the materials of interest are irradiated in this neutron spectrum. The γ -ray spectra and half-lives of the activated samples are measured in a lithium-drifted germanium spectrometer. The first measurements using a well-understood neutron spectrum have demonstrated the feasibility of the technique. Preliminary analysis of the data shows disagreements with calculations for several materials, as well as the importance of including self-shielding effects in the calculations. A more extensive series of measurements which is still being analyzed includes a variety of materials, as well as measurements designed to test self-shielding effects.

Accelerator Development

Two intense sources of 14-MeV D-T neutrons are under construction for the materials program of the Division of Magnetic Fusion Energy. The sources are designed to produce 4×10^{13} neutrons/sec. The design of the new sources (RTNS-II) is based on the presently operating rotating target source (RTNS-I). Development work for the new sources has benefited the old source and resulted in improved performance. Source strengths as high as 8×10^{12} neutrons/sec have recently been observed on RTNS-I.

Construction of the building for the new neutron source facility began in August 1976 and is expected to be completed on schedule in October 1977. High voltage supplies for the deuteron accelerator were purchased from a commercial supplier and have passed acceptance tests at the factory. One of the supplies is now being assembled here for preliminary tests on the accelerator.

The design requires 150 mA of atomic deuterons to be focused on the rotating target. Two ion sources of different design have been constructed and tested. One is a duoplasmatron ion source, the other is a multiple aperture type source (MATS-III). Modified MATS-III sources were selected for the accelerators. Such a source has produced 150-200 mA of magnetically separated H^+ ions on a 50-kV test stand.

The development of large (50 cm diameter) internally cooled rotating targets has encountered some difficulties and delays. Smaller (23 cm diameter) internally cooled targets have worked satisfactorily on the RTNS-I system, but there have recently been difficulties in the preparation of the tritium-loaded titanium layer, and another manufacturer has been asked to prepare targets.

The new facility will have a tritium scrubber to prevent the release of tritium from the target into the atmosphere. A prototype tritium scrubber has been tested, and no detectable release of tritium was observed during a six-day run.

For the use of the neutron source for radiation damage studies an accurate knowledge of the position of the neutron source, i.e., of the position of the incident beam on the target, is essential. A system has been developed which monitors visible radiation from the target during operation. It allows the operator to focus and position the beam spot on the target. A video processing system permits tracking of the beam spot and sounds an alarm if the beam spot leaves a preselected region which appears as a rectangle on a monitor screen. A second system displays five scan signals to give beam profiles.

The intense ion beam has to be brought onto the target without hitting and damaging the beam transport system. For this purpose the position of the ion beam can be monitored by observing with a television camera visible radiation from residual gas in the beam transport system. This system can be used at much higher beam currents than conventional wire beam scanners.

When positive ion beams with high current density are transported, electrical neutralization of the beam by low-energy electrons prevents the beam from expanding under the influence of its own space charge. Since electric fields remove the electrons which would neutralize the beam, electrostatic focusing lenses can ordinarily not be used for intense ion beams. The space charge lens which has been extensively studied in the Soviet Union, but is not well known elsewhere, redistributes the neutralizing electrons in an optically useful way. This is accomplished by axially symmetric crossed electric and magnetic fields. Lenses based on this

principle had been constructed here before we were aware of the earlier Soviet work. One such lens was installed in the RTNS-I accelerator. It decreased the size of the beam spot on the target, and, at the same time, increased the current on the target.

Beyond the beam crossover produced by the space charge lens the beam has an intense core. A similar phenomenon had been observed previously elsewhere when crossover of high current positive ion beams had been produced by other means. Since these cores may have other applications, a study of their behavior and properties is continuing.

RTNS-I uses a target which rotates at 1100 rpm. A rotating seal consisting of a loaded teflon ring sliding on mild steel separates the rotating target from the rest of the accelerator. RTNS-II requires larger charged-particle beams, hence dissipation of more power and higher rotation speed. The old design is not satisfactory at the higher speed. A new rotating seal capable of rotating at 5000 rpm has been constructed. In this design an air cushion prevents the rotating and stationary parts from touching. Two stages of differential pumping maintain the pressure gradient between the air cushion and the vacuum so that the leak rate into the vacuum is less than 10^{-4} Pa m³/s.

For some time a PDP-15 computer has been available for data analysis in the accelerator laboratory. The system had not had a satisfactory program for efficient real time data handling and analysis. A program which had been developed at the University of Oregon has been adapted for our use and has greatly improved the data handling capabilities of the computer.

Atomic Physics

An attempt is being made to find collision schemes which might lead to the design of an x-ray laser by measuring absolute population probabilities for lasable states in a highly-ionized beam of ions traversing a solid target. Effects of collisional broadening on the x-ray emission from some of these atomic states, and, for stationary target atoms excited by ion beams, effects of chemical environment on the lifetime of atomic states have been studied.

A simple technique permits the measurement of absolute population probabilities of an atomic state and the determination of its radiative transition rate. Knowledge of both of these quantities is necessary to

determine feasibility for lasing. The measurements show that x-rays emitted by ions moving inside different materials are broadened by different amounts. Crystalline material such as diamond, Si, Ge, and Zn produce more x-ray broadening than graphite, copper, or aluminum. The effects of line broadening in these dense solid environments help to understand the spectroscopy of dense hot plasmas. The effects of chemical environment on the lifetimes of stationary target states was found to be significant. Consequently, x-ray lasing schemes which depend upon the production of unique states in a molecular target must include the previously neglected effects of outer shell rearrangement.

An experiment to measure forbidden M1 transitions in alkali atoms is underway. The aim is to observe and measure parity violation in atomic transitions. The parity-forbidden component is submerged in allowed transitions but might be observable in forbidden transitions.

Dense Plasma Focus

The Dense Plasma Focus project which is based in T-Division involves measurements and technical support in E-Division. The aim is to investigate whether enough energy can be concentrated in a short time on a small target to produce thermonuclear reactions. The small targets consist either of CD_2 or small spheres filled with a DT mixture. On one occasion a yield of 10^6 DT neutrons was indicated. Six subsequent efforts to reproduce this result have been unsuccessful, i.e., the neutron yield was less than 10^5 . X-ray observations indicate that the failures may have been due to the fact that the small spheres were not at the focus. An effort is underway to control the position of the focus and of the sphere more accurately.

Safeguards

The interest in our safeguards effort has recently been revived because of the growing concern about the possibility of diversion of plutonium from reprocessing plants. We have developed a method based on x-ray fluorescence analysis for the nondestructive assay of uranium and plutonium. This method should provide accurate, fast and inexpensive assays in a reprocessing plant.

High Power Microwaves

High-intensity electromagnetic fields in the microwave frequency range are useful for heating plasmas, for generating intense charged-particle beams, and other applications. A method is under development for filling a superconducting resonant cavity with rf energy for a relatively long time and then extracting the energy during a much shorter time to achieve a power gain of the order of $10^6 - 10^8$. This would make power levels of many TW possible. The initial experiments attempt to determine the largest energy that can be stored in a superconducting spherical cavity with a volume of about one liter.

Fast Neutron Diagnostics for MFE Experiments

The neutron production rates in the next generation of controlled thermonuclear experiments, e.g. the Tokamak Fusion Test Reactor and the Mirror Fusion Test Facility, are expected to approach the high levels typical of reactor-like plasmas (of the order of 1 MJ per pulse). These anticipated neutron yields should permit extensive neutron diagnostic measurements from which primary plasma parameters such as temperature, density, spatial and temporal distributions, are to be derived.

In collaboration with the Princeton and Livermore MFE groups, a project has been initiated to develop various neutron diagnostic capabilities for the next generation of MFE experiments. Our activities have been concentrated on the evaluation of available neutron detection systems and their applicability to plasma diagnostics, as well as on the exploration of spectral response and energy resolution of specifically designed scintillation counters, recoil detectors, and ionization chambers. Detection systems of these types are expected to be widely used for neutron diagnostics of deuterium and tritium plasmas with temperatures near 1 keV.

Material Science

One of the most difficult problems in the design of a fusion reactor is the short lifetime of the wall of the plasma-containing vessel caused by radiation damage induced by 14-MeV neutrons. The selection of a suitable material requires a better understanding of the factors that influence the behavior of materials under bombardment by 14-MeV neutrons. There is a difference between the effect of fission neutrons and of 14-MeV neutrons

caused both by the difference in the primary recoil energy distribution and by the large difference in the probabilities for the production of hydrogen and helium by neutron-induced reactions.

Three different approaches to the study of this problem are being pursued. The first involves the measurement of the cross sections for the production of hydrogen and helium isotopes by 14-MeV neutrons, the second is the direct study of the effect of high fluences of 14-MeV neutrons on materials, and the third is the simulation of 14-MeV neutrons by energetic protons which should produce radiation damage effects similar to those induced by neutrons. All this work uses our accelerators; some of the experiments are performed by LLL staff, some are done by users at other laboratories who send samples to be irradiated, and several investigations are joint efforts between LLL and outside users.

In a cooperation between LLL and the University of Wisconsin, hydrogen and helium production cross sections have been determined by observing charged particles produced by 15-MeV neutrons. Measurements have been completed on two types of stainless steel, vanadium, niobium, and two isotopes of copper. A series of measurements on samples irradiated here is carried out at Atomics International where the helium generated by neutrons is analyzed with a mass spectrograph.

A variety of samples provided by investigators at LLL and other laboratories are irradiated to investigate the effect of the neutrons, particularly on the mechanical properties. Since a magnetically confined plasma is likely to require the use of superconducting magnets, a variety of superconducting materials have been irradiated, some at liquid helium temperature, some at room temperature.

Proton simulation experiments included a study of the effect of varying the primary recoil energy distribution by varying the energy of the cyclograaff proton beam. Radiation damage is probed by measuring the lifetime of positrons introduced in the damaged area. Samples of well annealed polycrystalline copper have been irradiated at temperatures ranging from -40° to $+30^{\circ}\text{C}$ and annealed at room temperature. The subsequent defect density and type were inferred from positron lifetime measurements. Proton energies varied from 4 to 24 MeV and fluences ranged up to 10^{18} protons/cm². Over the energy and dose range of the experiment the defect character is unchanged and the trapping rate is

proportional to dose. The results of preliminary isochronal annealing studies and the value of the lifetime of the trapped positrons suggest that the defects are three-dimensional groups of vacancies.

In a cooperative experiment between LLL and HEDL the creep induced in a stainless steel wire by irradiation with 15-MeV protons was measured. Data obtained on one specimen at elevated temperature showed that the irradiation creep was proportional to the proton flux density and that the rate of creep increased slightly with increasing fluence.

Hydrogen Depth Profiling

For many applications an accurate knowledge of the distribution of hydrogen isotopes as a function of depth in the material is important. We have developed a technique for measuring the hydrogen isotope depth profile by bombarding the material with a beam of charged particles which react with the hydrogen to produce neutrons. The energy of the neutrons that are produced depends on the energy of the charged particles at the depth at which the reaction takes place. Measurements of the neutron spectrum by time of flight permits a determination of the hydrogen isotope depth profile.

In the first application the distribution of tritium absorbed in titanium was determined by bombarding the material with protons. This investigation led to a better understanding of the behavior of the targets used in the RTNS intense neutron source.

Deuterium depth profiles have been studied by observing neutrons produced by deuteron bombardment.

Most recently light-hydrogen depth profiles were determined by triton bombardment. The Los Alamos Van de Graaff accelerator provided the tritium beam. A difficulty was the large neutron background produced by reactions of tritons with some of the host materials.

Biomedical Studies

The RTNS intense source of 15-MeV neutrons permits studies of their biological effects. This is of interest to the applications of neutrons to cancer therapy as well as for estimates of the effect of neutrons on personnel. Such studies have been carried out in cooperation with the Department of Radiation Oncology of the University of California, San Francisco, the M. D. Anderson Hospital of the University of Texas, and the Biomedical Department of Texas A&M University.

For neutron cancer therapy neutrons are usually produced either in the reaction of deuterons with beryllium or in the reaction of deuterons with tritium. It is important to be able to compare dose measurements and the biological effects for these two types of neutron sources. For this purpose mice were exposed to 15-MeV D-T neutrons and the dose was measured by techniques developed here. The results could be compared with similar exposures at the Be(d,n) source at Texas A&M.

The biological effects of radiation differ if the same dose is delivered in one or several fractions, since tissue repair can take place between exposures. There is evidence that this repair occurs more readily after exposure to x-rays or γ -rays than after exposure to neutrons. This information is needed for planning neutron cancer treatment. In a series of experiments eight different groups of mice were irradiated with 15-MeV neutrons and the results were compared with corresponding γ -ray exposures. One group of mice received a single 1200 rad dose, the others received ten equal fractions of doses ranging from 60 to 150 rad.

Patients undergoing neutron treatment should receive a smaller dose to the skin than to the internal tissue because the secondary charged particles originate inside the body. This effect, called skin-sparing, occurs for x-ray treatment as well as neutron treatment, but reports from various centers indicated a relatively much higher skin dose for D-T neutrons than for Be(d,n) neutrons, a difference for which there appeared to be no physical explanation. The skin-sparing properties can be studied with a thin-walled ionization chamber, and such a chamber which had been used at the Texas A&M Be(d,n) source was then exposed at the RTNS 15-MeV source. The conclusion

from a series of experiments was that secondary charged particles originating in the neutron-producing target and in the air were responsible for the lack of skin-sparing for the 15-MeV neutrons. A thin sheet of lead placed over the skin improves the skin-sparing for 15-MeV neutrons to the value found for Be(d,n) neutrons.

The cooperative program with the Department of Environmental Health and Community Medicine at the University of Washington has continued. The purpose is to study functional changes in the lungs caused by low ozone concentrations. Experiments on dogs use radioactive nitrogen and oxygen (in the form of carbon dioxide) produced at the Linac as tracers to measure changes in ventilation and clearance rates. A number of test animals showed changes in the distribution of inhaled gas after ozone exposure, especially in the peripheral regions of the lung. These results may be useful in studies of the effect of ozone contamination near industrial centers on the nearby population.

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