Cao-3080-10

HIGH ENERGY NUCLEAR INTERACTIONS WITH MATTER AND NUCLEAR PROCESSES IN NATURE

FINAL REPORT

O. A. Schaeffer

State University of New York at Stony Brook
Stony Brook, New York 11794

N O T I C E

This report was prepared as an account of work sponsored by the United State Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed or represents that its use would not infringe privately owned rights.

September 1976

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Prepared For

THE U. S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

UNDER CONTRACT NOS. AT (30-1) 3629 AND AT (11-1) 3080

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

HIGH ENERGY NUCLEAR INTERACTIONS WITH MATTER AND NUCLEAR PROCESSES IN NATURE

Contract Nos. AT (30-1) 3629 and AT (11-1) 3080

ABSTRACT - The research conducted during the period 1965 - 1975 was concerned with two areas: 1) high energy proton interactions, and 2) nuclear reactions in nature. The systematics of high energy proton produced rare gas nuclides from Cu, Ag, Au, and U targets were investigated. It was found that the lower mass nuclides up to A $\sim$ 30 were produced mainly by fragment emission, while the higher mass nuclides were produced mainly by spallation except for U targets for which fission dominates. The existence of $\beta\beta$ decay was firmly established for the first time on experimental grounds. The half-life of the $\beta\beta$ decay $^{130}Te - ^{130}Xe$ was measured to be 2.2×10^{21} years. The meteorites St. Severin, Lost City, and Suchy Dul were investigated for cosmic ray proton produced rare gases. Cosmic ray exposure ages of 11, 8, and 23 million years respectively were determined. At the same time, the K - Ar ages were found to be 4.4, 4.1, and 1.9 billion years respectively. A model was proposed which allows a tektite strewn field to be at least 100 km from the impact crater. The model removes one of the major constraints on the terrestrial origins of tektites. It was found that ^{228}Ra diffuses from sea sediments and as such is a good tracer for studying bottom currents and diffusion processes in the sea.

HIGH ENERGY NUCLEAR INTERACTIONS WITH MATTER AND NUCLEAR PROCESSES IN NATURE

Contract Nos. AT (30-1) 3629 and AT (11-1) 3080

FINAL REPORT

The research conducted during the period 1965 - 1975 concerned itself with two areas: 1) high energy proton interactions, and 2) nuclear reactions in nature. High energy proton interactions were conducted in collaboration with scientists at the Brookhaven National Laboratory and concerned mainly the systematics of spallation reactions at GeV energies. The nuclear interactions in nature were concerned with the observations of reactions for their physical properties, such as the double-beta decay, and the use of nuclear reactions for understanding natural processes, such as dating of meteorites and circulation of ocean water.

High Energy Nuclear Reactions

The stable and radioactive rare gas isotopes formed by 3- and 29-GeV protons on Cu, Ag, Au, and U were investigated. It was found that spallation processes can account for Ne yields from Cu, Ar, and Kr from Ag and Xe from Au, while fission and spallation mechanisms account for Kr from Au and Kr and Xe from U. On the other hand, Ne and Ar from Au and U do not seem to be formed by either spallation or fission but appear to result from a process with high yield of light fragments previously observed for radioactive products. It appears that by including stable rare gases to the radioactive elements measured that one can account for observed proton yields up to A $\sim$ 20 to 30 for Cu and Ag targets as fragment emission while spallation accounts for yields between this mass region and the target. The yield of light fragments from Au extends to A approximately 40. Between A 40 to 140, the observed yields are mainly

spallation. For U, the fragment emission extends to A = 40, but the major contribution in the 40 to 140 mass region is now chiefly fission.

The work on high energy interactions in space were summarized by Kirsten and Schaeffer and published in a book titled, INTERACTIONS OF ELEMENTARY PARTICLE RESEARCH IN SCIENCE AND TECHNOLOGY. This summary includes an extensive literature survey of proton production cross sections from 50-MeV to 30-GeV for targets up to Ni which are the targets mainly of concern for the bombardment of meteorites and the moon by cosmic rays.

Double-Beta Decay

The theoretical possibility of double-beta decay was under experimental investigation for a number of years. Early results looking for the production of ^{130}Xe from the double-beta decay of ^{130}Te by mass spectrometric analysis of Xe in old Te minerals were not conclusive as the Xe was contaminated with sizeable amounts of fission Xe and of proton produced Xe. We repeated the experiment with an extremely pure sample of native Te which contained only trace amounts of U. The results of this experiment conclusively demonstrated the existence of double-beta decay and permitted the measurement of a half-life of 2.2×10^{21} years. This number has been accepted by the physics community and has formed the basis of a number of theoretical investigations.

Meteorites and Tektites

The rare gases were studied in the St. Severin meteorite which fell near Bordeaux, France in June, 1966. The exposure was found to be 11 million years while the K - Ar age was found to be 4.4 G.y.

The rare gases were also investigated in the Lost City and Suchy Dul meteorites. These two meteorites were found to have exposure ages

of 8 and 23 million years respectively. The K - Ar age of the Lost City meteorite was found to be 4.1 G.y.; however, the Suchy Dul K - Ar age was only 1.9 G.y. It is possible that the Suchy Dul meteorite has suffered a collisional or metamorphic event 2 billion years ago.

A method for determining ^{36}Cl was developed by chemically converting the Cl in the meteorite to methyl chloride, which is a suitable counting gas. The methyl chloride can then be counted in very small low level counters so that one can have the same sensitivity for detecting ^{36}Cl that one has for ^{39}Ar. This allows the exposure ages of meteorites to be determined with several grams of samples rather than 30 to 50. The method was applied to high energy proton reactions on Ni and Fe targets.

In the 1960's, there was a great deal of concern about the origin of tektites. There was a debate whether tektites came from bombardment of the moon, the ejecta coming to the earth, or whether tektites were formed by meteoritic bombardment of the earth. One of the major arguments against the terrestrial origin was that aerodynamically it was impossible to throw tektites as far as required. A theoretical study by Remo and Skalafuris showed that it was possible to create a model which could account for a tektite strewn field as being far removed from the meteorite impact crater.

Dating of Fossil Carbonates

The U - He method of dating fossil carbonates which was developed at Brookhaven National Laboratory by Fanale and Schaeffer was extended by Michael Bender and applied to Pleistocene corals from Barbados. The method was put on a very quantitative basis by investigation of the effect of the size of the coral carbonate masses and the effect of voids in the coral structure. As far as the geology is concerned, the investigations

of corals determined the time sequence of the terraces at Barbados.

Oceanic Circulation and Deep Sea Basalts

Willard Moore studied the uranium, thorium, and radium isotopes in rivers and oceans of the world. The results of this work indicated that ^{228}Ra is apparently diffusing from the sediments by a chemical process. The evidence is that ^{228}Ra is more abundant in surface waters near land masses. In addition, the ^{228}Ra in the deep waters, less than 100 meters from the sea floor, have significant radium concentrations, which is not the case for the other deep waters. As a result, ^{228}Ra can serve as a tracer for deep water.

Excess Ar was found in deep sea rocks. The excess Ar was found to relate to the glass content of the samples. This work in 1968 was one of the first investigations of rare gases in deep sea rocks.

PUBLICATIONS SUPPORTED COMPLETELY OR PARTIALLY BY THE ATOMIC ENERGY COMMISSION UNDER CONTRACT NOS. AT (30-1) 3629 AND AT (11-1) 3080

Amazon and Mississippi River concentrations of uranium, thorium, and radium isotopes. Willard S. Moore; Earth & Planet. Sci. Lett. 2, 231-234 (1967).

Light and heavy rare gases in four fragments of the St. Severin meteorite. J. Funkhouser, T. Kirsten, and O. A. Schaeffer; Earth & Planet. Sci. Lett. 2, 185-190 (1967).

Massenspektrometrischer nachweiss von ββ zerfallsprodukten. T. Kirsten, W. Gentner, and O. A. Schaeffer; Zeitschrift für Physik 202, 273-292 (1967).

A physical model for tektites of meteoritic origin. J. L. Remo and A. J. Skalafuris; J. Geophys. Res. 73, 3727-3735 (1968).

Excess argon in deep-sea rocks. John G. Funkhouser, David E. Fisher, and Enrico Bonatti; Earth & Planet. Sci. Lett. 5, 95-100 (1968).

Experimental evidence for the double-beta decay of Te^{130}. T. Kirsten, O. A. Schaeffer, E. Norton, and R. W. Stoenner; Phys. Rev. Lett. 20, No. 23, 1300-1303 (1968).

Experimental limits of the existence of anomalous electrons. E. Fischbach, T. Kirsten, and O. A. Schaeffer; Phys. Rev. Lett. 70, No. 18, 1012-1014 (1968).

Measurement of Ra^{228} and Th^{228} in sea water. Willard S. Moore; J. Geophys. Res. 74, 694-704 (1969).

$^{234}Th/^{238}U$ ratios in the ocean. S. G. Bhat, S. Krishnaswamy, D. Lal and Rama, and W. S. Moore; Earth & Planet. Sci. Lett. 5, 483-491 (1969).

Oceanic concentrations of ^{228}radium. Willard S. Moore; Earth & Planet. Sci. Lett. 6, 437-446 (1969).

Yields of stable and radio-active rare gas isotopes formed by 3- and 29-GeV proton bombardment of Cu, Ag, Au, and U. J. Hudis, T. Kirsten, R. W. Stoenner, and O. A. Schaeffer; Phys. Rev. 1, 2019-2030 (1970).

An evaluation of the uranium-helium method of dating of fossil bones. K. K. Turekian, D. P. Kharkar, J. Funkhouser, and O. A. Schaeffer; Earth & Planet. Sci. Lett. 7, No. 5, 420-424 (1970).

Rare gases in the Lost City and Suchy Dul meteorites. Murdoch Baxter and John Funkhouser; J. Geophys. Res. 76, 4056-4060 (1971).

High energy interactions in space. T. Kirsten and O. A. Schaeffer; Elementary Particles, edited by L. C. L. Yuan, Academic Press, N. Y. (1971).

Cross sections and recoil properties of xenon isotopes formed in 11.5-GeV proton bombardment of ^{238}U. Y. W. Yu, N. T. Porile, R. Warasila, and O. A. Schaeffer; Phys. Rev. C, Vol. 8, No. 3, 1091-1098 (1973).

POST-DOCTORALS AND RESEARCH COLLABORATORS SUPPORTED BY THE ATOMIC ENERGY COMMISSION UNDER CONTRACT NOS. AT (30-1) 3629 AND AT (11-1) 3080

James C. Cobb

Willard S. Moore

John G. Funkhouser

Till Kirsten

Murdoch Baxter

Gerd Heusser

Gregory F. Herzog

William C. Burnett

Dennis Oberg

Robert Warasila

PH.D. THESIS

Albert Shih-Cheang Cheng - "Gas Proportional Counting of ^{36}Cl in Iron Targets and Iron Meteorites."

Willard S. Moore - "Oceanic Concentrations of Radium-228 and a Model for Its Supply."

Michael Bender (partial support) - "Helium-Uranium Dating of Corals." Ph.D. obtained through Columbia University.

MASTERS THESIS

Lawrence J. Muzyka - "Pb-210 Chronology in a Core from the Flax Pond Marsh, Long Island."

Carol Landeen (Edwards) - "Excess ^{131}Xe in Lunar Samples."

J. L. Remo - "Isotopes in Tektites."